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Identifying common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs)

Baldini, G., Cerutti, I., Chountala, C.

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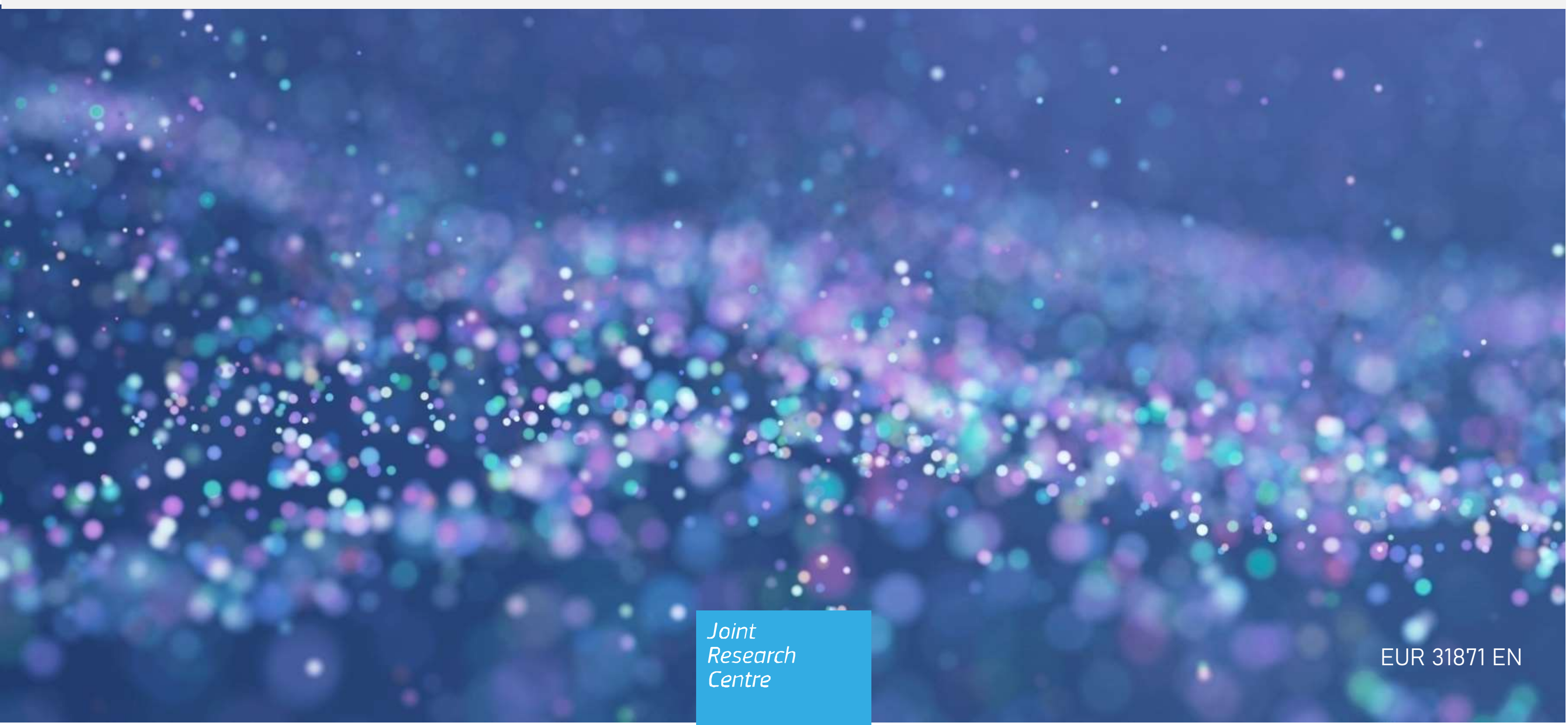

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Contents

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Abstract

Information and Communications Technologies (ICT) in general and telecommunications networks in particular can play an important role in the green digital transition of the EU's economy and society.

However, telecommunications also create sustainability impacts related to climate, energy and environmental aspects in their lifecycle. Notwithstanding technological evolution, these impacts may grow in the future due to the increase of traffic demand and pervasiveness of telecommunications networks in everyday life, which require a significant amount of energy for transmission and computing tasks. In turn, such energy demands generate significant greenhouse gas emissions in the various operational activities of the telecommunications network. Telecommunications networks are also extensive and complex ICT infrastructures composed of thousands of electronic components, which may pose significant challenges for e-waste and circular economy.

To address these aspects, the Commission's 2022 Digitalising the Energy System Action Plan sought to explore the possibility to develop common indicators for measuring the environmental footprint of electronic communications services, which is the purpose of this JRC report. The identification and analysis of the main sustainability indicators is to prepare the ground for a future Code of Conduct for telecommunications networks – a related task under the Digitalising the Energy System Action Plan.

Acknowledgements

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Acronyms

Acronym	Explanation
5G-EIR	5G-Equipment Identity Register
AF	Application Function
AMF	Access and Mobility Management Function
ASIC	Application-Specific Integrated Circuit
AUSF	Authentication Server Function
BBA	BroadBAnd
BB	Backbone network
BBU	Baseband Unit
BEREC	Body of European Regulators for Electronic Communications
BS	Base Station
CAPEX	Capital Expenditure
CC	Centralised Cloud
CE	Circular Economy
CEN	European Committee for Standardisation
CENELEC	European Committee for Electrotechnical Standardisation
Cloud RAN	Centralised and cloud computing-based Radio Access Network (RAN) architecture
CN	Core Network
CoC	Code of Conduct
COGEN	Cogeneration of heat and power
CoMP	Coordinated MultiPoint

COTS	Commercial Off-the-Shelf
CPU	Central Processing Unit
C-RAN	Centralised-RAN
CSP	Communications Service Provider
CU	Centralised Unit
DN	Data Network
D-RAN	Distributed RAN
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DU	Distributed Unit
DV	Data Volume
EC	European Commission
eCPRI	electronic communications networks
ECN	Electronic Communications Networks
ECS	Electronic Communications Services
EE	Energy Efficiency
EED	Energy Efficiency Directive
EIB	European Investment Bank
ES	Evaluation Scenarios
ESO	European Standards Organisation
ETS	Emissions Trading System
ETSI	European Telecommunications Standards Institute

EU	European Union
FAN	Fixed Access Network
FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform
FPGA	Field-Programmable Gate Array
FTTB	Fibre to the building
FTTC	Fibre to the curb/cabinet
FTTH	Fibre to the home
FTTN	Fibre to the node
FTTP	Fibre to the premises
GESI	Global Enabling Sustainability Initiative
GHG	Greenhouse Gas
GHG Protocol	Greenhouse Gas Protocol
GFLOPS	Giga floating-point Operations Per Second
gNBvCU	Virtual next generation NodeB centralised unit
gNBvDU	Virtual next generation NodeB distributed unit
GPON	Gigabit Passive Optical Networks
GPP/GPU	General-Purpose Processor vs General Purpose CPU
GRI	Global Reporting Initiative
GSMA	GSM Association
H-CRAN	Hybrid C-RAN
ICT	Information and Communication Technology

IEC	International Electrotechnical Commission
IFFT	Inverse FFT
ILCD	International Reference Life Cycle Data System
IMT	International Mobile Telecommunications
IP	Internet Protocol
ISO	International Organisation for Standardisation
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LOS	Line of Sight
MAC	Medium Access Control
MD	Maximum Distance
MEC	Mobile Edge Computing
MIMO	Multiple-Input Multiple-Output
MN	Mobile Network
MNO	Mobile Network Operator
NDAF	Network Data Analytics Function
NEF	Network Exposure Function
NF	Network Function
NFV	Network Function Virtualisation
NRF	Network Repository Function
NSR	Network Switches and Routers

NSSF	Network Slice Selection Function
OADM	Optical add-drop multiplexer
OECD	Organisation for Economic Cooperation and Development
OFDM	Orthogonal Frequency-Division Multiplexing
OLT	Optical line termination/terminal
ONU	Optical network unit
Open RAN, O-RAN, OPEN-RAN, ORAN	Different stakeholders use the terms OPEN-RAN, Open RAN, O-RAN and ORAN with the same meaning. In this report, the term Open RAN is mostly used, but the other terms can also be used when reporting the findings from external references.
OPEX	Operating Expenditures
OXC	Optical cross-connect
PCF	Policy Control Function
PDCP	Packet Data Convergence Protocol
PDU	Protocol data unit
PEF	Product Environmental Footprint
PODU	Power Distribution Unit
PHY	Physical Layer
PLMN	Public Land Mobile Network
PON	Passive Optical Network
PU	Processing Unit
PtP	Point to Point Equipment
QAM	Quadrature Amplitude Modulation

QOE	`Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
REC	Radio Equipment Controllers
RF	Radio Frequency
RIC	RAN Intelligent Controller
RLC	Radio Link Control
RoF	Radio-Over-Fibre
RRC	Radio Resource Control
RRH	Remote Radio Head
RU	Radio Unit
SBTi	Science Based Targets initiative
SDG	(UN) Sustainable Development Goal
SDO	Standards Development Organisation
SEE	Site Energy Efficiency
SEPP	Security Edge Protection Proxy
SISO	Single-Input Single-Output
SSF	Session Management Function
TCO	Total Cost of Ownership
TDM	Time Division multiplexing

UDM	Unified Data Management
UDR	Unified Data Repository
UDSF	Unstructured Data Storage Function
UPS	Uninterruptible Power Supply
UE	User Equipment
UP	User Plane
UPF	User Plane Function
vCPU	Virtual CPU
VM	Virtual Machine
VNF	Virtual Network Function
vRAN	Virtualized RAN

Definitions

Term	Definition
Access network operator	An organisation that has been issued a licence to operate fixed or mobile telecommunications services, responsible for connecting the end user to their immediate service provider.
Core network operator	An organisation that is responsible for implementing and running architectures, components and protocols that provide interconnection and network management functionalities, such as authentication, traffic delivery, etc.
Consumer	A consumer of telecommunications services provided by a telecom services operator or a virtual telecom operator.
Data centre operator	A data centre operator is an operator of a data centre (e.g., server farm), which provides computing and data storage services. In this report, the definition is used only to indicate data centres specific to network services and not generic cloud and application services.
Fixed Telecom operator	A telecom services operator providing fixed telecommunications services and/or managing a fixed telecommunications infrastructure.
National regulatory authority	National organisation charged by a Member State with the responsibility to regulate the provision of telecommunications services in the Member State.
Mobile telecom operator	A telecom services operator providing mobile telecommunications services and/or managing a mobile telecommunications infrastructure.
Network equipment provider (manufacturer/vendor)	A company that sells equipment as well as products and services to communications service providers as well as to enterprise customers.
Network infrastructure provider	An organisation, which owns and/or manages the physical infrastructure (e.g., base station towers, optical network nodes and fibres), hosting and supporting the network operation.
Network integrator	An organisation responsible for designing and building network architectures and integrate new capabilities into current solutions, by combining different hardware and software components. But it is not responsible for providing the communications services.
Software developer or provider	A company responsible for the development of software modules and products to implement or support a telecoms network and/or its services.

Sustainability auditor (also called third party sustainability auditor)	An organisation responsible for conducting independent audits of telecommunications operators, network infrastructure providers and telecoms virtual operators for specific sustainability indicators.
Telecoms services operator	An organisation that provides voice, media and data communication for its subscribed users, either fixed or mobile. It may or may not own the physical infrastructure (e.g., base station towers, fibre-based network) over which the services are provided.
Telecoms virtual operator	A telecoms virtual operator is a provider of management services and a reseller of network services from telecommunications services operators. It does not own the network infrastructure over which the services are provided.

Executive Summary

As mandated by the Commission's 2022 Digitalising the Energy System Action Plan,[1] this report undertaken by the EC JRC proposes common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs).

More specifically, the report has the objectives to 1) analyse the sustainability of fixed and wireless telecommunications networks in terms of environment, climate, and energy aspects, 2) identify sustainability indicators which can be commonly collected and reported across Europe, and 3) to prepare the ground for a Code of Conduct for telecommunications networks – a related task under the Digitalising the Energy System Action Plan.

This report provides an extensive analysis on 19 sustainability indicators in the context of telecommunications networks. Its scope is restricted to network infrastructure and equipment of mobile and fixed telecommunications infrastructures. While important, this scope does neither include users' equipment like mobile phones, tablets and even TVs, or customer premises equipment (CPE). The indicators are related to the whole lifecycle of telecommunications networks and equipment and not limited to the operational phase.

The 19 indicators of this report have been selected from ongoing activities in the area and parallel studies from various stakeholders in telecommunications: telecommunications operators, vendors, integrators and regulators, and most notably a study by the Body of European Regulators for Electronic Communications (BEREC 2023).

The key elements of the analysis were:

1) Desktop research to review the state of art in telecommunications sustainability indicators and recommendations from governmental, industrial and academic domains.

2) An analysis of the current regulatory framework for sustainability in ICT.

3) A survey conducted between 26 May and 23 June 2023 where stakeholders from all relevant sectors provided input for the prioritisation of the indicators and the potential areas and challenges to address.

4) A stakeholder workshop conducted on 10 of October 2023 with more than 50 participants to assess the preliminary findings from the analysis and the results from the survey. In addition, participants shared their experience and the lessons learnt in implementing sustainability activities.

On the basis of the input provided by the four elements above, the report has conducted an analysis to prioritise the main indicators, which can be used as input to establish a Code of Conduct for the sustainability of telecommunications networks, as it was already done for data centres (EC JRC 2021a) and broadband equipment (EC JRC 2021).

Among the 19 indicators analysed, the report identified 8 indicators that could be considered as high priority for the sustainability of telecommunications networks and are therefore classified as "Must Have", 6 indicators with medium priority and therefore classified as "Should Have" and 5 indicators with a low priority and therefore classified as "Nice to Have" as per the table below:

Indicator	**Classification**
Energy consumption	Must Have

[1] COM/2022/552 final

Energy efficiency	Must Have
Use of renewable energy (rate)	Must Have
GHG scope 1 emissions	Must Have
GHG scope 2 emissions	Must Have
GHG scope 3 emissions	Must Have
E-waste production	Must Have
Distribution or utilisation of recycled/ refurbished/ reused products	Must Have
Recycled/refurbished/ reused components (also the excavate mass) used in products	Should Have
Recyclability	Should Have
Reparability	Should Have
Expected lifetime	Should Have
Raw materials depletion (mineral)	Should Have
Water usage/ consumption	Should Have
Waste heat recovery/ reuse	Nice To Have
Land use	Nice To Have
Eco toxicity (including incidence on biodiversity, water pollution…)	Nice To Have
Human toxicity (including air pollution)	Nice To Have
Eutrophication (terrestrial, freshwater, marine)	Nice To Have

The work on a Code of Conduct should focus on the high priority indicators ("Must Have") to assess the most appropriate standards and processes to be followed by stakeholders to collect data and report information on their sustainability conduct.

1 Introduction

This introductory section describes the purpose and scope of the report, its methodology and structure. Sustainability has become a top priority in the European Commission policy activities since President Ursula von der Leyen has promised to broaden and strengthen EU climate policy (von der Leyen, 2019)[2] through a European Green Deal.[3] In about 20 different initiatives, the Commission included proposals on a reduction target from 40 to 55 percent of the EU's emissions by 2030 relative to 1990 figures towards climate neutrality by 2050, the introduction of a carbon border tax, the drafting of a Sustainable Europe Investment Plan[4], the partial transformation of the European Investment Bank (EIB) into a climate bank, the extension of the EU emissions trading system (ETS)[5] and the development of a new industrial policy for Europe (von der Leyen, 2019a)[6].

In this context, the Information and Communication Technology (ICT) sector accounts for between 7% and 9% of global electricity consumption (forecast to rise to 13% by 2030),7 around 3% of global greenhouse gas emissions,[8] and increasing amounts of e-waste. The telecommunications sector is a significant segment of the ICT sector. The analysis of its the energy, climate and environmental footprint telecommunications may help to decrease negative impacts on our planet. To support this analysis, it is important to develop common indicators that enable to monitor and benchmark sustainability based on objectively measurable evidence.

1.1 Objective and scope of the report

The objective of this report is to explore the possibility to develop common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs), herein referred to as telecommunications networks.

More specifically, the report seeks to:

- focus on the sustainability of fixed and wireless telecommunications networks in terms of climate, energy, and environmental aspects;
- identify sustainability indicators that can be commonly collected and reported across Europe, and
- prepare the ground for a sustainability Code of Conduct (Q4 2025) for the telecommunications sector that may assist the sector to join the implementation of the EU Taxonomy for sustainable activities (EC 2023a) developments ('taxonomy-readiness by design') by building on international and EU standards,
- prioritising easily verifiable and applicable indicators, leaving ideally no room for diverging interpretations, and relating to the climate and environmental EU Taxonomy objectives.

In this context, the report also aims to support current efforts in the definition and implementation of the EU taxonomy for sustainable activities a classification system which was established to clarify which investments are considered sustainable in the context of the European Green Deal.

As for scope, this report will focus specifically on the impact of the operation of telecommunications networks with their various architectural and deployment options, both terrestrial and non-terrestrial, but it will not extend to Customer Premise Equipment (CPE), already covered by the Broadband Equipment Sustainability Code of Conduct (CoC) (EC JRC 2021), nor to User Equipment (UE), including smartphones, tablets and even laptops, and the whole variety of IoT devices. It will not extend to TV equipment, already covered by the Digital TV Services CoC (EC JRC 2021b).

[2] https://ec.europa.eu/commission/presscorner/detail/fr/speech_19_6749.
[3] https://www.consilium.europa.eu/en/policies/green-deal/
[4] https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_24
[5] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en
[6] https://single-market-economy.ec.europa.eu/industry/strategy_en
7 Strategic Foresight Report 2022; EU Action Plan on Digitalising the Energy System
8 The Shift Project, "Déployer la sobriété numérique", October 2020, p. 16; World Bank 2022

Then, this report does not address the following aspects:

- The analysis of the improvement and positive impact on some indicators due to the use of telecommunication networks. For example, traffic efficiency can improve with subsequent reduction of GHG by vehicles, but this aspect is not in the scope of the study.
- Impact of the indicators from elements not directly related to the telecommunication networks, but which are part of the telecoms operator business like vehicles fleets or office buildings. The potential exception to this aspect is the use of the vehicle fleet for the maintenance of the telecoms infrastructure as part of the GHG scope 3 indicator.

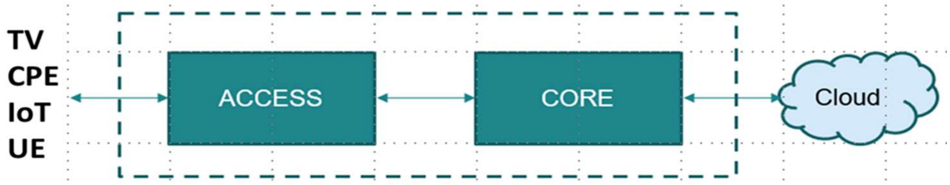

Figure 1 High-level functional architecture of telecommunications networks

1.2 Methodology

Desktop research was used to analyse existing publications on sustainability indicators for telecommunications networks, spanning from the regulatory environment in the EU and beyond over EU and international standardisation activities to research and stakeholder publications. The results of this desktop research fed into an EU survey on a draft list of indicators, which ran from 26 May to 23 June 2023 to collect stakeholder feedback.

On the basis of the received feedback from stakeholders and additional input from discussions with specific categories of stakeholders, an in-depth analysis was conducted for each indicator. The indicative findings were discussed with a representative sample of the stakeholder community at a workshop on 10 October 2023 in Brussels.

Building on the received feedback at the workshop as well as further exchanges with stakeholders, the analysis was completed with additional elements per indicator, such as its impact across the different components of the network (whenever possible) and across different categories of stakeholders (Network Operator or association, Data centre operator or association, Network equipment providers or association, National Regulatory Authority, Third-party sustainability auditor or association, Software provider or association, Consumer/civil society association).

1.3 Structure of the report

The structure of the report is as follows.

Section 2 provides an overview of the basic concepts in modern telecommunications networks and a description of the technological evolutions that may impact the estimation of the sustainability indicators for telecommunications networks. The goal of section 2 is not to provide a comprehensive overview of the future trends of telecommunications networks but only to summarise the key architecture and technology aspects that are related to the sustainability indicators.

Section 3 provides a systematic review of the publications related to sustainability indicators. There are a number of reports already drafted and published on one or more sustainability indicators, which are taken into consideration as an input to this study. Publications during the last 5 years are prioritised in the analysis.

Section 4 provides a summary of the study results in table format, and notably from the survey conducted by DG JRC during the period from 26 May to 23 June 2023 to collect input on sustainability indicators from stakeholders involved in the design, development, deployment, and operation of telecommunications networks, providing electronic communications services to business and residential customers.

Section 5 provides an in-depth analysis of key indicators on the basis of the results from the survey, the feedback from the stakeholder workshop and the input from the desktop research. Indicators can be evaluated differently depending on the category of stakeholder (e.g., telecoms operator vs. equipment vendor) or the element of the network.

Section 6 summarises the key findings and provides recommendations with a focus on preparing the ground for a Code of Conduct on sustainable telecommunications networks.

This report is also complemented by a set of Annexes (from A to G) which provides additional details on the concepts described in this report (e.g., detailed report of the stakeholder workshop and additional figures from the survey)

2 Telecommunications networks - basic concepts Telecommunications networks architecture and main elements

The objective of this section is to provide an overview of the basic concepts of telecommunications networks and technological trends, which can be helpful to support the analysis of sustainability indicators.

A high-level view of a combined fixed and mobile network architecture is shown in Figure 2, which can be used as a simplified reference model. The figure also presents the different network segments that are considered in this work, as well as the broader context of relevant Codes of Conduct.

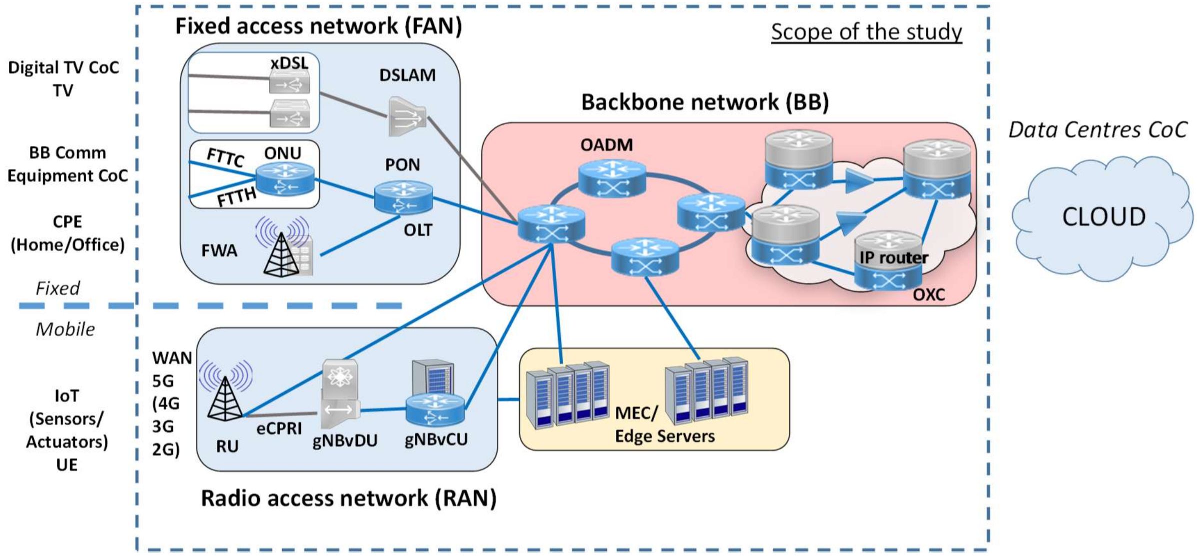

Figure 2 Overall telecommunications network architecture (combining both fixed and cellular networks)

The features of the core network or **backbone (BB)** are similar in both fixed and cellular telecommunications networks: it has to provide very high throughput with high quality of service. It is usually built with fibre optic cables and switches, apart from specific cases where radio links may be used. Optical cross-connect (OXC) devices are used by telecommunications carriers to switch high-speed optical signals in a fibre optic network, while networking devices, i.e., the IP (Internet Protocol) routers, forward data packets between computer networks.

Between the access network and the core network, there is typically a metro network aggregating traffic from the access network and distributing traffic from the core. Since it shares many characteristics with the core network such as being mostly based on fibre optics cabling, **it has been considered part of the backbone for the purpose of this work**. From a sustainability point of view, it has to be noted that the metro network is somewhat richer with network devices, which are responsible for interfacing fibre optics cabling with digital electronic communications devices of the access network, which have a higher energy consumption rate than fibre optics devices. Also traffic control functions of the metro network may consume somewhat more energy than the functions of the core network (Dourado 2018).

The **access network** is the part of the network interfacing with the final user. As with the metro network, it is equipped with devices, which interface the fibre optics cabling with digital electronic communication devices like the OLT and the DLSAM. The optical line termination/terminal (OLT) is an active device at the end of the fibre network and serves as the service provider endpoints of a passive optical network (PON). The digital subscriber line access multiplexer (DSLAM) is an active device of a copper network, which collects data from its many modem ports and aggregates the voice and data traffic into one complex composite signal via multiplexing, enabling multiple subscribers to access broadband services.

The **fixed access network (FAN)** is deployed up to the user facilities or the near proximities (e.g. offices or homes). There is still a large variety of access network architectures and components because of the significant legacy copper-based infrastructure, which was supporting xDSL. xDSL represents various forms of the digital subscriber line (DSL), such as the predominant asymmetric digital subscriber line (ADSL). Alternative solutions like fibre to user premises or their proximity are being deployed or are already deployed. The term FTTx comprises these solutions, including fibre to the premises (FTTP), with its subcategories of fibre to the home (FTTH, e.g., an apartment) and fibre to the building (FTTB, usually the basement of a multi-unit building) as well as fibre to the curb/cabinet or node (FTTC/N) in the street, with copper wires completing the connection to the premises all the way from the optical network unit (ONU). Depending on the category of FTTx, the impact of sustainability indicators can be different. For example, the digging involved to deploy new fibre optics has an obvious environmental impact, while at the same time fibre uses less energy per bit than copper (Baliga 2009).

An alternative to the placement of cables in the ground is to use Fixed Wireless Access (FWA) technologies, which can be installed with wireless communication links between the user premises and the nearest visible access network node (e.g., to support Line of Sight (LoS) communication for greater data quality). While avoiding digging has a positive environmental impact, the energy efficiency of FWA is not as good as fibre. On the other hand, FWA is designed to support many users at the time, which can improve the ratio of energy consumption per user.

The **Radio Access Network (RAN)** is the access network used by cellular networks to support communication with mobile users using cellular technologies (2G to 5G). With the evolution towards 5G and the trends in virtualisation and cloudification, the conventional distributed RAN (D-RAN) in which all the radio functionalities resided in the cell site is overcome by the centralised RAN (C-RAN), whereby the radio functions are moved to a shared, centralised location and separated from the base station (BS) antenna or remote radio head (RRH).One key aspect in the evolution of telecommunications networks towards 5G is the increasing disaggregation of base stations by separating the lower-level processing performed by a distributed unit (DU) from the higher layer processing performed by a centralised unit (CU). The functionalities can be implemented in software (i.e. virtualised) and thus run on multi-purpose computing platforms in regional/distributed data centres as cloud services. This novel architecture is named Cloud-RAN or Centralised RAN and includes a virtual next generation centralised unit and eventually also a virtual distributed unit (gNBvCU and gNBvDU in 5G terminology). They are connected to the radio units (RUs) using standardised interfaces like the enhanced Common Public Radio Interface (eCPRI). Figure 2 5G currently co-exists with 2G, 3G and 4G,

Besides cellular, we need also to take into consideration Wide Area Networks (WAN) solutions like LoRa and SigFox, addressing IoT devices over long distances with low data rates. The anticipated trillions of IoY devices will also be address by 5G massise Machine-Type Communications (mMTC), but certain classes will still be served by WAN.In terms of energy consumption, on the one hand, already 4G and even more 5G introduced a number of technical solutions and components to improve energy efficiency like the sleep mode. On the other hand, the increasing traffic demand and the use of complex Multiple Input and Multiple Output (MIMO) communication systems has increased the computing needs of the RAN components, which may have an impact on the power consumption (Agiwal 2016). In addition, the virtualisation and cloudification of the cellular networks can lead to increased energy consumption and optimised patterns need to be sought combining high network capacity and energy efficiency (Alhumaima 2018) (Alnoman et al. 2017). Currently, the main source of power consumption is still related to the Radio Frequency (RF) transmission by the radio terminals of the base station, also called radio unit (RU). These aspects will be discussed more in detail in Section 4 for the energy efficiency and energy consumption indicators.

While not the focus of this study, Edge Servers offer high computing capabilities for the main functions of the telecom networks, including virtualised network functions. Historically, they have been used in mobile and fixed telecommunications networks to support the implementation of FCAPS (fault, configuration, accounting, performance, security) for data analysis to identify faults for maintenance, store the network configuration files, perform accounting and host the databases for security (e.g., authentication centre). In the context of 5G, Edge Servers coexist with mobile edge computing (MEC), in support of virtualisation functionalities. However, as the focus of this work is on telecommunications networks rather than data services, Edge Servers and MEC are not considered.

Note: In this study, there is a distinction between edge Servers, mobile edge computing (MEC) and Cloud Data Centres! Data centres are usually implemented with server farms with a significant number (hundreds or thousands) of blade servers with dedicated cooling equipment, while edge severs and MEC server are relatively minuscule in comparison, which is the reason why there are not considered in this study.

Note: in this report we use the term data centres interchangeably with server farms because some references use either one of the two terms with the same meaning.

3 State of play of sustainability in the telecommunications sector

This section provides an overview of the various government activities in the European Union (sub-section 3.1), United States of America (sub-section 3.2) and China (sub-section 3.3). This is complemented by an overview of the standardisation activities in sub-section 3.4 and the review of the research literature in sub-section 3.5.

3.1 Policy and regulatory initiatives in the European Union

Telecommunications networks have so far not been in the focus of the Commission's sustainability policy. As shown in Figure 3 below, sectors such as energy or agriculture are far bigger GHG emitters than the ICT sector as a whole. Still, ICT emits more than, for instance, aviation or shipping.

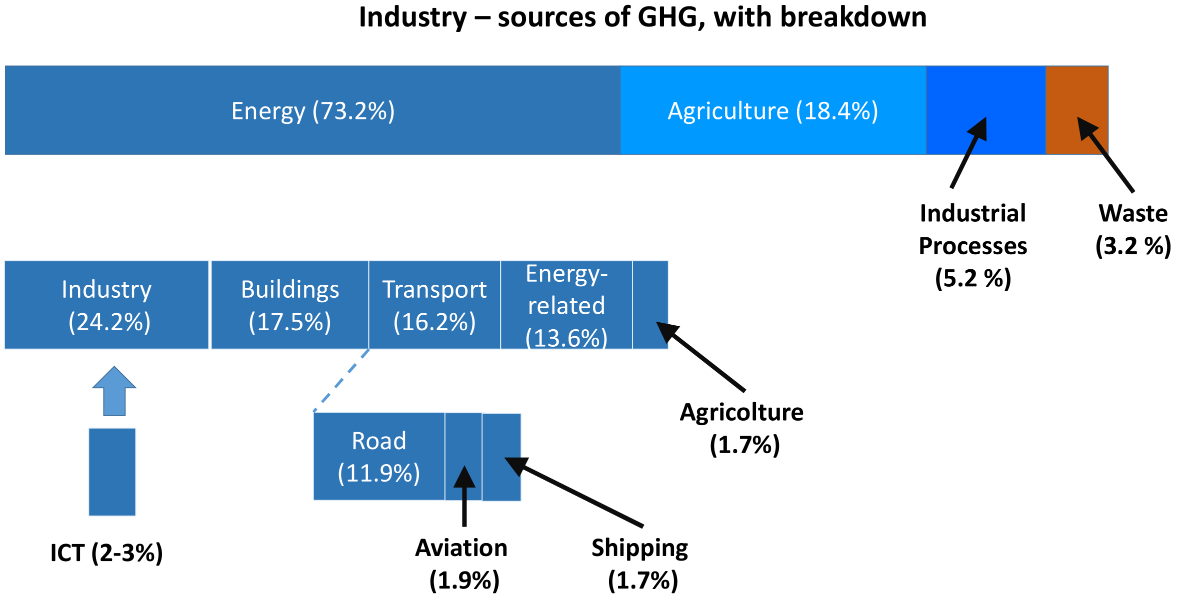

Figure 3 Sources of GHG with breakdown. Figure created by the JRC with data sources from Cullen International (https://www.cullen-international.com/) in 2023 on the basis of data sourced from Our World in Data (https://ourworldindata.org/).

Within the ICT sector, networks are not main contributor of emissions (see Figure 4 below), but this may change as data traffic continues to grow significantly and infrastructure needs to expand accordingly.

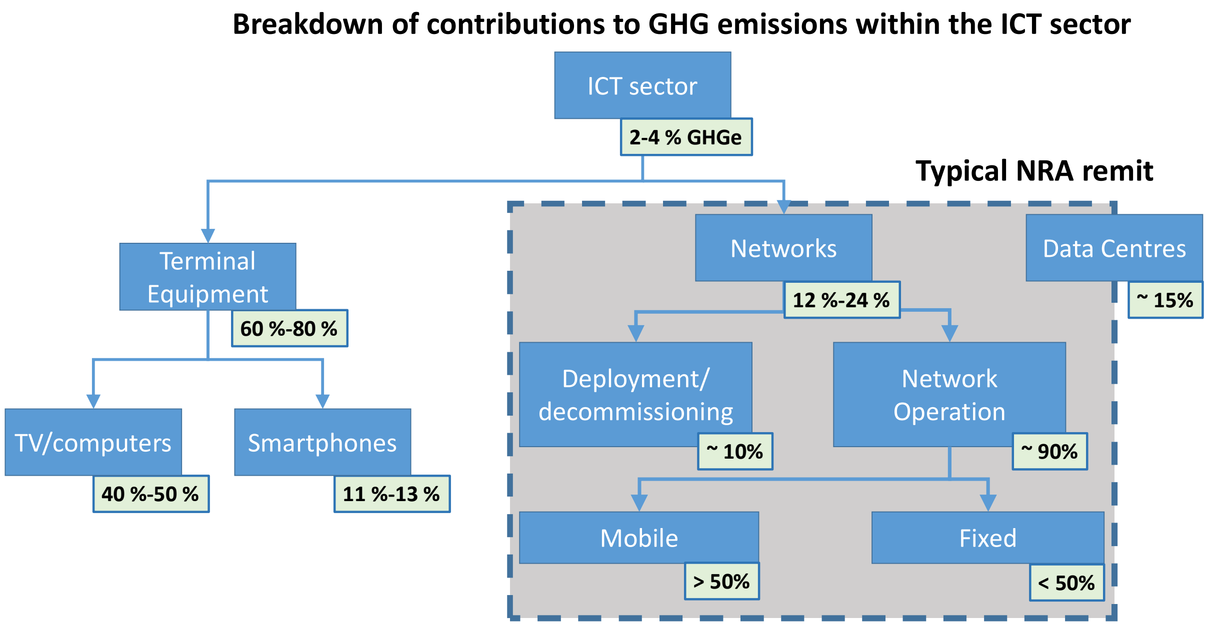

Figure 4 Breakdown of contributions to GHG emissions within the ICT sector. Image drafted by the JRC with data source from (WIK-Consult 2021)).

While their relatively small impact may explain why telecommunications networks so far have not been at the forefront of regulatory efforts, this may change going forward, in particular when we reflect upon sustainable financing of these networks, critical for the economic growth. It is therefore useful to explore which initiatives in related areas could provide relevant insights to build on.

This section summarises the applicable regulatory frameworks and ongoing actions in the European Union.

3.1.1 Recast of the Energy Efficiency Directive

On 10 October 2023, the recast of the Energy Efficiency Directive (EED recast)[9] was formally agreed. The EED recast significantly raises the EU's ambition for energy efficiency, promotes 'energy efficiency first' as an overall principle of EU energy policy and introduces measures to promote energy efficiency in the ICT sector.

In particular, the Directive recommends (Recital 85 and Annex VII) that in order to promote sustainable development in the ICT sector, particularly of data centres, Member States should collect and publish data on the energy performance and water footprint of data centres. In addition, Article 12 that refers to data centres with a complementary Delegated Act is being drafted and is expected to be adopted in the beginning of 2024.

While this provision is focusing on data centres and as such does not apply to telecommunications networks, it may become relevant as such networks progress towards increased virtualisation. In addition, energy efficiency efforts in data centres could result in the optimisation of the production, processing and transmission of data, thus driving efficiencies in telecommunications networks as well.

Since a comprehensive reporting scheme for data centres will be established, some of the indicators could inform indicators for ECNs, thus, creating a wider and consistent reporting space for the ICT sector. The energy performance to be reported by data centres are a prime example in this regard (e.g., energy consumption, power utilisation, temperature set points, waste heat utilisation, water usage and use of renewable energy, using as a basis, where applicable, the CEN/CENELEC EN 5060).

[9] http://data.europa.eu/eli/dir/2023/1791/oj

3.1.2 Sustainable finance

The foundations of the EU sustainable finance framework are laid down in the **Action Plan on Financing Sustainable** Growth (COM/2018/097) and the **Strategy for Financing the Transition to a Sustainable Economy** (COM/2021/390).

The bases of sustainability reporting are established in Directive 2014/95/EU, known as the **Non-Financial Reporting Directive (NFRD)**[10], which requires certain large companies to disclose relevant non-financial information. It amended Directive 2013/34/EU - also known as the Accounting Directive.

The disclosure of corporate sustainability information has been extended to a wider set of companies by Directive (EU) 2022/2464, known as the **Corporate Sustainability Reporting Directive (CSRD)**[11]. The CSRD aims at improving the flow of sustainability information in the corporate world.

The CSRD obliges large companies and listed SMEs to report sustainability information as a part of their annual management report. The CSRD also stipulates that the collection of sustainability information is to be conducted through independent auditing. The new obligations will apply from the financial year 2024 to companies previously subject to the NFRD, from 2025 to large companies (which includes all major telecom operators and vendors), and from 2026 to listed SMEs.

Sustainability disclosure concerns the following environmental factors:

(a) climate change mitigation, including scope 1, scope 2 and, where relevant, scope 3 greenhouse gas (GHG) emissions. Scope 1 emissions are direct emissions), scope 2 emissions are indirect emissions from the use of purchased energy and scope 3 emissions are all other indirect emissions that occur across the value chain and are outside of the organisation's direct control. See sections 5.2.3,5.2.4 and 5.2.5 for additional details on these indicators.

(b) climate change adaptation;

(c) Use of water and marine resources;

(d) Use of resource and the circular economy;

(e) Pollution (non-GHG);

(f) biodiversity and ecosystems.

While the CSRD considers also social and governance aspects of sustainability, its 'green' elements rely on the classification system established by the EU Taxonomy.

3.1.2.1 Taxonomy

To enable a common understanding as regards activities contributing to EU environmental objectives, an EU Taxonomy is legally established in Regulation 2020/852, known as **Taxonomy Regulation**[12]. It is a centrepiece of the EU sustainable finance framework. By disclosing information on their activities aligned to the Taxonomy,

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[10] Directive 2014/95/EU of the European Parliament and of the Council of 22 October 2014 amending Directive 2013/34/EU as regards disclosure of non-financial and diversity information by certain large undertakings and groups.

[11] Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting.

[12] Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088

companies can help investors take informed investment decisions. Moreover, governments and local communities, together with the EIB (European Investment Bank), can use the taxonomy to identify and classify actions to support the transition to a climate neutral and sustainable economy.

The taxonomy is relevant for the sustainability objectives as well as for financial aspects. Indeed, the taxonomy-aligned 'environmentally sustainable' investment can be automatically qualified as 'sustainable investments' for broader investment purposes under the Sustainable Finance Disclosure Regulation[13] (Commission Notice C(2023) 3719).

Different taxonomy delegated acts define the activities and associated criteria for considering them sustainable according to the six environmental objectives of the Taxonomy Regulation. The aim is to enable investments in the sectors and economic activities recognised as environmentally sustainable. The taxonomy delegated acts include the Commission Delegated Regulation (EU) 2021/2139 known as **Taxonomy Climate Delegated Act[14],** amended by Commission Delegated Regulation (EU) 2022/1214 known as **Complementary Climate Delegated Act[15]**, covering climate change mitigation and adaptation objectives. The Taxonomy Climate Delegate Act defines conditions under which an economic activity qualifies as contributing substantially to climate change mitigation and adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives.

On 27 June 2023, the Commission adopted two additional Taxonomy Delegated Acts that extend the taxonomy, including criteria for the remaining four environmental objectives. More specifically, Commission Delegated Regulation (EU) 2023/2486, known as **Taxonomy Environmental Delegated Act[16],** establishes the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to the following objectives:

- sustainable use and protection of water and marine resources
- transition to a circular economy
- pollution prevention and control
- protection and restoration of biodiversity and ecosystems

In addition, Commission Delegated Regulation (EU) 2023/2485[17], which is a targeted **amendment to the Climate Delegated Acts**, establishes additional technical screening criteria for determining the conditions under which certain economic activities qualify for the following objectives:

- contributing substantially to climate change mitigation
- contributing substantially to climate change adaptation

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[13] Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on sustainability-related disclosures in the financial services sector

[14] Commission Delegated Regulation (EU) 2021/2139 of 4 June 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives.

[15] Commission Delegated Regulation (EU) 2022/1214 of 9 March 2022 amending Delegated Regulation (EU) 2021/2139 as regards economic activities in certain energy sectors and Delegated Regulation (EU) 2021/2178 as regards specific public disclosures for those economic activities.

[16] Commission Delegated Regulation (EU) 2023/2486 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to the sustainable use and protection of water and marine resources, to the transition to a circular economy, to pollution prevention and control, or to the protection and restoration of biodiversity and ecosystems and for determining whether that economic activity causes no significant harm to any of the other environmental objectives and amending Delegated Regulation (EU) 2021/2178 as regards specific public disclosures for those economic activities

[17] Commission Delegated Regulation (EU) 2023/2485 amending Delegated Regulation (EU) 2021/2139 establishing additional technical screening criteria for determining the conditions under which certain economic activities qualify as contributing substantially to climate change mitigation or climate change adaptation and for determining whether those activities cause no significant harm to any of the other environmental objectives

As data becomes increasingly available, the benefits from applying the Taxonomy and the rest of the sustainable finance framework are expected to become more evident.

3.1.2.2 Relevance of sustainable finance for the sustainability indicators for telecommunications networks

The main relevant regulations and directives are summarised in Table 1. The sustainability reporting under NFRD/CSRD together with the specific rules for reporting the taxonomy-eligible and taxonomy-aligned activities provides a comprehensive framework for disclosures underpinning sustainable financing.

Table 1: List of the most relevant directives and regulations in sustainable finance and their relevance for the sustainability indicators for the telecommunications networks considered in this study.

Directive and Regulation Name	Legislation	Scope	Relevance for the sustainability indicators for telecommunications network
Non-Financial Reporting Directive (NFRD)	Directive 2014/95/EU	Introduces sustainability reporting.	Sustainability reporting obligations.
Taxonomy Regulation	Regulation (EU) 2020/852	Defines EU taxonomy.	Taxonomy framework and activities.
Taxonomy Climate Delegated Act	Delegated Regulation (EU) 2021/2139	Conditions for an economic activity to qualify as contributing substantially to climate change mitigation or adaptation, and not causing significant harm.	Activities in the taxonomy for climate change mitigation and adaptation and related conditions.
Corporate Sustainability Reporting Directive	Directive (EU) 2022/2464	Sustainability reporting obligations with auditing for large companies and SME.	Sustainability reporting obligations, also covering social and governance aspects.
Taxonomy Environmental Delegated Act	Delegated Regulation (EU) 2023/2485	Conditions for an economic activity to qualify as contributing to the sustainability objectives of water and marine resources; resource use and the circular economy, pollution, biodiversity and ecosystems.	Activities in the taxonomy for sustainability objectives that are not climate related as well as related conditions.
Amendments to the Climate Delegated Acts	Delegated Regulation (EU) 2023/2486	Amends the Taxonomy Climate Delegate Act	As for the Taxonomy Climate Delegate Act

While telecommunications networks are currently not explicitly covered by the EU Taxonomy[18], the below reported activities are at least indirectly relevant for the part of supporting actions related to climate change mitigation (activity 8.1 and 8.2) and adaptation (activity 8.1 and 8.3) as defined in the Taxonomy Climate Delegated Act[19]:

• **Activity 8.1: Data processing, hosting and related activities contribution to climate mitigation,** i.e., storage, manipulation, management, movement, control, display, switching, interchange, transmission or processing of data through data centres, including edge computing.

For climate mitigation, the substantial contribution criteria are as follows:

1. The activity has implemented all relevant practices listed as "expected practices" in the most recent version of the European Code of Conduct on Data Centre Energy Efficiency, or in CEN-CENELEC document CLC TR50600-99-1 "Data centre facilities and infrastructures - Part 99-1: Recommended practices for energy management". The implementation of those practices is verified by an independent third-party and audited at least every three years.

2. Where an expected practice is not considered relevant due to physical, logistical, planning or other constraints, an explanation of why the expected practice is not applicable or practical is provided. Alternative best practices from the European Code of Conduct on Data Centre Energy Efficiency or other equivalent sources may be identified as direct replacements if they result in similar energy savings.

3. The global warming potential (GWP) of refrigerants used in the data centre cooling system does not exceed 675.

For the climate adaptation, the substantial contribution requires also that

"*the activity has implemented all expected practices that have been assigned the maximum value of 5 according to the most recent version of the European Code of Conduct on Data Centre Energy Efficiency*."

Criteria for Do not significantly harm (DNSH) on the circular economy are as follows:

"The equipment used meets the requirements laid down in Directive 2009/125/EC for servers and data storage products.

The equipment used does not contain the restricted substances listed in Annex II to Directive 2011/65/EU, except where the concentration values by weight in homogeneous materials do not exceed the maximum values listed in that Annex.

A waste management plan is in place and ensures maximal recycling at end of life of electrical and electronic equipment, including through contractual agreements with recycling partners, reflection in financial projections or official project documentation.

At its end of life, the equipment undergoes preparation for re-use, recovery or recycling operations, or proper treatment, including the removal of all fluids and a selective treatment in accordance with Annex VII to Directive 2012/19/EU."

• **Activity 8.2: Data-driven solutions for GHG emissions reductions contribution to climate mitigation**, i.e., development or use of ICT solutions that are aimed at collecting, transmitting, storing data and at its modelling and use where those activities are predominantly aimed at the provision of data and analytics enabling GHG emission reductions.

For climate mitigation for 8.2, the substantial contribution criteria include the following

"1. The ICT solutions are predominantly used for the provision of data and analytics enabling GHG emission reductions.

[18] See reply to question 159 in the Commission Notice C/2023/267 on the interpretation and implementation of certain legal provisions of the EU Taxonomy Climate Delegated Act establishing technical screening criteria for economic activities that contribute substantially to climate change mitigation or climate change adaptation and do no significant harm to other environmental objective

[19] https://ec.europa.eu/sustainable-finance-taxonomy/taxonomy-compass/the-compass

2. Where an alternative solution/technology is already available on the market, the ICT solution demonstrates substantial life-cycle GHG emission savings compared to the best performing alternative solution/technology.

Life-cycle GHG emissions and net emissions are calculated using Recommendation 2013/179/EU or, alternatively, using ETSI ES 203 199(320), ISO 14067:2018(321) or ISO 14064-2:2019(322).

Quantified life-cycle GHG emission reductions are verified by an independent third party, which transparently assesses how the standard criteria, including those for critical review, have been followed when the value was derived."

• **Activity 8.3: Programming and broadcasting activities**, i.e., programming and broadcasting activities, which include creating content or acquiring the right to distribute content and subsequently broadcasting that content, such as radio, television and data programmes of entertainment, news, talk, and data broadcasting, typically integrated with radio or TV broadcasting.

For climate adaptation, the criteria for Do not significantly harm (DNSH) for circular economy are as for activity 8.1.

The new Taxonomy Environmental Delegated Act introduces the following activities indirectly related to telecommunications networks as part of the taxonomy:

1) for the sustainable use and protection of water and marine resources:

*• **Activity 4.1: Provision of IT/OT data-driven solutions for leakage reduction**. The activity manufactures, develops, installs, deploys, maintains, repairs or provides professional services, including technical consulting for design or monitoring, for information technology (IT) or operational technology (OT) data driven solutions to control, manage, reduce and mitigate leakage in water supply systems (WSSs). 'IT or OT data-driven solutions' include connectable products, sensors, analytics and other software, and information and communication technologies (ICT) for the transmission, storage and display of data and system management.*

2) for the transition to a circular economy:

*• **Activity 1.2: Manufacture of electrical and electronic equipment**. Manufacturing of electrical and electronic equipment for industrial, professional and consumer use.*

*• **Activity 4.1: Provision of IT/OT data-driven solutions**. The activity manufactures, develops, installs, deploys, maintains, repairs or provides professional services, including technical consulting for design or monitoring of*

- *software and information technology (IT) or operational technology (OT) systems for:*
    - *remotely collecting, processing, transferring, and storing data from equipment, products or infrastructure during their use or operation;*
    - *analysing the data and generating insights about the operational performance and condition of the equipment, product or infrastructure;*
    - *providing remote maintenance and recommendations about measures required to avoid operational failure and maintain the equipment, product or infrastructure in an optimal operating condition and prolong their useful life and reduce resource use and waste;*
- *tracking and tracing software and IT or OT systems built for the purpose of providing identification, tracking and tracing of materials, products and assets through their respective value chains (including digital material and product passports) with the predominant objective to support the circularity of material flows and products or other objectives set out in Regulation (EU) 2020/852.*

It is to note that 'IT or OT systems' include connectable products, sensors, analytics and other software, and information and communication technologies (ICT) for the transmission, storage and display of data and system management.

3.1.3 Other relevant EU policy and regulatory initiatives for the sustainability of electronic products

The following policy and regulatory initiatives are relevant for the aspects of ecodesign, energy labelling, restriction of hazardous substances and waste of electric and electronic equipment.

Directive 2009/125/EC, known as ***ecodesign* Directive**[20], establishes a framework for the setting of ecodesign requirements for energy-related products. Regulation (EU) 2019/424[21] applies the ecodesign to servers and data storage products, including network servers, and sets the ecodesign requirements including the power consumption requirements for the different states (i.e., idle, active). Regulation (EU) 2019/1782 implementing the ecodesign directive for External Power Supplies sets out requirements both for no-load power consumption and active efficiency[22]. In addition, the ecodesign regulation on off mode, standby mode, and networked standby ((EC) No 1275/2008, to be repealed by (EU) 2023/826) sets out requirements for home and office electric and electronic equipment. This includes HiNA equipment, such as routers, switches wireless network access points, etc., and equipment with HiNA functionalities[23].

With the new Commission Regulation (EU) 2023/826[24], the ecodesign requirements for off mode, standby mode, and networked standby energy consumption have been established for electrical and electronic household and office equipment. It applies also to network equipment, but solely for domestic use (class B equipment as set out in the EN 55022:2010 standard).

Directive 2011/65/EU, known as **Restriction of Hazardous Substances (RoHS) in Electrical and Electronic Equipment (EEE) Directive**[25], establishes restrictions of the use of certain hazardous substances (e.g., lead, mercury, cadmium) in electrical and electronic equipment for the protection of human health and the environment, including the recovery and disposal of waste EEE. It also covers IT and telecommunications equipment. Since the original directive, various amendments (e.g., Directive (EU) 2017/2102 and Directive (EU) 2015/863) and exemptions have been published.

Directive 2012/19/EU, known as **Waste from Electrical and Electronic Equipment (WEEE) Directive**[26], aims at preventing the creation of WEEE as a first priority, contributing to the efficient use of resources and the retrieval of secondary raw materials through re-use, recycling and other forms of recovery, and improving the environmental performance of everyone involved in the life cycle of EEE. For this purpose, the Commission Implementing Regulation (EU) 2017/699 establishes a common methodology for the calculation of the weight of electrical and electronic equipment placed on the market and a common methodology for the calculation of the quantity of WEEE generated by weight. The calculation methodology is to be applied by each Member State, i.e., it is not addressed to individual companies.

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[20] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products.

[21] Commission Regulation (EU) 2019/424 of 15 March 2019 laying down ecodesign requirements for servers and data storage products pursuant to Directive 2009/125/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 617/2013.

[22] https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products/external-power-supplies_en

[23] https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products/mode-standby-and-networked-standby-devices_en

[24] Commission Regulation (EU) 2023/826 of 17 April 2023 laying down ecodesign requirements for off mode, standby mode, and networked standby energy consumption of electrical and electronic household and office equipment pursuant to Directive 2009/125/EC of the European Parliament and of the Council and repealing Commission Regulations (EC) No 1275/2008 and (EC) No 107/2009

[25] Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

[26] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE).

Another regulation, which is potentially applicable is the Registration, Evaluation, Authorisation and Restriction of Chemicals **(REACH) Regulation**. REACH was adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals, while enhancing the competitiveness of the EU chemicals industry. It also promotes alternative methods for the hazard assessment of substances in order to reduce the number of tests on animals[27].

3.1.4 Codes of Conduct

The European Commission launched the EU Code of Conduct (CoC) for ICT in 2000 as a *voluntary* policy instrument[28]. The following Codes of Conduct have been established:

- AC Uninterruptible Power Systems Code of Conduct (EC JRC 2021c)
- Broadband Communication Equipment Codes of Conduct (EC JRC 2021)
- Data Centres Code of Conduct (EC JRC 2021a)
- Digital TV Services Code of Conduct (EC JRC 2021b)
- External Power Supplies Code of Conduct (EC JRC 2021d)

Three of them are closely related to the telecommunications network sectors. **The Broadband Communication Equipment Codes of Conduct** (EC JRC 2021) sets the basic principles to be voluntarily followed by the involved stakeholders (e.g., manufacturers, operators, vendors), operating in the EU, in respect of energy efficient equipment. More specifically, energy efficiency targets for the equipment are set yearly for different operating modes and loads. It focuses on the user terminals and Customer Premise Equipment (CPE) for broadband network equipment such as digital subscriber line (DSL) equipment, optical line terminals (OLT) or Gigabit Passive Optical Networks (GPON), point-to-point equipment (PtP) equipment and WiFi access points (APs). In addition, it includes also radio base stations, 2G to 5G.

The EU BBA CoC (EC JRC 2021) covers telecom operators and covers the network side equipment as well the CPE equipment. It is very strongly recommended that the energy efficiency and energy consumption criteria are either to be: 1) related to elements of the EU BBA CoC or 2) used to purchase/procure/install BBA equipment that is aligned with the BBA CoC. Additional EE could be achieved in the electricity distribution and conversion, i.e. transformers, PDUs, power cables, AC/DC converters, UPSs, COGEN, batteries.

Regarding the UPS, we can also highlight that the USP CoC (EC JRC 2021c) could be relevant to define criteria and specifications for UPS. The **Uninterruptible Power Systems (USP) Code of Conduct (CoC)** sets out the basic principles to be followed by all parties involved in Uninterruptible Power Systems, operating in the European Union in respect of energy efficient equipment. The Uninterruptible Power Systems (UPS) are widespread in the European Industry and service and data centres (see below). Expectations are that UPS will increase in the European Union in the near future. The energy supply with UPS generates energy losses that are higher than the supply of the consumer direct from the low voltage network. With the general principles and actions resulting from the implementation of this Code of Conduct, the additional electricity energy losses caused by UPS will be limited.

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[27] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC (Text with EEA relevance)Text with EEA relevance. https://echa.europa.eu/regulations/reach/understanding-reach.

[28] https://joint-research-centre.ec.europa.eu/scientific-activities-z/energy-efficiency/energy-efficiency-products/code-conduct-ict_en

The **Data Centres Code of Conduct** (EC JRC 2021a) sets out best practices for data centres, which have been made mandatory for market players to correctly disclose their Taxonomy alignment as part of their non-financial reporting. This Code of Conduct was complemented with an assessment framework providing auditors with the necessary tools to verify whether a data centre correctly applies the practices contained within the Code of Conduct.

The efficiency criteria for the data centres of telecoms operators should coincide or should be strongly related with the implementation of the Best Practice document of the EU DC CoC as this is already requested by the Taxonomy delegated act for climate change mitigation[29] and also recommended to MSs in the 2023 Revised Energy Efficiency Directive Art. 12[30]. This aspect will be investigated more in detail in the subsequent (after this report) analysis, which will be conducted by DG CNECT and JRC on the definition of the Code of Conducts in telecommunication networks.

In addition, it should be highlighted that the assessment framework under the DC CoC is for operators to be aligned with the Taxonomy delegated act for climate change mitigation, which requires third party assessment, while the DC CoC is based on self-assessment.

The **Digital TV Services** Code of Conduct (EC JRC 2021b) sets out the basic principles to be followed by all parties involved in digital TV services, operating in the European Community, in respect of energy efficient equipment, considering that the energy consumption of the equipment is influenced by the services offered, the number of features as well as the components used. It includes equipment for the reception, decoding and interactive processing of digital broadcasting and related services are contributing substantially to the electricity consumption of households in the European Union. Note that currently most of the digital broadcasting is done over telecommunications networks (triple-play - provisioning, over a single broadband connection, of Internet access, television, and telephony.)

3.1.5 Environmental Footprint Recommendation

The European Commission proposed in 2021 the Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) methods as a common way of measuring environmental performance (EU Commission Recommendation 2021/2279) (EC 2021).[31] The PEF and OEF are the EU recommended Life Cycle Assessment (LCA) based methods to quantify the environmental impacts of products (goods or services) and organisations.

The overarching purpose of PEF and OEF information is to enable reducing the environmental impacts of goods, services and organisations, taking into account full supply chain activities (from the extraction of raw materials, through production and use, and re-use, to final waste management). This purpose is achieved through the provision of detailed requirements for modelling the environmental impacts of the flows of material/energy and the emissions and waste streams associated with a product or an organisation throughout the life cycle.

[29] COMMISSION DELEGATED REGULATION (EU) …/... of 27.6.2023 amending Delegated Regulation (EU) 2021/2139 establishing additional technical screening criteria for determining the conditions under which certain economic activities qualify as contributing substantially to climate change mitigation or climate change adaptation and for determining whether those activities cause no significant harm to any of the other environmental objectives. https://finance.ec.europa.eu/system/files/2023-06/taxonomy-regulation-delegated-act-2022-climate_en_1.pdf.

[30] Energy efficiency directive. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en.

[31] Environmental Footprint . https://eplca.jrc.ec.europa.eu/EnvironmentalFootprint.html.

3.1.6 Energy Labelling regulation

The Energy Labelling regulation 2017/1369[32] was adopted in July 2017, replacing the former Energy Labelling Directive 2010/30/EU. It includes a reintroduction of the original A–G scale for labelling and a new database (EPREL). Energy labels are used to help consumers choose products that save energy.

This Regulation lays down a framework that applies to energy-related products ('products') placed on the market or put into service. It provides for the labelling of those products and the provision of standard product information regarding energy efficiency, the consumption of energy and of other resources by products during use and supplementary information concerning products, thereby enabling customers to choose more efficient products in order to reduce their energy consumption.

This Directive is part of the legislative framework for the free movement and marketing of products in the European community. The Directive is applied to energy-related products placed on the market or put into service. Then, it may not be directly related to telecommunications equipment but to energy-related products, which are used in the telecommunication sector like power generators or UPSs in data centres. This directive does not apply to second-hand products, unless they are imported from a third country and the means of transport for persons or goods.

The products to be put on the European market must comply with essential requirements such as labelling of the products and the provision of consistent information for energy efficiency, the consumption of energy and other resources. As of 1 January 2019, suppliers (manufacturers, importers or authorised representatives) need to register their appliances, which require an energy label in the European Product Database for Energy Labelling (EPREL), before selling them on the European market.

3.1.7 Relationships among EU policies, regulations and code of conducts

The initiatives described in the previous sub-sections are often dependent on each other, even if they are borne out of different drivers and rationales.

Figure 5 provides a visual description of these relationships.

[32] Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU (Text with EEA relevance). https://eur-lex.europa.eu/eli/reg/2017/1369/oj.

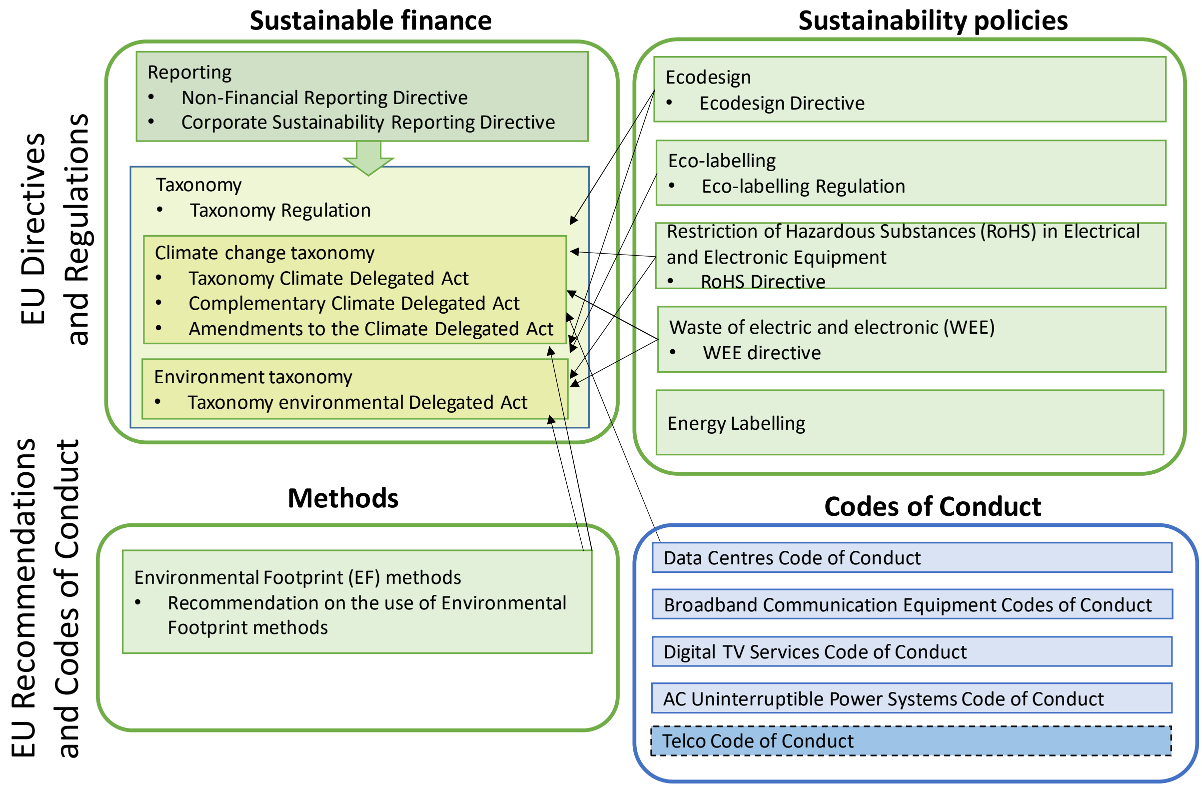

Figure 5 Relationships among regulations and indicators for sustainability of telecommunications networks in the European Union.

3.1.8 Overview of the current European Union projects

A number of research and innovation projects funded by the European Commission and the Smart Networks and Services Joint Undertaking (SNS JU) have investigated the implementation of sustainability and sustainability indicators in telecommunications networks.

A sustainable 6G infrastructure is a key objective of the SNS JU, the EU funding body for 6G research, and 6G should also become an enabler of sustainability, benefitting other sectors and verticals. In its 2024 Research and Innovation (R&I) Work Programme, the SNS JU addresses specifically how 6G networks should be sustainable ("**Sustainable 6G**") and how 6G will contribute to the sustainability of other sectors ("**6G for Sustainability**"), by dedicating a Research and Innovation Lighthouse on Sustainability, a first-of-a-kind EU initiative to fully focus on sustainability dimensions (including the environmental, energy and circular dimensions, as well as the societal and economic aspects) with a dedicated budget of EUR 13 million. Moreover, the SNS JU also considers funding Large-Scale Trials and Pilots where tangible results on sustainability have to be provided, coupled with the involvement of the vertical industries (EUR 25 million EU funding).[1]

An overview of the relevant R&I SNS projects are listed in Annex E.

3.2 Policy and regulatory initiatives in the United States of America

In November 2021, the Department of State and the Executive Office of the President have published the "Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050", involving all sectors of the economy (USA 2021a).

In line with the above strategy, a recent initiative by Senators Edward J. Markey (D-Mass.) and Ron Wyden (D-Ore.) introduced the Generating Resilient and Energy Efficient Network (GREEN) Communications Act, to harden the communications networks against climate change and natural disasters, while simultaneously reducing the carbon footprint of communications infrastructure (USA 2021b).

The initiative proposes the application of green and/or energy efficiency technologies in order to make communications networks more energy and resource efficient. It also promotes the use of renewable energy sources (owned or purchased) for powering the infrastructure, the use of upgraded equipment which complies to energy efficiency standards and the reduction of water consumption in data centres.

Another significant piece of legislation in USA is the Small Network Equipment (SNE) Voluntary Agreement, established in 2015, which covers Internet modems, routers, and other equipment that deliver broadband service to more than 85% of the U.S. residential broadband market. The primary objective of the Voluntary Agreement for ongoing Improvements in the Energy Efficiency of Small Network Equipment (SNE) agreement is to increase the energy efficiency of equipment used to access residential broadband Internet access services while promoting rapid innovation and timely introduction of new features for consumers. Participants in the agreement include all of the largest Internet service providers and many major manufacturers[33].

3.3 Policy and regulatory initiatives in China

China is the world's largest emitter of CO_2 and carbon emissions continue to increase rapidly. Therefore, mitigation of climate change is of high importance and the country has increased its efforts to promote low-carbon development in recent years by efficiently reducing GHG emissions, effectively boosting the adaptive capacity of the climate and continuously improving systems and mechanisms of operation (Xinmin 2022). The policy in the field is complex, consisting of national laws, ministerial regulations, guiding opinions, measures and procedures, local rules and regulations, self-regulation rules of the industry and internal governance rules for each of the state-owned power companies and grid companies[34]. The main laws in the field are the following:

- Laws on Electricity: The Electric Power Law of the People's Republic of China
- Laws on Energy Policy: The Renewable Energy Law and The Energy Conservation Law
- Laws on Resource and the Environment: The Water Law; The Land Management Law; and The Environmental Impact Assessment Law (Law of the People's Republic of China on Evaluation of Environmental Effects)

China has committed itself to setting up a carbon footprint database by 2025 and introducing the option of calculating the carbon footprint of 50 products. This could be expanded to 200 products by 2030. The National Development and Reform Commission (NDRC), China's top economic planner, published a document to this effect on 22 November 2023. In doing so, the country is once again aiming to fulfil Xi Jinping's promise to achieve the emissions peak before 2030.

Observers commented that China, the world's largest greenhouse gas emitter, intends to use its methods for calculating its carbon footprint to catch up with other countries, especially since the European Union's new Carbon Border Adjustment Mechanism came into force. A 2021 study by Tsinghua University concluded that the EU law would put China, the world's largest producer of industrial raw materials such as cement and steel, under the most pressure.

As regards the telecommunications industry, Chinese telecommunications operators are implementing the national carbon emission reduction goals and offering energy efficient solutions[35] in order to comply with the relevant environmental policies.

[33] Energy Efficiency Voluntary Agreements https://www.energy-efficiency.us/.
[34] https://ppp.worldbank.org/public-private-partnership/china-legal-framework-energy-laws-and-regulations
[35] http://www.chinatelecom-h.com/en/ir/report/csr2022.pdf

3.4 Standardisation activities

Most standards related to the sustainability of telecommunications networks are developed by the European Telecommunications Standards Institute (ETSI) and the International Telecommunication Union – Telecommunications Sector (ITU-T), by working groups ETSI Technical Committee Environmental Engineering (TC EE) and ITU-T Study Group 5 (SG5). The International Organisation for Standardisation (ISO) has also developed standards related to environmental management and life cycle assessment.

It needs to be noted that ETSI's TC EE and ITU-T 's SG5 are working together to develop technically aligned standards on energy efficiency, power feeding solutions, circular economy and network efficiency KPIs, and eco-design requirements for ICT[36].

Besides the above Standards Development Organisations (SDOs), there are also the Greenhouse Gas Protocol Standards (GHG Protocol) and the Global Reporting Impact (GRI) providing accounting and reporting standards to support private and public organisations with their sustainability targets.

In the following sections, the work of each of these organisations regarding sustainability of telecom networks is presented in further detail.

3.4.1 ETSI TC EE

TC EE of ETSI is responsible for defining the equipment engineering, including the bonding and grounding, the power supply interface and environmental aspects for telecommunications infrastructures and equipment[37].

Apart from various engineering aspects of telecommunications equipment in different types of installations, i.e. environmental conditions, physical requirements of equipment (racks and cabinets) and power supply and grounding, they also develop standards on sustainability. These include eco-environmental matters on energy efficiency, environmental impact analysis and energy sources associated with ICT devices.

Most of the work on energy efficiency supports European Commission policies and regulation on eco-design aspects, where ETSI liaises with the European Committee for Electrotechnical Standardisation (CENELEC) and the European Committee for Standardisation (CEN) to develop relevant standards. Next to researchers and public authorities, TC EE also includes telecoms network operators and equipment suppliers from Europe, China, Japan, South Korea and the US.

Among others, ETSI has developed the ETSI ES 203 228 V1.4.1 (2022-04) standard on metrics used for the energy efficiency assessment of mobile networks, including also 5G networks, and the ETSI EN 303 472 V1.1.1 (2018-10) which defines the energy efficiency measurement methodology and metrics for RAN equipment (ETSI EN 303 472 V1.1.1). The ETSI ES 203 199 V1.3.1 (2015-02) defines a methodology and requirements for the environmental Life Cycle Assessment (LCA) of ICT equipment, networks and services (ETSI ES 203 199 V1.3.1). Finally, ETSI EN 303 215 V1.3.1 (2015-04) provides measurement methods and limits for power consumption in broadband telecommunications networks equipment (ETSI EN 303 215 V1.3.1). A full list of the standards developed by ETSI relevant to environmental sustainability is provided in Annex C.

3.4.2 ITU

ITU develops standards providing guidance on how to set science-based targets and achieve net-zero emissions in order to help countries and the ICT sector to meet the targets of the Paris Agreement and achieve the

[36] https://www.etsi.org/technologies/energy-efficiency
[37] https://www.etsi.org/committee/ee

Sustainable Development Goals (SDGs). ITU's key areas of activity related to environmental sustainability are the following:

Enabling the use of digital technologies for monitoring, mitigating and adapting to climate change

Protecting human health and the environment from e-waste

Facilitating digital solutions for energy efficiency by driving down emissions and reducing carbon footprint.

ITU-T Study Group 5 is responsible for dealing with environment, climate action, sustainable digitalisation, and the circular economy. The objective of ITU-T SG5 is to develop international standards that help improve the safety and environmental efficiency of ICTs, support the transition to circular economy, and support the ICT sector to reach net-zero emissions[38].

Considering net-zero emissions, ITU has developed Recommendation ITU-T L.1470 "GHG emissions trajectories for the ICT sector compatible with the UNFCCC Paris Agreement" in collaboration with the Global Enabling Sustainability Initiative (GeSI), the GSM Association *(*GSMA) and the Science Based Targets initiative (SBTi) (ITU-T L.1470 2020). It is supported by its Supplements ITU-T L.Suppl.37[39] and ITU-T L.Suppl.38[40], which provide guidance to operators of mobile networks, fixed networks, data centres and ICT manufacturers on how to set the science-based targets in compliance with ITU-T L.1470. On this topic, ITU published Recommendation ITU-T L.1471 "Guidance and criteria for information and communication technology organisations on setting net-zero targets and strategies", which enables ICT organisations to clarify the meaning of net-zero in the context of the ICT sector and to set net-zero targets and strategies. It also identifies actions that would lead the sector towards net-zero according to the trajectories described in Recommendation ITU-T L.1470 (ITU-T L.1471 2021). Moreover, in 2023, it has published together with GeSI and GSMA guidance to harmonise methods for telecommunications operators to assess and report their Scope 3 GHG emissions (see section 5.2.5 of this report), and to increase the coverage and transparency of this indicator (GSMA, GeSI, ITU 2023).

Similar to ETSI, ITU-T has also published standards on metrics used for the energy assessment of mobile networks (ITU-T L.1330 2015, ITU-T L.1331 2022) and the energy efficiency measurement and metrics for radio access network equipment (ITU-T L.1310 2017, ITU-T L.1350 2016, ITU-T L.1351 2018, ITU-T L.1390 2022).

ITU-T's recommendations relevant to the environment and ICTs, climate change, e-waste and energy efficiency, are included in the L series and are indexed according to the category they belong to. The most relevant recommendations on environmental sustainability of telecom networks are shown in Annex C.2.

3.4.3 ISO

ISO delivers projects on standardisation focused on climate change combat and requirements for solutions to energy efficiency and renewable sources, under United Nations Sustainable Development Goal (SDG) 13 Climate Action and SDG 7 Affordable and Clean Energy, respectively. The main two technical committees (TC) within ISO dealing with such projects are the Climate Change Coordinating Committee (CCCC), ISO/TC 207[41], and the TC on energy management and energy savings, ISO/TC 301[42].

ISO/TC 207 and its subcommittees (SCs) deal with standards on environmental management to address environment and climate impact in support of sustainable development. It is focused on environmental management systems (ISO/TC 207/SC 1), auditing, verification/validation (ISO/TC 207/SC 2), environmental labelling (ISO/TC 207/SC 3), environmental performance evaluation (ISO/TC 207/SC 4), life cycle assessment

[38] https://www.itu.int/en/ITU-T/climatechange/Pages/default.aspx
[39] https://handle.itu.int/11.1002/1000/14318-en?locatt=format:pdf&auth
[40] https://www.itu.int/ITU-T/recommendations/rec.aspx?rec=14582
[41] https://policy.iso.org/environmental-management.html
[42] https://committee.iso.org/home/tc301

(ISO/TC 207/SC 5), climate change and its mitigation and adaptation (ISO/TC 207/SC 7). It also deals with ecodesign, material efficiency, environmental economics and environmental and climate finance.

ISO/TC 301 works on the improvement and maintenance of energy performance, energy security and decarbonisation and the development of tools to facilitate the implementation of energy management and monitoring systems. It also supports the transparent and effective evaluation and reporting of energy performance improvements and energy savings. Its mission is to develop standards and guidance in the field of energy management for improved energy performance and energy savings calculations and the work is targeted to all sizes and types of organisations, groups, networks, cities, countries and regions.

It needs to be noted that ISO works together with the International Electrotechnical Commission (IEC) on some standards on environmental sustainability and have created joint technical committees for their development[43]. An example is the Joint Technical Committee 1, subcommittee 39 (JTC1/SC391 which deals with sustainability, IT and data centres also including the entire artificial intelligence ecosystem[44].

The most relevant standards developed by the above TCs are presented in Annex C.

3.4.4 GHG Protocol

The Greenhouse Gas (GHG) Protocol provides accounting and reporting standards, guidance and tools for public and private companies to measure and manage climate-warming emissions[45]. It is a partnership of private companies, non-governmental organisations and governments convened in 1998 by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD)[46].

The Corporate Accounting and Reporting Standard provides the accounting platform for virtually every corporate GHG reporting programme in the world[47]. It provides guidance for companies and other organisations for preparing a GHG emissions inventory at corporate level, covering the accounting and reporting of seven greenhouse gases covered by the Kyoto Protocol, i.e. carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). The Scope 1 standard, taking into account direct emissions, was amended by the Scope 2 Guidance, which offers some clarity on how corporations measure emissions from electricity and other types of energy purchases. This guidance can be important in corporate demand for more renewable electricity[48].

To allow for the assessment of the companies' entire value chain emissions impact and the identification of the emissions reduction policy, the GHG Protocol has developed the Corporate Value Chain (Scope 3) Accounting and Reporting Standard. It provides a methodology that can be used for accounting and reporting emissions from companies of all sectors, globally[49]. It is complemented by some guidance and tools[50].

Moreover, the Product Life Cycle Accounting and Reporting Standard can be used for assessing the full life cycle emissions of a product and it can provide GHG reduction recommendations[51]. GeSI has published a guidance for the ICT sector based on this standard[52].

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[43] https://www.iec.ch/blog/energy-efficiency-improves-when-iec-and-iso-work-together
[44] https://www.iec.ch/blog/isoiec-ai-meeting-discusses-sustainability-ethics-and-emerging-regulation
[45] https://ghgprotocol.org/about-us
[46] https://ghgprotocol.org/about-wri-wbcsd
[47] https://ghgprotocol.org/corporate-standard
[48] https://ghgprotocol.org/scope-2-guidance
[49] https://ghgprotocol.org/corporate-value-chain-scope-3-standard
[50] https://ghgprotocol.org/scope-3-calculation-guidance-2
[51] https://ghgprotocol.org/product-standard
[52] https://ghgprotocol.org/guidance-built-ghg-protocol

Finally, the GHG Protocol Policy and Action Standard provides a standardised approach for estimating and reporting the change in GHG emissions and removals resulting from policies and actions[53]. The GHG Protocol Mitigation Goal Standard has been developed to provide guidance for designing national and subnational mitigation goals and standardised approaches for the assessment and reporting progress towards goal achievement[54]. They can be used for the estimation of the impact of policies and actions on greenhouse gas emissions.

3.4.5 Global Reporting Initiative (GRI)

The Global Reporting Initiative (GRI) is an international non-governmental organisation that works independently to help private and public organisations take responsibility for their impacts, by providing them with the global common language to communicate those impacts. It was established in 1997 as a collaboration between the United Nations Environment Programme (UNEP) and the Coalition for Environmentally Responsible Economies (CERES)[55]. The GRI Standards enable an organisation to report data about its most significant impacts on the economy, the environment, and the people, including impacts on human rights, and how these impacts are being managed.

Standards relevant to activities for reporting environmental sustainability in the telecommunications field are listed in Annex C.

3.5 Literature review

The aim of this section is to provide a brief overview of the academic perception on sustainability for telecommunications networks. The related literature review is quite extensive, so only comparably recent studies are selected (2017-2023). Additional academic references focused on specific indicators are also reported in Section 5 and related sub-sections.

Research on sustainability indicators in telecommunications networks has grown considerably in recent times for all indicators, while the energy efficient indicator was supported by an intensive research activity in the last 5-10 years, which has introduced new energy efficient solutions in 5G networks.

A recent analysis of the electricity consumption and operational carbon emissions of European telecom network operators was provided in (Lunden 2022). This study presents operational electricity consumption and greenhouse gas emissions for named European telecom network operators (ETNO) during 2015–2018. These results are also compared to data for 2010–2015, which show that energy consumption is growing between 3% and 4% every year. The results also show that ETNO operators increased the use of renewable energy of 9% between 2015 and 2018. The study provides an extensive primary data set, collected from European Telecommunications Network Operators (ETNO) members, covering operations in Europe and beyond, providing data with higher granularity than publicly available sources.

A comprehensive overview on the research trends in sustainability indicators for mobile networks and more specifically 5G networks is presented in (Shehab 2021), which reports that most of the research studies in the last 10 years were concentrated on the energy efficiency (20%), followed by the power consumption (17%), carbon footprint (9%) and pollution (6%). The study also points out that 5G networks will be a strong enabler for the development and deployment of smart applications and domains, which can foster a more sustainable approach in domains other than telecoms. For example, 5G can support the collection of real-time data, which can be used for the implementation of ICT solutions to lower GHG emissions in transportation or increase energy efficiency in buildings.

[53] https://ghgprotocol.org/policy-and-action-standard
[54] https://ghgprotocol.org/mitigation-goal-standard
[55] https://www.globalreporting.org/

In (Lorincz 2020), the authors investigate the recent trends in communications networks for carbon footprint and energy consumption. The findings show that estimations of network energy consumption trends for the main communications sectors by 2030 suggest that the highest contribution to global energy consumption will come from wireless access networks and data centres (DCs), i.e., for the RAN for wireless networks. The authors highlight that it is important to support the design and deployment of energy efficient solutions in 5G networks to reduce the energy consumption.

Regarding energy efficiency and virtualisation of networks in 5G, the authors of (Bolla 2017) investigate the energy efficiency of the trend in Network Function Virtualisation (NFV), which is also an important aspect in Open RAN, C-RAN and Cloud-RAN of 5G networks. The results from the study show that in opposition to the common perception that NFV will be intrinsically green, this technology may lead to at least a doubling of the energy requirements in comparison to a non-virtualised infrastructure. Moreover, an assessment of the authors outlines how the cost of virtualisation may rapidly increase up to five times or more, if the best combination of hardware and software is not selected, or if the packet processing latency is considered as an objective. These results were confirmed by a subsequent study focused on C-RAN architectures in (Bolla 2020), which shows that with virtualisation the power consumption is on average around 250% higher in the commercial deployment, and OPEX and CAPEX costs above 66% higher. However, further results of the same study show that the deployment of NFVs alongside specialised hardware solutions exhibited energy savings up to 20% and costs in line with the ones of dedicated hardware deployments, demonstrating that the impact on energy consumption is determined by the right combination of software and hardware.

In another study (Vishwakarma 2022), the authors investigate the trends in e-waste in the ICT sector, including telecommunications networks. Some findings of the work underline that there is a considerable increase in e-waste in ICT due to the faster technology lifecycle, which prompts users to purchase new equipment and throw away the old one even after 3-4 years. More notable in the telecommunications sector, the e-waste from mobile phones is growing considerably. More alarming is the finding that there is not a strong perception (Vishwakarma 2022) on the need to improve e-waste for collection, processing and recycling. While there are a number of actions ongoing by vendors, in reality, such actions are slow to materialise.

Regarding the use of renewable energies, the authors in (Deevela 2023) explore the various options available to telecom operators to lower the GHG emissions thanks to the use of renewable energy, taking into consideration the increased energy consumption in the telecommunications network due to traffic demand. There is also the consideration that almost all telecommunications towers are equipped with a diesel generator (DG) set as a backup power supply option during outages of grid power supply, even if outages should happen only in rare cases. On the other hand, local DGs produce a considerable amount of GHG in comparison to electric grid power, especially when it is based on renewable energy. Some important findings from the study are: 1) Currently, grid electricity, and electricity from DG sets are the most common forms of conventional power supply for telecommunications towers. Due to poor or non-existent grid infrastructure, DG sets in remote areas tend to operate for longer hours than in more populated areas; 2) Among various renewable energy technologies, solar photovoltaic array-based systems have greater potential. However, since renewable energy sources are intermittent, complete reliance on these technologies to provide reliable power to telecommunications towers may not be possible; 3) Policy recommendations, such as government support through incentives, subsidies, tax credits, programmes for access to finance from the private sector, and establishing the proper regulatory framework, can be explored in order to expedite the adoption of hybrid systems powered by renewable energy for telecommunications towers.

4 Summary of the results

During the period from 26 May to 23 June 2023, a survey was carried out to collect input on sustainability indicators from stakeholders involved in the design, development, deployment, and operation of telecommunications networks, providing electronic communications services to business and residential customers.

This section reports both the findings from the survey and the ranking proposed in this report. The detailed findings from the survey are presented in Annex B.

Figure 6 reports on the distribution of the categories of the participants to the survey, displaying an overall diverse set of respondents.

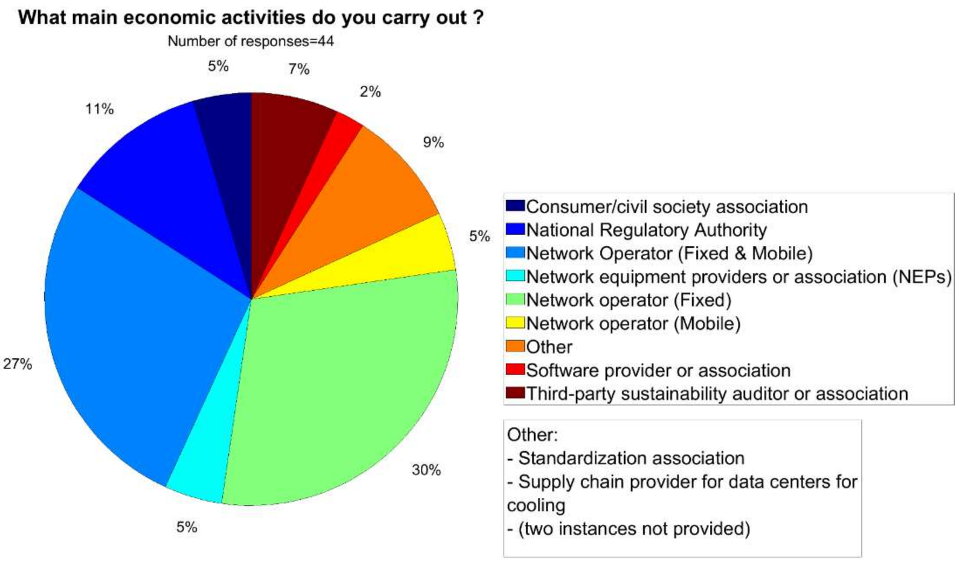

Figure 6 Categories of survey participants.

Figure 7 reports on the distribution of the categories of the survey participants. All of them are at least partially active in the EU with a majority active only in a single EU Member State.

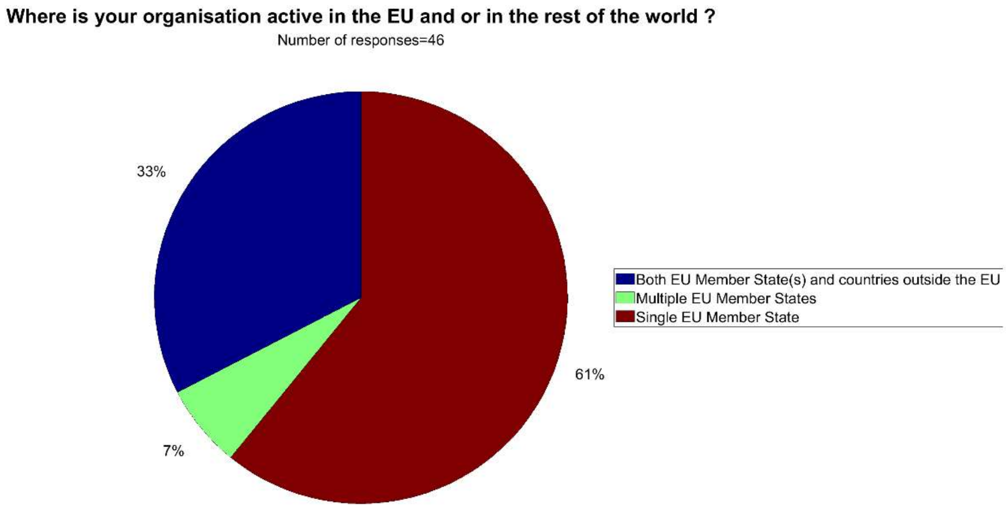

Figure 7 Geographical activity of the participants.

Figure 8 provides the distribution of the responses per category of private undertaking, showing an expected majority of large businesses among the respondents.

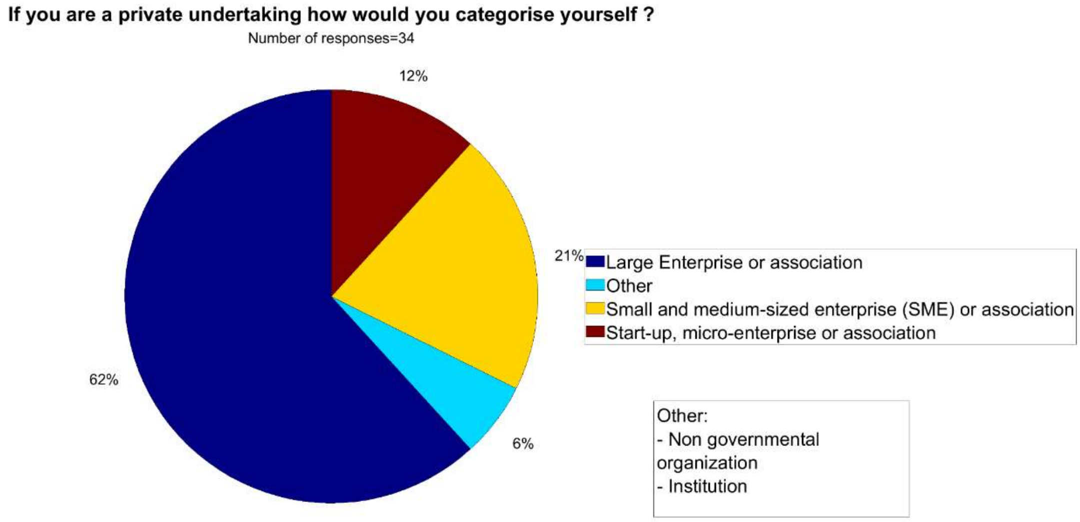

Figure 8 Categories of participants as a private undertaking.

Table 2 provides a summary of the survey results for all indicators analysed in this report.

The acronyms for network components used in the table are:

- BB: network backbone (both mobile or fixed)
- RAN: radio access network
- FAN: fixed access network
- SF: server farm or data centre
- NSR: network switches and routers (network equipment)
- Facility: building where the personnel office is hosted or the buildings where large network components or data centres are hosted

Note: Where the number of answers was less than one third of the total number of participants (46), the number of responses is mentioned in the table.

Note: the results with the * indicate that the number of responses were below 15 responses from the survey.

Table 2 Detailed survey results

Indicator	Main network components (type/level) and their relevance	Standardisation gaps	Main standard/ methodology/ procedure	Main audit process	Main metrics	Highest implementation cost	Agreement with proposed ranking
Indicators on Energy							
Energy consumption	BB **(19%)** RAN **(18%)** AN **(18%)** SF **(13%)**	No gaps **(28%)** Minor standardisation gaps **(26%)** Significant standardisation gaps for data collection **(23%)** Significant standardisation gaps for data analysis **(19%)** Other Considerations **(5%)**	ISO **(25%)** GHG Protocol **(18%)** Global Reporting Initiative **(14%)** ITU **(14%)**	Voluntary **(39%)**: • self (21%), third party (18%) Mandatory **(36%)**: • third party (30%), self (6%) No Audit **(21%)** Other **(3%)**	Power consumed (e.g., MWh) **(68%)** Tons of Carbon Dioxide **(18%)**	CAPEX <0.1% OPEX <0.1% *	"Must Have" (proposed) **(98%)** "Should Have" **(2%)** "Nice to Have" **(0%)**
Energy efficiency	BB **(19%)** RAN **(19%)**	Significant standardisation gaps for data analysis **(39%)**	ISO **(26%)**	Voluntary **(52%)**:	Power saved (e.g., MWh) **(34%)**	CAPEX 0.5-1% OPEX 0.5-1%	"Must Have" (proposed) **(89%)**

	FAN **(19%)** SF **(13%)**	Significant standardisation gaps for data collection **(22%)** Minor standardisation gaps **(22%)** No gaps **(17%)** Other Considerations **(0%)**	Global Reporting Initiative **(18%)** GHG Protocol **(15%)** ITU **(15%)**	• third party (32%), self (20%) No Audit **(28%)** Mandatory **(20%)**: • third party (16%), self (4%) Other **(0%)**	Data volume divided by energy consumption **(23%)**	*	"Nice to Have" **(7%)** "Should Have" **(4%)**
Use of renewable energy (rate)	RAN **(18%)** BB **(17%)** FAN **(17%)** SF **(12%)**	No gaps **(29%)** Minor standardisation gaps **(29%)** Significant standardisation gaps for data analysis **(21%)** Significant standardisation gaps for data collection **(18%)** Other Considerations **(3%)**	ISO **(27%)** GHG Protocol **(25%)** Global Reporting Initiative **(23%)**	Voluntary **(48%)**: • third party (26%), self (22%) No Audit **(30%)** Mandatory **(23%)**: • third party (19%), self (4%) Other **(0%)**	Share of renewable energy of total energy consumed **(51%)** Renewable energy consumed **(28%)**	CAPEX 0.1% OPEX 0.1% *	"Must Have" (proposed) **(80%)** "Nice to Have" **(13%)** "Should Have" **(7%)**
Indicators on Climate							
Carbon emissions - Energy direct emissions **GHG scope 1**	Facility **(17%)** Organisation **(17%)** BB **(15%)** FAN **(14%)**	No gaps **(38%)** Minor standardisation gaps **(32%)** Significant standardisation gaps for data collection **(18%)** Significant standardisation gaps for data analysis **(9%)** Other Considerations **(5%)**	GHG Protocol **(34%)** ISO **(25%)** Global Reporting Initiative **(14%)**	Voluntary **(42%)**: • third party (21%), self (21%) Mandatory **(40%)**: • third party (29%), self (11%) No Audit **(14%)** Other **(4%)**	Tons of carbon dioxide equivalent **(65%)** Power **(27%)**	CAPEX <0.1% OPEX <0.1%	"Must Have" (proposed) **(91%)** Nice to Have **(4%)** Should Have **(2%)**

Carbon emissions - Energy indirect emissions (e.g., scope 2 emissions)	BB **(17%)** FAN **(17%)** RAN **(15%)** Facility **(14%)**	Minor standardisation gaps **(38%)** No gaps **(32%)** Significant standardisation gaps for data collection **(16%)** Significant standardisation gaps for data analysis **(11%)** Other Considerations **(0%)**	ETSI **(36%)** GHG Protocol **(24%)** ISO **(15%)**	Voluntary **(55%)**: • third party (36%), self (19%) Mandatory **(37%)**: • third party (30%), self (7%) No Audit **(4%)** Other **(4%)**	Tons of carbon dioxide equivalent **(69%)** Power **(24%)**	CAPEX <0.1% OPEX <0.1%	"Must Have" (proposed) **(89%)** "Should Have" **(7%)** "Nice to Have" **(4%)**
Carbon emissions - Other indirect emissions (e.g., scope 3 emissions)	RAN **(16%)** BB **(15%)** FAN **(14%)** Organisation **(14%)**	Significant standardisation gaps for data collection **(36%)** Significant standardisation gaps for data analysis **(29%)** Minor standardisation gaps **(17%)** No gaps **(14%)** Other Considerations **(5%)**	GHG Protocol **(33%)** ISO **(22%)** Global Reporting Initiative **(17%)**	Voluntary **(56%)**: • third party (36%), self (20%) Mandatory **(24%)**: • third party (20%), self (4%) No Audit **(16%)** Other **(4%)**	Tons of carbon dioxide equivalent **(72%)** Power **(18%)**	CAPEX <0.1% OPEX <0.1% *	"Must Have" (proposed) **(76%)** "Should Have" **(13%)** "Nice to Have" **(11%)**
Indicators for environment							
E-waste production	FAN **(22%)** BB **(18%)** RAN **(15%)** SF **(11%)**	No gaps **(27%)** Minor standardisation gaps **(27%)** Significant standardisation gaps for data collection **(27%)**	ISO **(24%)** GHG Protocol **(24%)** ETSI **(20%)**	Voluntary **(44%)**: third party **(31%)**, self **(23%)** No Audit **(27%)** Mandatory **(16%)**:	Weight of produced e-waste **(87%)**	N/A *	"Must Have" (proposed) **(80%)** "Should Have" **(11%)** "Nice to Have" **(9%)**

		Significant standardisation gaps for data analysis (**15%**) Other Considerations (3%)		third party (**12%**), self (**4%**) Other (**4%**)			
Distribution or utilisation of recycled/ refurbished/ reused products	FAN (**19%**) NSR (**18%**) BB (**16%**) RAN (**14%**)	Significant standardisation gaps for data analysis (**33%**) Significant standardisation gaps for data collection (**26%**) Minor standardisation gaps (**22%**) No gaps (**19%**) Other Considerations (**0%**)	ISO (**22%**) Global Reporting Initiative (**20%**) GHG Protocol (**17%**)	Voluntary (**55%**): third party (**30%**), self (**25%**) No Audit (**40%**) Mandatory (**5%**): self (**5%**), third party (**0%**) Other (**0%**)	Weight of recycled/refurbished/ reused products (**25%**) Share of returned products (**23%**) Number of refurbished products (**21%**)	N/A *	"Must Have" (proposed) (**67%**) "Should Have" (**22%**) "Nice to Have" (**11%**)
Recycled/refurbished/ reused components (also the excavate mass) used in products	RAN (**21%**) FAN (**21%**) NSR (**21%**) BB (**16%**) SF (**16%**) Organisation (**5%**) Do not know (**5%**)	Significant standardisation gaps for data collection (**46%**) Significant standardisation gaps for data analysis (**46%**) Minor standardisation gaps (**8%**) *	ITU-T (**31%**) ETSI (**16%**) GHG (**8%**) ISO (**31 %**) GRI (**8%**) Other (**8%**) *	No audit (**83%**) Voluntary third party audit (**17%**) *	Weight (kg, tons) of recycled/refurbished/reused components in products (**50%**) Number of recycled/refurbished/reused components in products (**30%**) Percentage (%) of recycled/refurbished/reused components used in products (**20%**) Other (**0%**)	N/A *	"Should Have" (proposed) (**59%**) "Must Have" (**21%**) "Nice to Have" (**20%**)
Recyclability	RAN (**19%**) FAN (**19%**) BB (**14%**)	Significant standardisation gaps for data collection (**46%**)	ITU (**50%**) GHG protocol (**25%**) GRI (**25%**)	No Audit (**83%**) Voluntary Third Party Audit (**17%**)	**50%** the weight of the recycled network elements	N/A *	"Should Have" (proposed) (**72%**) "Must Have" (**20%**)

	SF **(14%)** NSR **(19%)** Organisation **(5%)** Do Not Know **(5%)**	Significant standardisation gaps for data analysis **(46%)** Minor Standardisation Gaps **(8%)**	*	*	**30%** using the number of recycled network elements, **20%** using the percentage of the recycled network elements on all the network elements, *		"Nice to Have" **(9%)**
Reparability	FAN **(25%)** RAN **(19%)** BB **(19%)** SF **(12.5%)** NSR **(12.5%)** Organisation **(6%)** Do not know **(6%)**	Significant standardisation gaps for data collection **(50%)**, Significant standardisation gaps for data analysis **(38%)**, Minor standardisation gaps **(8%)** *	GRI (33%), GHGP **(22%),** ITU (22%), ISO **(11%)** and Other **(11%)** *	No Audit **(100%)** *	Percentage of repaired devices **(54%)**, Reparability index **(36%)**, Number of repaired devices **(6%)**. *	N/A	"Should Have" (proposed) **(72%)** "Must Have" **(24%)** "Nice to Have" **(4%)**
Expected Lifetime	NSR **(25%)** SF **(25%)** BB **(24%)** RAN **(16%)** FAN **(16%)** Organisation **(4%)** Do not know **(4%)**	Significant standardisation gaps for data collection **(36%)**, Significant standardisation gaps for data analysis **(36%)**, Minor standardisation gaps **(27%)** *	GRI (28%), GHGP **(17%),** ITU (17%), ETSI **(17%)**	**88%** No Audit **12%** Mandatory with third party *	**54 %** Years **36 %** Months **10%** Real lifetime *	N/A *	"Should Have" (proposed) **(63%)** "Must Have" **(28%)** "Nice to Have" **(9%)**
Raw materials depletion	RAN **(17%)** FAN **(17%)** NSR**(17%)**	Significant standardisation gaps for data collection **(44%)** Significant standardisation gaps for data analysis **(44%)** No gaps **(12%)**	ISO**(40%)** ITU-T**(20%)** ETSI**(20%)** Other **(20%)** *	No audit **(50%)** Voluntary third party **(25%)** Other **(25%)** *	Weight (kg, tons) **(50%)** Other **(40%)** Tons of carbon dioxide equivalent (tCO2e) **(10%)** *	N/A *	"Should Have" (proposed) **(65%)** "Nice to Have" **(20%)** "Must Have" **(15%)**

	BB (**13%**) SF (**13%**) Facility (**9%**) Organisation (**9%**) Other (**4%**)	*					
Water usage consumption	FAN (**17%**) BB (**17%**) SF (**17%**) RAN (**11%**) NSR (**11%**) Organisation (**11%**) Facility (**5%**) Other (**5%**) Do not know (**5%**)	Significant standardisation gaps for data collection **(38%)** Significant standardisation gaps for data analysis **(38%)** Minor standardisation gaps **(12%)** No gaps **(12%)** Other Considerations **(0%)** *	ISO (**28%**) ITU-T (**24%**) Other (**18%**) Global Reporting Initiative (**12%**) ETSI (**12%**) GHG Protocol (**6%**)	Voluntary **(50%)**: • third party (25%), self (25%) Mandatory **(0%)**: • third party (0%), self (0%) No Audit **(25%)** Other **(25%)** *	Water Usage Effectiveness **(38%)** Cubic meters (m^3) (**31%**) Megaliters (**24%**) Tons (**7%**) *	N/A	"Should Have" (proposed) (**59%**) "Must Have" (**21%**) "Nice to Have" (**20%**)
Waste Heat Recovery	RAN **(50%)** SF **(50%)** *	Significant standardisation gaps for data collection **(50%)** Significant standardisation gaps for data analysis **(25%)** Minor standardisation gaps **(25%)** *	ITU-T **(33%)** ETSI **(33%)** ISO **(33%)** *	No audit (**100%**). *	Tons of waste going to heat recovery treatment **(33%)** Tons of carbon dioxide equivalent (tCO2e) **(33%)** Recovered energy (kWh, MWh) **(33%)** *	x<0.1% x<01% *	"Nice to Have" (proposed) **(74%)**, "Should Have" **(17%)** "Must Have" **(9%)**

Land use	One each for each component *	Significant standardisation gaps for data collection **(40%)** Significant standardisation gaps for data analysis **(40%)** No gaps **(20%)** *	ISO *	No audit(**100%**) *	Square metres (m^2) or kilometres (km^2) (**100%**) *	N/A	"Nice to have" (proposed) (**74%**) "Should Have" (**15%**) "Must Have" (**11%**)
Eco toxicity	BB **(20%)** FAN **(20%)** RAN **(10%)** Facility **(10%)** SF **(10%)** NSR (**10%**) Organisation (**10%**) Do not know (**10%**) *	Significant standardisation gaps for data collection **(43%)** Significant standardisation gaps for data analysis **(29%)** No standardisation gaps (**29%**) *	GHG Protocol **(33%)** ISO **(33%)** Global Reporting Initiative **(33%)** *	No audit *	Area (m^2, km^2) of installations in area protected or of high biodiversity **(33%)** Other (**33%**) Percentage (%) of sites in protected or of high biodiversity (**17%**) Cubic metres (m^3) of waste water (**17%**) *	N/A *	"Nice to Have" (proposed) **(74%)** "Must Have" **(13%)** "Should Have" **(11%)**
Human toxicity	BB **(10%)** FAN **(20%)** RAN **(20%)** Facility **(10%)** SF **(10%)** NSR (**10%**) Organisation (**10%**) Do not know (**10%**) *	Significant standardisation gaps for data analysis **(33%)** Minor standardisation gaps **(33%)** Significant standardisation gaps for data collection **(17%)** No gaps **(17%)** Other Considerations **(0%)**	GHG Protocol **(33%)** ISO **(33%)** Global Reporting Initiative **(33%)** *	No Audit **(50%)** Voluntary self audit **(50%)** *	Tons of water pollutant **(50%)** Tons of Air Pollutant **(33%)** Emitted electromagnetic field **(17%)** *	N/A *	"Nice to Have" (proposed) **(72%)** "Must Have" **(13%)** "Should Have" **(13%)**

		*					
Eutrophication	FAN **(22%)** BB **(11%)** RAN **(11%)** Facility **(11%)** SF **(11%)** NSR **(11%)** Organisation **(11%)** Do not know **(11%)** *	Significant standardisation gaps for data analysis **(40%)** Significant standardisation gaps for data collection **(20%)** Minor standardisation gaps **(20%)** No standardisation gaps **(20%)** *	ISO **(50%)** GHG Protocol **(25%)** Global Reporting Initiative **(25%)** *	No Audit **(100%)** *	Total nitrogen, total phosphorus, suspended solid (mg/L) **(33%)** Weight (kg) of phosphate (PO4) equivalent **(33%)** pH, biological oxygen demand (BOD), chemical oxygen demand (COD) **(17%)** Dissolved oxygen **(17%)** *	N/A *	"Nice to Have" (proposed) **(80%)** "Must Have" **(11%)** "Should Have" **(7%)**

Table 3 summarises the estimates on the sustainability impact of main network components, recommendations for potential standards for a future Code of Conduct, and the ranking proposed by this report. This is based on the subsequent detailed analysis per indicator.

Note: for some indicators (mostly Must Have indicators), it was possible to collect sustainability impacts from the analysis of the literature and direct feedback from stakeholders. In other cases, the sustainability impact is derived only from the survey. In these cases, the symbol ** is used to indicate that the sustainability impact is derived only from the survey results

Table 3 Sustainability impact, standards and priority ranking of indicators

Indicator	Estimated actual sustainability impact of main network components (type/level)	Main standard/ methodology/ procedure recommended by this study	Priority
Energy consumption	RAN **(70-80%)** SF **(9-12%)**	ISO 50001: Energy management for processes management and certification. ITU-T L.1330, ITU-T L.1310, ITU-T L.1331 for data collection from the network and analysis.	"Must have"

Energy efficiency	RAN **(70-80%)** SF **(9-12%)**	ISO 50001: Energy management for processes management and certification. ITU-T L.1330, ITU-T L.1310, ITU-T L.1331, ETSI ES 203 228 for data collection from the network and analysis.	"Must have"
Use of renewable energy (rate)	BB (**19%)** RAN (**19%)** FAN (**19%)** SF (**13%)**	GHGP, ETSI, ITU	"Must have"
Carbon emissions - Energy direct emissions **GHG scope 1**	Facility and Organisation **(34%)** BB **(15%)** FAN **(14%)**	GHGP, ETSI, ITU	"Must have"
Carbon emissions - Energy indirect emissions (e.g., scope 2 emissions)	BB (**19%)** RAN (**19%)** FAN (**19%)** SF (**13%)**	GHGP, ETSI, ITU	"Must have"
Carbon emissions - Other indirect emissions (e.g., scope 3 emissions)	RAN **(16%)** BB **(15%)** FAN **(14%)** Organisation **(14%)** (Note: since this indicator focuses on broader value chain aspects, see potential other distributions in the respective indicator section) **	GHGP: in particular the GHG Protocol Corporate (Value Chain) Standard for the supply chain aspects.	"Must Have"

E-waste production	FAN **(22%)** BB **(18%)** RAN **(15%)** SF **(11%)** **	GRI 306: Effluents and Waste 2020 standard. ITU-T L.1020	"Must Have"
Distribution or utilisation of recycled/ refurbished/ reused products	FAN **(19%)** NSR **(18%)** BB **(16%)** RAN **(14%)** **	GRI 306: Effluents and Waste 2020 standard ISO 14040:2006 ITU-T L.1020	"Must Have"
Recycled/refurbished/ reused components (also the excavate mass) used in products	RAN **(21%)** FAN **(21%)** NSR **(21%)** BB **(16%)** SF **(16%)** Organisation **(5%)** Do not know **(5%)** **	GRI 306: Effluents and Waste 2020 standard ISO 14040:2006 and related standards for Life Cycle assessments.	"Should Have"
Recyclability	RAN **(19%)** NSR **(19%)** FAN **(19%)** BB **(14%)** SF **(14%)** Organisation **(5%)**	GRI 306: Effluents and Waste 2020 standard ITU-T L.1022	"Should Have"

	Do Not Know **(5%)** **		
Reparability	FAN **(25%)** RAN **(19%)** BB **(19%)** SF **(12.5%)** NSR **(12.5%)** Organisation **(6%)** Do Not Know **(6%)** **	GRI 306: Effluents and Waste 2020 standard. (GSMA 2022b) also indicated ITU-T Standard L.1023 Assessment method for circular scoring	"Should Have"
Expected Lifetime	BB **(33%)**, NSR **(20%)**, SF **(16%)**, RAN **(16%)** FAN **(16%)** Organisation **(4%)** Do not know **(4%)** **	GRI and ITU standards for circular economy could be a starting point.	"Should Have"
Raw materials depletion	RAN **(17%)** FAN **(17%)** NSR **(17%)** BB **(13%)** SF **(13%)**	ISO standards like the ISO 14000 series	"Should Have"

	Facility **(9%)** Organisation **(9%)** Other **(4%)** **		
Water usage consumption	FAN **(17%)** BB **(17%)** SF **(17%)** RAN **(11%)** NSR **(11%)** Organisation **(11%)** Facility **(5%)** Other **(5%)** Do not know **(5%)** **	ISO or ITU-T and EN 50600-4-9	"Should Have"
Waste Heat Recovery	RAN **(50%)** SF **(50%)** **	GHG protocol calculation tool for emissions in Scope 3	"Nice to Have"
Land use	Equally distributed among components **	ISO 14000 family (e.g., ISO 14040)	"Nice to Have"
Eco toxicity	BB **(20%)** FAN **(20%)** RAN **(10%)** Facility **(10%)** SF **(10%)**	The results of the survey were not conclusive and references did not indicate a specific standard.	"Nice to Have"

	NSR **(10%)** Organisation **(10%)** Do not know **(10%)** **		
Human toxicity	FAN **(20%)** RAN **(20%)** BB **(10%)** Facility **(10%)** SF **(10%)** NSR **(10%)** Organisation **(10%)** Do not know **(10%)** **	GHG/ISO/GRI	"Nice to Have"
Eutrophication	FAN **(22%)** BB **(11%)** RAN **(11%)** Facility **(11%)** SF **(11%)** NSR **(11%)** Organisation **(11%)** Do not know **(11%)** **	ISO 14040:2006 and related standards for Life Cycle assessments GRI 307: Environmental Compliance 2016	"Nice to Have"

5 Key indicators for the sustainability of telecommunications networks

5.1 Preliminary information

The aim of this section is to describe the main indicators analysed in this study as well as the reasons why these indicators have been prioritised for their application in ECS.

The analysis is both quantitative and qualitative, as it is based on the following main inputs:

- Results from the survey conducted by DG JRC between 26 May to 23 June 2023, to which 46 participants provided their input. Input and feedback from the analysis conducted in previous studies, where indicators are proposed.
- Desktop research and analysis of stakeholder initiatives related to specific technological aspects, such as the maturity of the technology or the maturity of the standards.
- Feedback from the stakeholder workshop on 10 October 2023 on the preliminary results of this report. Note that a detailed report on the discussion and analysis conducted during the workshop is provided in Annex A.

5.2 Analysis of the indicators

The following subsections discuss each specific indicator on the basis of the following aspects:

— Input from desktop research.

— Input from the survey conducted between 26 May and 23 June 2023.

— Input from the stakeholder workshop on 10 October 2023.

Note that in some cases, the input from the desktop research can be similar because some indicators are strongly related among them (e.g., energy consumption/energy efficiency) and similar considerations and analyses were put forward.

Note: in some cases the precise number of responses is indicated.

5.2.1 Energy consumption

5.2.1.1 Definition

The energy consumption is the integral of power consumption over a specific time (e.g., one hour) and it is measured in Watt per Hour (Wh).

Standardisation bodies (i.e., ETSI) also define different Key Performance Indicators (KPI) to measure energy consumption, like static consumption, defined as the average power consumption under static test conditions, or dynamic consumption, defined as the power consumption under dynamic traffic load, or power consumption per line of broadband equipment, defined as the power consumption of broadband equipment.

5.2.1.2 Results from desktop research

According to (Dourado 2018), 70% of the overall energy consumption in a fixed network occurs in the access network. In a similar way for mobile networks, (GSMA 2022) mentions that 70-80% of the overall energy consumption in a mobile network occurs in the RAN. In particular, (Observatorio National 5G 2021) reports on more detailed figures (still derived from GSMA analysis) of 73% for the RAN, backbone of the network (13%), own data centres (9%) and other operations of the organisation (5%).

A slightly different breakdown was provided in (Chochliouros 2021), where the RAN has a smaller percentage of 50.6%, but the authors specifically mention that these values were for 5G networks, where energy efficiency solutions (e.g., sleep mode) were designed and may be deployed. Considering that the values from (Observatorio National 5G 2021) are derived from GSMA (GSMA 2021), whose members have detailed information on the energy consumption of their networks, we lean on this breakdown, also as it is not described clearly how the values in (Chochliouros 2021) were generated (on the basis of a simulation or on the basis of real data).

These sustainability impacts are summarised in Table 4.

Table 4 Sustainability impact (%)

Source	Type of Networks	RAN	FAN	BB	DC	Organisation	Facility
(GSMA 2022), (Observatorio National 5G 2021)	Mobile	73		13	9	5	
(Dourado 2018)	Fixed		70	20	10	5	
(Chochliouros 2021)	Mobile	50.6	12.8	2.2	23.3	11.1	

Regarding the standards adopted to measure energy consumption in the network, (BEREC 2023) indicated the ITU (ITU-T L.1330, ITU-T L.1310 and ITU-T L.1331) and ETSI family of standards (ETSI EN 303 215) are the ones most adopted by stakeholders. (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) also indicated ITU L.1331/32 for energy consumption. The NGMN association in (NGMN 2022) indicated ETSI ES 203 228 and ITU-T L.1331, for mobile network data collection on energy consumption. It should also be considered that ETSI ES 202 706-1 is currently used in the Code of Conduct (CoC) for broadband equipment (EC JRC 2021) for wireless broadband network equipment (e.g., base stations).

Regarding the measurement metric, (BEREC 2023) reported that kWh, MWh, or GWh are by far the most common measures. The French organisation ADEME also reported in (Ademe, Arcep 2022), (Ademe, Arcep 2023) that kWh is one of the most used metrics. (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) reports that 45% of the survey respondents use energy intensity measured as kWh/Gbyte as a measurement metric. (Lunden 2022) reported on the results of a survey among ETNO members, which points out TWh as the evaluation metric for power consumption for the overall networks and KWh per subscriber to take into consideration the subscribers to the network.

Table 5 provides a breakdown of our assessment of how important different types of stakeholders consider the energy consumption indicator. The breakdown is also based on the category of the stakeholder, i.e. whether it is a telecom operator, a national regulatory authority, or a telecom equipment vendor. Across most of the stakeholder categories, it can be seen that this indicator is widely considered a “Must Have” (MH) indicator.

In the table, some sources combine the analysis of energy consumption with other related indicators like energy efficiency or GHG scope 2 (which focuses on the energy supply from energy providers). In this case, the other indicators are mentioned for completeness, but the focus of this section is on energy consumption.

The data centre category is relevant for telecom networks because of the trend for softwarisation and virtualisation, which is already happening but likely to grow in future years. Even if the specific kind of computing operations may be slightly different from ‘conventional’ data centres (e.g., data analysis rather than the execution of communication algorithms as in telecom networks), most of the energy consumption aspects are quite similar.

There are three stakeholder categories where this indicator is considered ‘“Should Have”’: Consumers, Network Equipment Providers, and Software Providers. In the first case, while the consumer perception of energy consumption is important for the choice of the telecom operator, it does not seem to be predominant. For the network equipment providers, the outcome is related to the consideration that their requirements are driven by 1) the telecom operators (still focused on metrics like equipment cost and service provision and its performance) rather than an internal demand and 2) regulation, which does not exist yet. Finally, for the software providers, this is not a “Must Have” indicator, because the responsibility for the hardware platform falls under other categories (e.g., data centre operators).

Table 5 Indicator relevance for categories of stakeholders

Category of stakeholder	**Reference**	**Priority**	**Summary**
Cross-cutting	(BEREC 2023)	“Must Have”	The level of support from the surveyed companies is high, with 61 companies collecting this indicator (the highest number in BEREC’s report).
Data centre operators	(Avgerinou 2017), (IEA 2023), (Wang 2022), (Data Centre Magazine 2022), (Uptime Institute 2022)	“Must Have”	Energy consumption in data centres has been growing in the last years (Avgerinou 2017). Even a study outside Europe (Wang 2022) in China reported that the total energy consumption in data centres grew at an annual growth rate of 1.5% between 2001 and 2030. Other sources show that “data centres are estimated to be responsible for up to 3% of global electricity

			consumption today and are projected to touch 4% by 2030" (Data Centre Magazine 2022), while (Uptime Institute 2022) stated that "server power consumption [is] increasing by 266% since 2017". The future application of the Energy Efficient Directive (EED) may impact this indicator for data collection and reporting in data centres.
Network operators (Fixed)	(NGNM 2023), (GESI 2014), (IEA 2023)	"Must Have"	The reduction of energy consumption is indicated in various reports by network operator associations as a primary requirement for their operation, even if in fixed networks nearly 70% of total energy is consumed at the access segment, and only 30% at the core-network.
Network operators (Mobile)	(Dourado 2018), (GSMA 2022), (NGNM 2023)	"Must Have"	For mobile operators, between 20% and 35% of their OPEX is related to energy consumption. In comparison to fixed network operators, 90% of the total energy consumption is related to the operations of the mobile network and in particular the Radio Access Network (RAN), which accounts for 70%-80% of the total consumed power.
Consumer/civil society	(Analysis Mason 2021), (Garg 2022) (Deloitte 2022)	"Should Have"	There is an increased perception of the link between energy consumption and global climate issues, but it does not seem to influence telecom provider choices (Analysis Mason 2021). As reported in (Analysis Mason 2021), 46% of respondents in Europe and the USA considered the environmental sustainability goals and green credentials of their telecom providers to be 'important' or 'essential' in their choice of provider. On the other hand, Analysis Mason asked mobile customers that intended to churn within the next 6 months what rational would drive their choice: a) 10% of respondents intended to churn considered 'lower environmental impact'. A further 8% of consumers who did not intend to churn still considered it to be one of the three most important factors for improving their current service. These percentages are still considerably low. In another report (Deloitte 2022), a consumer survey showed that only 20% of the respondents said that sustainability is an important decision factor when buying a new smartphone. Also, academic studies like (Garg 2022) show that aspects like corporate social responsibility have a relatively low priority (rank 12 on 15 criteria) in the choice of consumers in selecting the telecom provider.
Network equipment providers or associations (NEPs)	(GSMA 2022)	"Should Have"	The requirements to decrease energy consumption are mostly defined by the telecom operators. This means that the requirements to drive down energy consumption while trying to preserve QoS in network equipment usually originate from market demand by telecom operators, unless some regulatory action

			requires the implementation of specific technical solutions (e.g., sleep mode).
Software providers	(GSMA 2022, GSMA 2023)	"Should Have"	Energy consumption in a telecom network is mostly driven by hardware components (e.g., the amplifiers in the radio access network). Therefore, reducing the energy consumption of the software execution (e.g., in the data centre) can be pursued, but it may have a limited impact (and create a risk of degrading the quality of service).
Third-party sustainability auditor	(BEREC 2023)	"Should Have"	Auditing of the energy consumption indicators has become increasingly important with new legislation. For example, NRAs are collecting data on energy consumption (BEREC 2023). On the other hand, sustainability auditors in Europe are nowadays using the indicators according to the European Environmental Footprint (EF) method[56], where energy consumption is not explicitly mentioned. The advantage of the energy consumption indicator for auditors is that it is a good proxy for climate change, which is present in EF. That is why the ITU L.1410 "Methodology for environmental life cycle assessments of information and communication technology goods, networks and services", which is used by auditors, considers energy consumption amongst the recommended indicators.
National Regulatory Authority	(BEREC 2023)	"Must Have"	Energy consumption is collected by NRAs from FR, BE, ES and FI.

5.2.1.3 Results from the survey

Network components and their relevance: The survey results confirm that the stakeholders consider the data centres as relatively less important than RAN, but rank BB, RAN and FAN as almost evenly relevant, with 18% or more.

Standardisation: In the survey, a majority of stakeholders identified no (28%) or only minor standardisation gaps (26%). One fourth of them ranked ISO standards somewhat higher than other standards. In particular, ISO 50001 on energy management was mentioned. On the other side, it was also highlighted that ISO 50001 is too general and does not specify a clear level of energy consumption for telecom operators. Other standards focusing on energy consumption include the GHG protocol standards and the Global Reporting Initiative.

Audit: A large majority of survey respondents (75%) indicated that they audit energy consumption, with the slightly larger half of them (39%) doing so on a voluntary instead of mandatory basis (36%). However, for those for which the audit of this indicator was mandatory, it was mainly done by a third party (30% vs. 6% mandatory self-audit). For the voluntary audit (39%), the respondents were almost equally divided among self-audit (21%) and third party (18%).

Metrics: The main metric indicated by 68% of survey respondents was power consumed (e.g., in MWh), with tons of carbon dioxide mentioned far behind (18%). This may be explained by the latter being mainly perceived as a climate metric instead of an energy metric, while both can, however, be perceived as different sides of the same coin.

[56] European Environmental Footprint (EF) method. https://eplca.jrc.ec.europa.eu/EnvironmentalFootprint.html.

Implementation cost: While only less than one third of all participants answered this question, the ones who did indicated the cost of implementing this indicator at less than 0.1% of both their capital and operative expenditures. On the other hand, some respondents provided a value of higher capital expenditure and operational expenditure between 0.5% and 1%.

Agreement with proposed ranking: Based on initial research, this indicator had been proposed as "Must Have", to which practically all survey respondents (98%) agreed.

5.2.1.4 Results from the stakeholder workshop

The feedback from the stakeholder workshop confirmed that power consumption is a "Must Have (MH)" indicator, to which there were no objections from the audience. In addition, the input and key messages from the telecom operators (Telefonica, Orange, and the European Competitive Telecommunications Association (ECTA)) and vendor (Ericsson) were mostly supportive of energy consumption (and related sustainability indicators like GHG scope 2 and energy efficiency) as a high priority indicator.

5.2.1.5 Ranking and outlook for a future Code of Conduct

Our analysis has confirmed that energy consumption is a "Must Have" indicator to measure the sustainability of telecommunications networks. There are a number of standards already defined for telecom networks to measure energy consumption. In particular, the ISO standards (e.g., ISO 50001) seem to be widely accepted and could be considered for a future Code of Conduct (CoC), although some fragmentation remains with regards to other standards families like GHG, GRI, ETSI and ITU. Consequently, a more detailed investigation of a coherent set of standards for CoC should be explored, taking into consideration that the different families of standards may not be mutually exclusive, as some standards could be used for the definition of processes for reporting and others for data collection from the network itself. For example, the ISO 50001 standard focuses on setting up an energy management system, whereas ITU and ETSI standards provide methodologies for measuring and assessing the energy consumption in the whole network, in some segments, or at the equipment level.

Energy consumption can be calculated either from direct data collection from the power supply (measurement taken by the energy provider) or from power probes on the telecom network itself, from computational models (e.g., based on the data rate throughput), or from a mix of these options. It is possible that all three data collection methods must be used, because telecom operators also generate their own energy for parts of the network (e.g., base stations in rural or remote areas). At the operational level, data collection can be relatively straightforward, even if some operational processes must be set up and personnel may be involved, even if some degree of automation can be adopted, especially as technology evolves.

Energy consumption is particularly important for telecom operators, also due to the related energy costs, and it was considered "Must Have" by most stakeholders analysed in this report.

5.2.2 Energy efficiency

5.2.2.1 Definition

The energy efficiency indicator evaluates how effective the consumed energy is for performing a task (i.e., carrying data traffic in the network). Most of the evaluation metrics are focused on measuring how much the energy consumption is in relation to the traffic, how much the energy consumption of an element of the network is in comparison to the whole network, or how much was the energy consumption of the network decreased before and after the application of an energy efficient solution.

There are some specific metrics, such as the energy efficiency rating (EER), which is a metric generally defined as a functional unit divided by the energy used. Various types of equipment have their own EER definitions. For access, edge, and core routers, it is defined as the ratio of the weighted throughput and the weighted power. Weights are assigned for the utilisation levels (ITU-T L.1310 2020).

Mobile network data energy efficiency ($EE_{MN,DV}$) indicates the bits delivered with a Joule of energy and is defined as the ratio between the data volume (DV_{MN}) and the energy consumption (EC_{MN}) when assessed during the same measurement period. It is based on data volume (capacity). Its definition is provided in (ETSI ES 203 228 V1.4.1) and in (ITU-T L.1331 2020) by the following equation:

$$EE_{MN,DV} = \frac{DV_{MN}}{EC_{MN}} \ (\frac{bit}{J})$$

Power usage effectiveness (PUE) is commonly used for data centres and defined in ISO/IEC 30134-2:2016 + AMD 1 as:

$$\mathrm{PUE} = \frac{E_{DC}}{E_{IT}} \ ,$$

E_{DC} is the total annual DC energy consumption of the facility in kWh and E_{IT} is the annual IT equipment energy consumption in kWh. Energy efficiency metrics and indicators are also defined and being currently defined in the Energy Efficiency Directive (EED).[57]

There are other energy efficiency metrics defined in the standards (see Annex C for a detailed list of standards), but these are the ones that are most commonly used.

Another potential new metric not defined in the current standards is the effectiveness of energy efficiency solutions in the telecommunications infrastructure, e.g., reduction (in percentage) of power consumption when an energy-efficient solution is deployed in the network. Although more difficult to measure than the previous metrics, this metric is important for evaluating how technologically advanced the network infrastructure is regarding aspects of energy efficiency.

5.2.2.2 Results from desktop research

Regarding the actual sustainability impact, various sources provide an indication of how important energy efficiency is across the different network components of the network infrastructure. There is a strong relationship between this indicator and the energy consumption indicator because the network elements with the highest energy consumption in the network may be the most suitable candidates for an improvement in energy efficiency. As a result of this, some of the results presented here may be similar to those presented for energy consumption. The largest energy efficiency gains are seen by (Huawei and Analysis Mason 2020) in the RAN portion (i.e., base stations) for a mobile network. Similar findings were also provided in (McKinsey 2020). Researchers and academics (Usama 2019) also pointed out the importance of energy efficiency in mobile networks for the RAN portion and the data centres (Avgerinou 2017), (Koronen 2020)) of the telecom networks, which are going to be used more due to the virtualisation and softwarisation of mobile networks. In fixed networks and the fibre optic backbone, other researchers (Tucker 2021) pointed out the need to improve energy efficiency, in particular for the DAC transponders. In a similar way for the access network using cable legacy access infrastructure, the authors of (Lange 2015) point out the need to improve the energy efficiency of the copper-based and related interfaces in the fixed access networks. Even if the energy consumption may be relatively limited, the massive amount of copper-based legacy systems can still be relevant. Consequently, the introduction of energy efficient solutions in part of the network can have a significant impact.

A discussion on the energy efficiency aspects in various elements of the ICT infrastructure including communication systems was presented in (ITU 2021), which is the technical report produced by the ITU-T Working Group 2 - Assessment and Measurement of the Environmental Efficiency of AI and Emerging Technologies. In particular, the report identifies and discusses various solutions to improve the energy efficiency in telecommunication networks (in particular 5G) by adopting techniques like sleep mode, dynamic adaptation (e.g., performance scaling), smart standby (e.g., through proxying network presence and virtualization of functions) and energy aware management. From the same working group, (ITU 2021a) discusses the trade-off between the increased demand on data centres due to Artificial Intelligence, Blockchain and other applications/technologies and the need for a greater energy efficiency, which can be achieved by developing larger, more efficient data centers, instead of smaller and more inefficient ones.

[57] Energy efficiency directive. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en.

These sustainability impacts are summarised in Table 6.

Table 6 Sustainability impact(% and qualitative measures)

Source	Type of Networks	RAN	FAN	BB	DC	Organisation	Facility
(GSMA 2022), (Observatorio National 5G 2021)	Mobile	73		13	9	5	
(Dourado 2018)	Fixed		70	20	10	5	
(Chochliouros 2021)	Mobile	50.6	12.8	2.2	23.3	11.1	
(Lange 2015) (no figures provided)	Fixed		Significant for the copper-based access infrastructure	Significant for the transponders	Significant for the data centres		

Regarding the standard(s) to be adopted to measure energy efficiency in the network, (BEREC 2023) indicated that ITU (ITU-T L.1330, ITU-T L.1310, ITU-T L.1331) and ETSI (ETSI EN 303 472) are the ones mostly adopted by stakeholders. (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) also indicated ITU L.1331/32 for energy efficiency. The NGMN association in (NGMN 2022) indicated ETSI ES 203 228 and ITU-T L.1331 for the mobile networks data collection to measure energy efficiency.

Regarding the measurement metric, (BEREC 2023) reported that a number of measurement metrics are used for energy efficiency, including kWh, MWh or GWh per unit of transmitted traffic (e.g., per Gigabit per second) and PUE. The French organisation ADEME reported in (Ademe, Arcep 2022) ISO/IEC 30134 the energy efficiency in data centres used in telecoms networks. (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) reports that 45% of the survey respondents use energy intensity measured as kWh/Gbyte as a measurement metric. Similarly, (Lunden et al. 2022) consider kWh per subscription. (GSMA 2022) indicated various measurement metrics for energy efficiency, including energy per unit of traffic (kWh / GB), energy per connection (kWh / connection), energy per cell site (MWh / cell site) and energy per revenue (MWh / € million). A discussion of different metrics can be found in (NGMN 2023).

Table 7 provides a breakdown of our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on the category of the stakeholder – e.g., telecoms operator, national regulatory authority, and telecoms equipment vendor. Across most of the stakeholder categories, it can be seen that this indicator is considered a “Must Have” (MH) indicator.

Table 7 Indicator relevance for categories of stakeholders

Category of stakeholder	References	Priority	Summary
Cross-cutting	(BEREC 2023)	"Must Have"	The level of support from the surveyed companies is high, with 61 companies collecting this indicator (the highest number in BEREC's report).
Network operator (Fixed)	(Dourado 2018), (Tucker 2010), (Lange 2015)	"Must Have"	In a similar way to energy consumption, energy efficiency is important for network operators because its introduction decreases energy consumption. As described in the references, fixed network operators have at least two main network elements, which may be relevant for energy efficiency: the digital analogue transponders and the data centres.
Network operator (Mobile)	(Dourado 2018), (GSMA 2022), (Huawei and Analysis Mason 2020), (McKinsey 2020).	"Must Have"	Similarly to energy consumption, energy efficiency is important for network operators because its introduction decreases energy consumption. This is more important for mobile operators where energy consumption is a significant component of the OPEX. Nevertheless, there are costs related to the deployment of energy efficient solutions, which could hamper their deployment and incentives may be useful.
Data centre operator or association (this is only for the data centres used for network operations and management including virtual Distributed units and centralized units)	(Avgerinou 2017), (Koronen 2020)	"Must Have"	Energy efficiency is very important for owners of data centre operators because data centres (even the ones used in telecommunications networks) can consume a significant amount of electric power. It is worth noticing that energy efficient solutions in the specific case of the servers can also be related to actions in parallel domains, including the use of generated heat for building heating or the use of an auxiliary source of energy. The future application of the Energy Efficiency Directive (EED) may impact this indicator for data collection and reporting in data centres.
Network equipment providers or association (NEPs)	(GSMA 2022), (Ericsson 2023), (Ericsson 2023a) (Huawei and Analysis Mason 2020)	"Must Have"	Energy efficiency is an important driver of innovation for network equipment vendors if it is supported by demand from the network operators to justify the costs of R&D. This is particularly important for the elements of the network identified in Table 1 (e.g., RAN for mobile networks).

National Regulatory Authority	(BEREC 2023)	"Must Have"	Energy efficiency has a direct positive input to energy consumption and GHG scope 2. Therefore, this indicator has grown in importance for national authorities, as shown in recent reports.
Software provider or association	(GSMA 2022,GSMA 2023), (Ericsson 2023a)	"Must Have"	Many energy-efficient solutions are based on the implementation of AI algorithms to balance the use of resources. Consequently, they are software-based, which is relevant for this category of stakeholder.
Third-party sustainability auditor or association	(BEREC 2023)	"Should Have"	Auditing the introduction of energy efficient solutions could become important in the future, as today it is not investigated in detail. The reason is that energy efficiency is not considered a primary indicator, but it is a proxy of energy consumption, which is also a proxy of GHG scope 2.
Consumer/civil society association	(EC 2020)	"Should Have"	Energy efficiency supports energy consumption and GHG scope 2, and there is an increased perception of the link between energy consumption and global climate issues, but it does not seem to be strong enough to influence consumers' provider choice. In addition, it is difficult to divulge the technical details of energy efficient solutions so that consumers can appreciate the differences and trade-offs.

In Table 7, some sources combine the analysis of energy efficiency with other related indicators like energy consumption or GHG scope 2 (which focuses on the energy supply from energy providers). In this case, the other indicators are mentioned for completeness, but the focus of this section is on energy efficiency.

The data centre category is relevant for telecom networks because of the trend of softwarisation and virtualisation, which is already happening and is likely to grow in future years. Even if the computing operations for telecom may be slightly different from 'conventional' data centres (e.g., data analysis rather than the execution of communication algorithms as in telecom networks), most of the energy efficiency aspects are quite similar.

5.2.2.3 Results from the survey

Network components and their relevance: The survey results confirm that the stakeholders consider the data centres as relatively less important, but rank BB, RAN and FAN evenly relevant with 19%.

Standardisation: In the survey, a majority of stakeholders identified significant standardisation gaps for data analysis (39%) and data collection (22%), but there is also a significant number of participants, who answered that there are no (17%) or minor standardisation gaps (22%). Regarding the choice of standards, 26% of the respondents ranked ISO standards somewhat higher than other standards. In particular, ISO 50001 on energy management was mentioned. Other standards focusing on energy efficiency include the GHG protocol standards and the Global Reporting Initiative.

Audit: A large majority of survey respondents (72%) indicated that they audit energy efficiency, with half of them (52%) doing so on a voluntary basis instead of a mandatory basis (20%). However, for those for which the audit of this indicator was mandatory, it was mainly done by a third party (16% vs. 4% mandatory self-audit). For the voluntary audit (52%), the respondents use a third party (32%) or conduct a self-audit (20%). By summarising the results for third party for voluntary and mandatory, we can conclude that there is a significant preference for the use of a third-party auditor.

Metrics: There were no predominant metrics from the survey. The two highest scores were the power saved with 34% (e.g., after the application of an energy efficiency solution) and the data volume divided by energy consumption with 23% (which is the inverted ratio of the metrics identified in the desktop research phase, like MW/Gbit). This result may imply that there is probably not one optimal metric to measure energy efficiency.

Implementation cost: While only less than one third of all participants answered this question, the ones who did indicated the cost of implementing this indicator ranges between 0.5% and 1% both for their capital and operative expenditures. On the other hand, some respondents provided a value of higher capital expenditure and operational expenditure between 0.5% and 1%.

Agreement with proposed ranking: Based on initial research, this indicator had been proposed as "Must Have", to which a large majority (89%) of survey respondents agreed.

5.2.2.4 Results from the stakeholder workshop

The feedback from the stakeholder workshop confirmed that power efficiency is a "Must Have" (MH) indicator, to which there were no objections from the audience. In addition, the input and key messages from the telecom operators (Telefonica, Orange, and ECTA) and vendor (Ericsson) were mostly supportive of energy efficiency as a high priority indicator. Some participants from the stakeholder workshop indicated that the power saved is an important metric for them because it may justify the expenses of deploying new energy efficient solutions. Participants also underlined the challenge of measuring energy efficiency, especially when there is a sharing of infrastructure. One participant pointed out the massive presence of copper-based legacy systems, which are not efficient but may need considerable effort to be replaced (then impacting environmental indicators).

5.2.2.5 Ranking and outlook for a future Code of Conduct

Our analysis has confirmed that energy efficiency is a "Must Have" indicator to measure the sustainability of telecommunications networks. The deployment of energy efficient solutions in the telecoms infrastructure can decrease energy consumption, which has a positive effect on GHG scope 2 emissions as well. Energy efficient solutions are important to ensure a sustainable scaling of traffic for the green digital transition, and thus it is important to measure the evolution of the energy efficiency of the telecommunications networks over time. On the other hand, the introduction of new energy efficient solutions may require the costly upgrade of the network equipment. From a purely economic point of view, the introduction of energy efficient solutions may eventually outweigh the costs related to their deployment, but regulatory incentives and benefits could support a quicker network transition. The need to deploy new equipment, which is more energy efficient, may go against other indicators like the life expectancy or the recyclability of network equipment at least, in the short term. Thus, trade-offs between contrasting solutions need to be properly balanced.

There are a number of standards already defined for telecom networks to measure energy efficiency. In particular, the ISO standards (e.g., ISO 50001), ITU, and ETSI standards seem to be widely accepted and could be considered for a future Code of Conduct. On the other hand, some standards may be relevant for some activities (process definition), while other standards are needed for the data collection itself. In addition, there may still be some gaps regarding recent evolutions of the networks for cloudification and virtualisation. In view of the above, a more detailed investigation of a coherent set of standards for CoC should be explored, taking into consideration the different families of standards that support the certification process.

The ITU and ETSI standards provide methodologies for measuring and assessing energy efficiency in the whole network, in some segments, or at the equipment level. Thus, they are suitable for the CoC in which the participating manufacturers and operators voluntary commit to measure, analyse and improve the energy consumption (e.g., the CoC for broadband equipment).

The collection of data on the energy efficiency of the network at the operational level can be relatively straightforward, even if some operational processes must be set up and personnel may be involved, although some automation can be adopted, especially as technology evolves. In particular, there is a temporal dimension in the measurement of energy efficiency to evaluate the energy consumption before and after an energy efficient solution is deployed and its evolution over time. The data on the traffic throughput is already collected for accounting reasons, which facilitates metrics based on the efficiency ratio between energy consumption and the amount of data traffic.

5.2.3 Carbon emissions – Energy direct emissions or GHG Scope 1 emissions

5.2.3.1 Definition

Carbon emissions - Energy direct emissions or GHG Scope 1 emissions (ITU-T L.1450 2018) are Greenhouse gas (GHG) emissions from owned or controlled sources (e.g., company facilities and vehicles). Some examples of GHG Scope 1 emissions include direct emissions from an operator, such as from running its vehicle fleet for network maintenance and using diesel to operate base stations in hard-to-reach areas (GSMA 2023).

5.2.3.2 Results from desktop research

GHG scope 1 has been extensively investigated in the literature, as it is one of the most important indicators for assessing climate change. For the sake of brevity, in this section we report on the main references only.

Regarding the actual sustainability impact, various sources provide an indication of how important the GHG scope 1 across the different network components of the network infrastructure is. In comparison to GHG scope 2, which is directly related to the energy consumption of the telecommunications network, GHG scope 1 is mostly related to the organisation and facility. For example, maintenance operations are based on a fleet of vehicles, which can be a strong contributor to GHG scope 1 emissions. The effort required for deployment or maintenance operations may vary depending on the elements of the network. The direct use of energy by the telecoms network is not considered in scope 1 (because it belongs to scope 2) unless it is produced by energy supplies like diesel generators or solar panels deployed and owned by the telecoms operators.

Indications on impacts within each segment are reported in Table 8.

Table 8 Sustainability impact (%)

Source	Type of Networks	RAN	FAN	BB	DC	Organisation	Facility
(Huawei 2022),(Ericsson 2022), (Malmodin 2014)	Mobile	Significant for RAN maintenance and energy supply that is owned by the operator.				Significant	Significant
(Lange 2015)	Fixed		Significant for maintenance of the legacy		Significant for data centres	Significant	Significant

(no figures provided)			cooper access infrastructure				

Regarding the standards to be adopted to measure GHG scope 1 in the network, similar findings can be provided to the other GHG indicators. (BEREC 2023) indicated (in Annex I) ITU-T L.1470, ITU L.1471 and ITU-T L.1420, ISO 14064-1:2018 to monitor the impact on climate change. The GHG Protocol set of standards are often used by stakeholders. The Global Reporting Initiative (GRI) 305: Emissions 2016 standard is also used for such climate indicators.

(IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) indicated a similar set of standards for this indicator, including the Global Reporting Initiative (GRI) and the GHG Protocol (GHGP). They also mention ISO standards and notably ISO 14 001 and ISO 50 001.

(Ademe, Arcep 2022) conducted a literature review of the standards to measure climate change in telecoms networks. 132 studies were evaluated, but the large majority did not point out a specific set of standards (section 2.3.4 of (Ademe, Arcep 2022)). Only 7% of the studies indicated some standards, and 2% discussed in detail how these standards are used by stakeholders involved in the telecommunications domain. The GHG Protocol is the set of standards with the highest relevance, but the ITU L.1420 and the ETSI standards ETSI TS 103 199 are also cited.

Regarding the measurement metric, the findings are similar for all GHG indicators. (BEREC 2023) reported that the metric ton of CO2 equivalent is a common metric, sometimes in conjunction with kWh/MWh. The French organisation ADEME reported in (Ademe, Arcep 2022) the metric of kg of equivalent CO2. (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) reported that all respondents to a survey conducted by them used the equivalent CO2 as a measurement metric. The GSMA association also uses metric tons of CO2 equivalents in their reports (GSMA 2023).

As regards differences across stakeholders, (BEREC 2023) reports GHG scope 1 as one of the most used indicators by various categories of stakeholders. In particular, the 49 companies replying to the BEREC survey use this indicator. For mobile network operators, all network elements are very commonly reported. The NRAs involved in the BEREC study also indicated that GHG scope 1 is one of the main indicators for which they collect data. GHG scope 1 is also important for telecoms vendors, as highlighted in different sources from telecoms associations like (GSMA 2023) and it is often reported in Corporate Social Responsibility reports. In particular, (GSMA 2022) reports that telecoms operators providing 66% of the connectivity and having 82% of revenues disclose their climate impacts. In the same reference, it is disclosed that telecom operators providing 44% of the connectivity and having 63% of revenues have committed to science-based targets. Specific telecoms operators like Telefonica claim significant efforts into improving their GHG scope 1 scores, as described in (Telefonica 2023), where the company's main goals are described, i.e., a reduction of 90% of GHG scope 1 and scope 2 emissions for 2040. Orange is also committed (Orange 2023) to reducing GHG scope 1, 2, and 3 CO2 emissions by 2040, with the first milestone in 2025 for a reduction of 30% of scope 1 and 2 compared to the 2015 emissions and a 14% reduction of scope 3 emissions compared to the 2018 emissions; and a second milestone in 2030 for a 45% reduction in emissions across all scopes compared to 2020. To achieve these objectives, Orange has developed a Green IT & Networks programme, which claims to have resulted in avoiding approximately 3.4 million metric tons of CO2 between 2015 and 2022 through the improvement of the energy efficiency of the networks and information systems.

The need for action to reduce scope 1 in data centres is underlined by academic studies such as (Cao 2022) and (Bieser 2023), where it is mentioned that the production of GHG scope 1 emissions is significant and large companies like Microsoft, Amazon and Facebook are working on reducing such emissions. An example are diesel generators, which are often integrated into the data centre microgrid. The corresponding carbon emissions due to diesel combustion are classified as scope 1 emissions.

Manufacturers are also engaging in commitments to reduce GHG scope 1 emissions. For instance, the reduction of GHG scope 1 is the main target of Huawei as reported in (Huawei 2022), where various approaches were proposed and used to reach their target of Net Zero 2040 including new generators, hybrid solutions, intelligent batteries, and the deployment of sites powered by solar energy. In (Ericsson 2022), Ericsson reported its objective of Net Zero emissions within the company's value chain by 2040. The majority of Ericsson's value chain emissions are in scope 3, but Ericsson considers it essential to also reduce its own emissions (scopes 1 and 2).

For auditors, GHG scope 1 is one of the most important indicators, as it is included in the indicators required in the PEF (Product Environmental Footprint), which are the ones used by all standard LCA reports[58], as well as the International Reference Life Cycle Data System (ILCD) handbook, which includes climate change indicators like GHG scope 1 (EC 2023). The ILCD is an initiative developed by EC DG JRC and EC DG ENV since 2005, with the aim of providing guidance and standards for greater consistency and quality assurance in applying LCA. ILCD publications have been established through a series of extensive public and stakeholder consultations.

Table 9 provides a breakdown of our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on the category of the stakeholders – e.g., a telecoms operator, a national regulatory authority, or a telecoms equipment vendor. Across most of the stakeholder categories, it can be seen that this indicator is considered a "Must Have" indicator.

Table 9 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
National Regulatory Authority	(BEREC 2023)	"Must Have"	This indicator has grown in importance for national authorities, as shown in recent reports like (BEREC 2023), which mention that NRAs are increasingly collecting data on climate indicators like GHG scope 1. However, it is difficult to collect data.
Network equipment provider or association (NEPs)	(Huawei 2022), (Ericsson 2022)	"Must Have"	Network vendors support action plans to reduce significantly their carbon emissions scope 1.
Network operator (Fixed)	(Mamodin 2014), Griffa 2010).	"Must Have"	GHG scope 1 can be relevant for the deployment and maintenance of the vast legacy access network cabling system (i.e., copper cables) in addition to the GHG scope 1 for the organisation and facilities (including the ones hosting the data centres).
Network operator (Mobile)	(Orange 2023), (Telefonica 2023)	"Must Have"	GHG scope 1 can be relevant for the deployment and maintenance of the large number of base stations in addition to the GHG scope 1 for the organisation and facilities (including the ones hosting the data centres).
Third-party sustainability auditor or association	(BEREC 2023)	"Must Have"	GHG scope 1 is one of the climate change indicators present in the standards and methods adopted by auditors (e.g., for CSR).

[58] Commission Recommandation (EU) 2021/2279, https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32021H2279 https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32021H2279

Data centre operator or association (this is only for the data centres used for network operations and management including virtual Distributed Units and centralised units)	(Avgerinou 2017), (Koronen 2020)	"Should Have"	Data centres are typically considered important contributors to GHG emissions, but this may be related to the energy consumption in the operational phase and therefore GHG scope 2. The deployment of data centres may have an impact for GHG scope 1 in deployment and maintenance phases.
Consumer/civil society association	(Neumman 2020)	"Should Have"	There is an increased perception on the link between energy consumption and global climate issues, but it does not seem to be strong enough to influence consumers on the provider choice.
Software provider or association	(No source available)	"Nice to Have"	We did not find reports on the support by software providers or associations for GHG scope 1 in the telecommunications sector.

As noted above, the data centre category is relevant for telecoms networks for the trend of softwarisation and virtualisation, which is already happening and is likely to grow in future years. Even if the computing operations for telecoms may be slightly different from 'conventional' data centres (e.g., data analysis rather than the execution of communication algorithms as in telecom networks), most of the GHG reduction aspects are quite similar.

5.2.3.3 Results from the survey

Network components and their relevance: The survey results show results consistent with the desktop research input where organisations and facilities are set respectively at 17% and 17%, BB at 15% and FAN at 14%.

Standardisation: In the survey, a large majority of stakeholders (70%) indicated that there are no (38%) or minor (32%) standardisation gaps. Regarding the choice of standards, the GHG Protocol was supported by a significant number of stakeholders (34%), followed by ISO (25%) and the Global Reporting Initiative (14%), which is also consistent with the findings from the literature.

Audit: A large majority of survey respondents (82%) indicated that they audit GHG scope 1, with 42% doing so on a voluntary basis instead of a mandatory basis (40%). However, for those for which the audit of this indicator was done on a mandatory basis, it was mainly done by a third party (29% vs. 11% mandatory self-audit). For the voluntary audit (42%), 21% of the respondents indicated that they use a third-party company and 21% that they self-audit. By summarising the results for third party voluntary and mandatory audit, there is a preference for the use of a third-party auditor by 50% of the respondents.

Metrics: The tons of equivalent CO_2 were indicated as the main measurement metric by 65% of the respondents (this is consistent with the desktop research). The metric of consumed power was also relevant (27%).

Implementation cost: While only less than one third of all participants answered this question, the ones who did indicated the cost of implementing this indicator less than 0.1% both for their capital and operative expenditures. This low value is probably due to the consideration that it is relatively easy and cost effective to collect and measure this indicator.

Agreement with the proposed ranking: Based on the initial research, this indicator was proposed as "Must Have" and a significantly large majority (91%) of survey respondents agreed.

5.2.3.4 Results from the stakeholder workshop

The feedback from the stakeholder workshop confirmed that GHG scope 1 is a "Must Have" indicator. Telecoms operators unanimously supported this indicator as it is used in the Corporate Social Responsibility (CSR) plans and is one of the main goals of the climate change action plans (e.g., net zero emissions). It was noted during the workshop that GHG scope 1 should be measured across the entire lifecycle of the telecoms operator's organisation and its elements.

5.2.3.5 Ranking and outlook for a future Code of Conduct

Our analysis has confirmed that GHG scope 1 is a "Must Have" indicator to measure the sustainability of telecommunications networks. The use of renewable energy is a means used by telecoms operators to lower the GHG scope 1 for organisation and facilities. This indicator is supported by a large number of standards and standardisation bodies (i.e., no or minor standardisation gaps) and there are already processes set up in telecoms operators to collect data and analyse trends for GHG scope 1. For the auditors, this indicator is also particularly important, because it is one of the indicators included in the guidelines like (EU 2021) and (EU 2023).

Stakeholders pointed out that it is important to measure progress on the reduction of GHG scope 1 in addition to the specific value in one year. It was also highlighted both in desktop research and during the workshop that GHG scope 1 should be measured across the entire lifecycle of the telecoms organisation and elements by using of Life Cycle Assessment processes.

5.2.4 Carbon emissions – Energy indirect emissions or GHG Scope 2 emissions indicator

5.2.4.1 Definition

Carbon emissions - Energy indirect emissions or GHG Scope 2 emissions (ITU-T L.1450 2018) are greenhouse gas (GHG) emissions from the generation of electricity, heat or steam that has been purchased by the reporting organisation, e.g., indirect emissions from electricity use or energy bought for heating, cooling, network operations and data centre operations, produced on a company's behalf, as defined in (GSMA 2023).

This indicator will be called GHG scope 2 in the rest of this section.

5.2.4.2 Results from desktop research

Regarding the actual sustainability impact, various sources provide an indication on how important the GHG scope 2 across the different network components of the network infrastructure is. There is a strong relation between this indicator and the energy consumption indicator because the network elements with the highest energy consumption may be the most suitable candidates for an improvement in GHG scope 2. There is also a strong relation with the use of renewable energy because it helps to lower the GHG scope 2 emissions, but it may not always be applicable due to the limitations in the availability of renewable energy (see sub-section on the use of renewable energy). Moreover, there is a strong relation with the energy efficiency indicator because the deployment of energy efficient solutions can decrease GHG scope 2 emissions (see the example cited above for the data centres (Orange 2023)). Therefore, the sustainability impact is similar to indicators such as energy consumption and energy efficiency and is summarised in Table 10.

Table 10 Sustainability impact(% and quantitative measures)

Source	**Type of Networks**	**RAN**	**FAN**	**BB**	**DC**	**Organisation**	**Facility**
(GSMA 2022), (Observatorio National 5G	Mobile	73		13	9	5	

2021) (Energy consumption is used as proxy of GHG scope 2)							
(ITU-T L.1470), (GSMA 2023b) (user devices accounts for 54% but they are not addressed in this study).		16		9	19		
(Ademe 2020) – Table 66. Sec 5.2	Fixed		5.5	2.2	15.9	11.1	
(Lange 2015) (no figures provided)	Fixed		Significant for copper-based access infrastructure	Significant for transponders	Significant for data centres		

A clarification on Table 10 is that some sources also consider the user devices at the user premises, which are not considered in this study. For this reason, some rows do not total 100%.

The study of (BEREC 2023) considers the GHG scope 2 emissions as one of the most used indicators by various categories of stakeholders, as 52 survey participants reported this indicator. The NRAs involved in the study also indicated that GHG scope 2 is one of the main indicators on which they collect data. This indicator is in the 'Group A' indicators listed in (BEREC 2023), which are already collected by at least one NRA member of BEREC and are supported by a significant number of companies. GHG scope 2 is also important for telecom vendors as highlighted in different sources from telecom associations, like (GSMA 2023), where it is often linked to energy efficiency measures and renewable energy. For example, (GSMA 2023) mentions that "90% of Verizon's operational carbon footprint comes from the electricity used to power its networks. To tackle Scope 2 emissions, Verizon is focussing on two key drivers: maximising the energy efficiency of networks and facilities and transitioning to renewable energy". Other telecom operators like Telefonica put a significant effort in improving their GHG scope 2 scores. As described in (Telefonica 2023), the company's main goal is to reduce GHG scope 1 and scope 2 emissions by 90% by 2040. Orange has stated in (Orange 2023) that it is committed to **reducing GHG scope 1, 2 and 3 CO2 emissions** by 2040. Its first milestone for 2025 has been set for a reduction of 30% of scope 1 and 2 emissions compared to the 2015 emission levels, and a reduction of 14% of scope 3 emissions compared to the 2018 emission levels. A second milestone has been set in 2030 with a 45% reduction in emission levels across all scopes compared to 2020. To achieve these objectives, Orange has developed a Green IT & Networks program, which has resulted in avoiding approximately 3.4 million metric tons of CO2 between 2015 and 2022 by improving the energy efficiency of the networks and information systems.

A significant effort was put in reducing emissions of data centres by implementing new technological solutions like free cooling (Orange 2023).

Equipment vendors like Ericsson also support a significant reduction in GHG scope 2 within the company's own activities (Ericsson 2022). In a similar way, Huawei aims for Net Zero emissions by 2040; in particular, with reference to GHG scope 2 emissions, through a combination of use of renewable energy and energy efficiency (Huawei 2022).

For the auditor category, GHG scope 2 is one of the main indicators, as it is included in the indicators required in the PEF (Product Environmental Footprint), which are the ones used by all standard LCA reports[59], as well as the International Reference Life Cycle Data System (ILCD) handbook, which includes the climate change indicators like GHG scope 2 (EC 2023).

Regarding the standards to be adopted to measure GHG scope 2 in the network, (BEREC 2023) indicated (in Annex I) ITU-T L.1470, ITU L.1471, ITU-T L.1420, and ISO 14064-1:2018 to monitor the impact on climate. The GHG Protocol set of standards on scope 2 are also used by stakeholders. The GRI 305: Emissions 2016 standard is also used for climate indicators.

(IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) indicated a similar set of standards for this indicator, including the Global Reporting Initiative (GRI) and the GHG Protocol (GHGP). The ISO standards ISO 14 001 and ISO 50 001 are also mentioned.

(Ademe, Arcep 2022) conducted a literature review of the standards used to measure climate change in telecoms networks. 132 studies were evaluated but the large majority did not point out a specific set of standards (section 2.3.4 of (Ademe, Arcep 2022)). Only 7% of the studies indicated some standards and 2% discussed in detail how these standards are used by stakeholders involved in the telecommunications domain. The GHGP is the set of standards with highest relevance, but the ITU L.1420 and the ETSI standards ETSI TS 103 199 are also cited.

Regarding the measurement metric, (BEREC 2023) reported that the metric ton of CO2 equivalent is the common metric for measurement, sometimes in conjunction with kWh/MWh. The French organisation ADEME reported in (Ademe, Arcep 2022) the metric of kg of equivalent CO2. (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) reported that all of the respondents of a survey they conducted use the equivalent CO2 as measurement metric. The GSMA association also uses metric tons of CO2 equivalents in their reports (GSMA 2023).

Table 11 provides a breakdown on our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on the category of the stakeholders, e.g., telecoms operator, national regulatory authority, or telecom equipment vendor. Across most of the stakeholder categories, it can be seen that this indicator is considered a "Must Have" indicator.

Table 11 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
Cross-cutting	(BEREC 2023)	"Must Have"	The level of support from the surveyed companies is high, with 52 companies collecting this indicator (the highest number in BEREC's report).
Network operator (Fixed)	(Dourado 2018), (Tucker 2010), (Lange 2015)	"Must Have"	In a similar way to energy consumption and energy efficiency, GHG scope 2 is important for network operators because they have at least two main network elements, which are responsible for significant energy consumption and consequently GHG scope 2 emissions: the digital-analogue transponders and the data centres. In addition, the large amount of legacy access network based on copper-cables also contributes significantly to energy consumption and then GHG scope 2 emissions.

[59] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32021H2279

Network operator (Mobile)	(GSMA 2023), (Telefonica 2023), Orange (2023)	"Must Have"	As described in the previous table and the related text, telecom operators have significant GHG scope 2 emissions because of the high energy consumption in the network. Even if the deployment of new energy efficient solutions (e.g., 5G sleep mode) can decrease energy consumption, this is counterbalanced by the growing traffic demand.
Data centre operator or association (this is only for the data centres used for network operations and management including virtual Distributed Units and centralised units)	(Avgerinou 2017), (Koronen 2020), Orange (2023)	"Must Have"	GHG scope 2 is very important for owners of data centre operators because data centres (even the ones used in telecommunications networks) can consume a significant amount of electric power.
Network equipment provider or association (NEPs)	(Ericsson 2022), (Huawei 2022)	"Must Have"	GHG scope 2 is an important driver for innovation for network equipment vendors if it is supported by demand by the network operators to justify the costs for R&D. This is particularly important for the elements of the network identified in Table 1 (e.g., RAN for mobile networks).
National Regulatory Authority	(BEREC 2023)	"Must Have"	This indicator has grown in importance for national authorities as shown in the recent reports like (BEREC 2023), which mention that NRAs are increasingly collecting data on climate indicators like GHG scope 2.
Third-party sustainability auditor or association	(EU 2021), (EC 2023).	"Must Have"	GHG scope 2 is one of the climate change indicators present in the standards and methods adopted by auditor (e.g., for CSR).
Software provider or association	(GSMA 2022), (Ericsson 2023)	"Should Have"	Even if software developers are involved in the optimisation of the network resources to decrease energy consumption (use of artificial intelligence), software development does not appear to be the main means to reduce GHG scope 2 at the moment.
Consumer/civil society association	(Neumman 2020)	"Should Have"	Energy efficiency supports energy consumption and GHG scope 2 and there is an increased perception of the link between energy consumption and global

			climate issues, but it does not seem to be strong enough to influence consumers on the provider choice. In addition, it is difficult to divulge the technical details on energy efficient solutions so that consumers can appreciate the difference and trade-offs. On the other hand, this information could be reported to the final users/customer as is the case in France, where the monthly bill of telecoms services specifies the amount of consumed energy for the consumed data.

5.2.4.3 Results from the survey

Network components and their relevance: The survey results show that the RAN is a significant contributor to GHG scope 2 in mobile telecom networks with 15%, but both BB and FAN contribute even more with 17%. It is noted the significant contribution of the facility element (e.g., buildings with 14%).

Standardisation: In the survey, a large majority of stakeholders (70%) indicated that there are no (32%) or minor (38%) standardisation gaps. Regarding the choice of the standards, 36% of the respondents ranked ETSI standards somewhat higher than other standards, but GHGP was supported by a significant number of stakeholders (24%) as well as ISO (15%). In particular, ISO 50001 on energy management was mentioned.

Audit: A predominant majority of survey respondents (92%) indicated that they audit energy consumption, with more than half (55%) doing so on a voluntary instead of mandatory basis (37%). However, for those for which the audit of this indicator was done on a mandatory basis, it was mainly done by a third party (30% vs. 7% mandatory self-audit). For the voluntary audit (55%), 36% of the respondents indicated that they used a third-party company, and 19% carried out the audit by themselves. By summarising the results of voluntary and mandatory auditing, it can be concluded that there is a significant preference for the use of a third-party auditor (66%).

Metrics: The ton of equivalent CO_2 was indicated as the main measurement metric with 69% (which is consistent with the desktop research). The metric of consumed power was also relevant (24%).

Implementation cost: While only less than one third of all participants answered this question, the ones who did indicated the cost of implementing this indicator was less than 0.1% both for their capital and operative expenditures. This low value is probably due to the fact that it is relatively easy and cost effective to collect and measure this indicator.

Agreement with proposed ranking: Based on the initial research, this indicator was proposed as “Must Have”, to which a large majority (89%) of survey respondents agreed.

5.2.4.4 Results from the stakeholder workshop

The feedback from the stakeholder workshop confirmed that GHG scope 2 is a “Must Have” indicator. No objections were raised by the audience. Telecoms operators unanimously supported this indicator, as it is used in Corporate Social Responsibility (CSR) reports and is one of the main goals of the climate change action plans (e.g., net zero emissions). There could be some challenges to collecting this indicator, especially in situations of infrastructure sharing (e.g., base station towers). It was also noted that GHG scope 2 should be measured across the entire lifecycle of the network equipment and not only during the operation phase.

5.2.4.5 Ranking and outlook for a future Code of Conduct

Our analysis has confirmed that GHG scope 2 is a “Must Have” indicator to measure the sustainability of telecommunications networks. The deployment of energy efficient solutions in the telecom infrastructure can decrease GHG scope 2 emissions. The use of renewable energy is another means used by telecoms operators to lower the GHG scope 2. This indicator is supported by a large number of standards and standardisation bodies. Telecoms operators have already established processes to collect data and analyse trends for GHG scope 2. For auditors, this indicator is also particularly important.

Stakeholders pointed out that it is important to measure the progress on the reduction of GHG scope 2, in addition to the specific value in one year. It was also highlighted both in desktop research and during the workshop that GHG scope 2 should be measured across the entire lifecycle of the network infrastructure and equipment, as trade-offs may appear: some network components may generate a larger GHG scope 2 emission during deployment than during operation, while others may show an opposite trend.

In addition, during the stakeholder workshop of 10 October 2023, ARCEP mentioned that future CoC related to GHG scope 2 should be reported and monitored using both the "location-based" and "market-based" accounting methodologies developed by the GHG Protocol. Many players only report their emissions using the market-based methodology, which alone would not provide a complete assessment of GHG scope 2. Furthermore, to measure the actual progress achieved in reducing Scope 2 GHG emissions, it would also be relevant to look at the emissions factors associated with the electricity mix used by the players to calculate their emissions, as well as changes in these factors, to assess their influence on emissions.

5.2.5 Carbon emissions – Other indirect emissions (i.e., scope 3 emissions) indicator

5.2.5.1 Definition

Scope 3 emissions (ITU-T L.1450 2018) are defined as any other indirect greenhouse gas (GHG) emissions from sources that are located along the reporting organisation's value chain (GSMA 2023). These are emissions that are not associated with the operator itself but which the organisation is indirectly responsible for, up and down its value chain. For example, emissions related to procuring network equipment and those produced by its suppliers, as well as emissions from operator services when subscribers and enterprises make use of them. Scope 3 emissions are often the largest source of emissions and are claimed the hardest to measure accurately (GSMA 2023).

This indicator will be called GHG scope 3 in the rest of this subsection.

Note: GHG scope 3 can include a large number of activities including the energy spent in the construction of building and telecom towers, but in the context of this report, the focus is on the telecoms networks design, implementation and deployment including aspects related to the supply chain.

5.2.5.2 Results from desktop research

Academic research has shown that the impact of GHG scope 3 is quite important in the telecommunications sector (Radonjič 2018). The authors report a carbon footprint share for Telekom Slovenije (i.e., the Slovenian telecom operator) of 15,92%, which is smaller than what was reported by Orange and Telefonica but still not negligible. The authors also provided a breakdown of GHG scope 3 across different company activities for three large European telecom operators, including Telekom BT, Deutsche Telecom, and Swisscom. It was reported that the largest contributors to GHG scope 3 (in the period 2014 to 2018) were the "Purchased goods and services" with percentages of 42% (BT), 21.7% (Deutsche Telekom) and 73.2% (Swisscom). This finding shows that the supply chain plays a major role in GHG scope 3 emissions and their reduction. The authors of (Radonjič 2018) also underline the significant percentage difference among operators, which shows that "not only business-related differences have an impact on absolute and relative values of scope 3 emissions, but also the tradition of sustainable policies and management commitment in each individual company".

The actual sustainability impact of GHG scope 3 therefore appears more difficult to evaluate in comparison to GHG scope 1 and GHG scope 2, even if some data can be extracted from corporate social responsibility (CSR) reports or other sources from telecom operators. For example, (Orange 2021) has shown that capital goods and purchased goods and services are predominant among the GHG scope 3 emissions contributors. (TIM 2022) also gave a distribution of the GHG scope 3 in 2022 of 72% for capital goods, 19% for purchased goods and services, and 9% for the use of sold products.

Since the focus of GHG scope 3 emissions is not on the network itself but on other aspects of the value chain, Table 12 below highlights these elements.

Table 12 Sustainability impact (%)

Source	Purchased goods and services	Capital goods	Use of sold Products	Fuel and energy related activities not included in scopes 1 and 2	Employee commuting	Upstream transport and distribution	Business travel	Other
(TIM 2022)	19	72	9					
(Orange 2021)	31	43	17	4	2	1	0.1	
(Telefonica 2022a)	52.4	11.8	28.5	6.2			1.1	
(Vodafone 2023)	27	20	11	8		2		30 (Joint Venture and associates)
(Radonjič 2018).	42 (BT) 21.7 (DT) 73.2 (SwissCom)							

Regarding the standard(s) to be adopted to measure GHG scope 3 in the network, (BEREC 2023) indicated (in Annex I) similar standards used for GHG scope 1 and scope 2: ITU-T L.1470, ITU L.1471 and ITU-T L.1420, ISO 14064-1:2018 to monitor in general the impact on the climate. The GHG Protocol standards are also used by stakeholders. The GRI 305: Emissions 2016 standard is also used for climate indicators like this one. We also underline that some stakeholders suggested the need to address standardisation gaps for GHG scope 3 in (BEREC 2023): “The need to standardise the scope used, specifically scope 3, for measuring the emissions of the sector was mentioned by five respondents” (which is still a small percentage considering the 80 participants in the survey, NDE).

A similar set of standards to the ones used for GHG scope 1 and GHG scope 2 has also been indicated for GHG scope 3 (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022), i.e., the Global Reporting Initiative (GRI) and the GHGP standards. In particular, for GHG scope 3, the GHG Protocol Corporate (Value Chain) Standard has been recommended. ISO standards are also mentioned, including ISO 14 001 and ISO 50 001.

(Ademe, Arcep 2022) also conducted a literature review of the standards used to measure climate change in telecoms networks including GHG scope 3. 132 studies were evaluated, but the large majority did not point out a specific set of standards (section 2.3.4 of (Ademe, Arcep 2022)). Only 7% of the studies indicated some standards, and 2% discussed in detail how these standards are used by stakeholders involved in the telecommunications domain. The GHGP is the set of standards with the highest relevance, but the ITU L.1420 and the ETSI standards ETSI TS 103 199 are also cited.

Regarding the measurement metric, we obtained similar results to the findings from GHG scope 1 and scope 2. (BEREC 2023) reported that the metric ton or metric kg of CO2 equivalents is the typical metric for measurement. The French organisation ADEME reported (Ademe, Arcep 2022) in kg of equivalent CO2. (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) reported that all of the respondents in a survey they conducted use tons of equivalent CO2 as measurement metric. The GSMA association also uses the metric tons of CO2 equivalents in their reports (GSMA 2023).

(BEREC 2023) reports GHG scope 3 as an indicator used by various categories of stakeholders. In particular, 40 companies who responded to the BEREC survey use this indicator. The NRAs involved in the study also indicated GHG scope 3 as important, but not at the same level as GHG scope 1 and scope 2. For example, in section 4.2.3 (BEREC 2023), it is reported that ARCEP (the French NRA) collects data on GHG scopes 1 and 2, but GHG scope 3 is not underlined. BIPT (the Belgian NRA) collects data on GHG scopes 1 and scope 2 but GHG scope 3 data is collected only upon availability. In addition, (BEREC 2023) highlighted that "Methodologies and studies have been published to collect or standardise the use of these indicators (GHG scope X, NDE) even if challenges remain, for instance, in calculating scope 3 emissions".

GHG scope 3 is also important for telecoms vendors, as highlighted by telecoms associations like (GSMA 2023), where it is mentioned that 61 mobile network operators reported Scope 3 emissions in 2022. (GSMA 2023) also indicated that Scope 3 is often the largest in terms of emissions and the hardest to measure accurately.

Other telecoms operators, like Telefonica, claim to put significant effort into improving their GHG scope 3 scores as described in (Telefonica 2023). One reason is that GHG scope 3 represents a very important percentage of overall carbon emissions by Telefonica. In (Telefonica 2023), it is reported that Scope 3 was 84.5% of the overall carbon emissions in 2022 (almost 2 million equivalent CO2 tons). Similarly, Orange is committed to reducing GHG scope 1, 2 and 3 CO2 emissions by 2040 (Orange 2023). The first milestone is set for 2025 when the company will need to reduce by 30% the scope 1 and 2 emissions compared to the ones of 2015, and scope 3 emissions will need to be reduced by 14% compared to the 2018 emissions. A second milestone has been set for 2030, when a 45% reduction in emissions across all scopes compared to 2020 will need to be achieved. (Tim 2022) reported a predominance of GHG scope 3 emissions at 91% of the overall carbon emissions. The Orange telecoms operator also reports in (Orange 2023) that GHG scope 3 emissions are 5 times larger than GHG scope 1 and scope 2 emissions. Therefore, Orange is working closely with the suppliers (equipment manufacturers, transporters, etc.) to reduce GHG scope 3 emissions.

Regarding the supply chain and the equipment vendors, Ericsson supports a significant reduction in GHG scope 3 either with actions towards its supply chain or by providing a more energy efficient portfolio of products for the next generation of mobile communications (5G,6G) (Ericsson 2022). In a similar way, Huawei reports that GHG scope 3 were much higher than GHG scope 1 and GHG scope 2 in 2021 with GHG scope 3 at 63.63% GHG scope 2 at 35.62% and GHG scope 1 at 0.76% (Huawei 2021).

For data centres, references indicating the importance of GHG scope 3 emissions are scarce. Some academic references (Cao 2022), (Gandhi 2023) indicate that GHG scope 3 is more difficult to collect than GHG scopes 1 and GHG scope 2. (Cao 2022) also pointed out that estimated carbon emissions for GHG scope 3 are lower in data centres than GHG scopes 1 and 2. We also underline that DC CoC requires data centre operators to report REF, ERF, CUE and water consumption.

For auditors, GHG scope 3 is one of the main indicators as it is included in the indicators required in the PEF (Product Environmental Footprint), which are the ones used by all standard LCA reports[60], as well the International Reference Life Cycle Data System (ILCD) handbook, which includes climate change indicators like GHG scope 3 (EC 2023) as with the other GHG scope 1 and scope 2 indicators.

Table 13 provides a breakdown of our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on the category of the stakeholder – e.g., telecoms operator, national regulatory authority, or telecoms equipment vendor. Across most of the stakeholder categories, it can be seen that this indicator is considered a "Must Have" indicator.

Table 13 Indicator relevance for categories of stakeholders

Category of stakeholder	References	Priority	Summary

[60] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32021H2279

Cross-cutting	(BEREC 2023)	“Must Have”	The level of support from the surveyed companies is high, with 40 companies collecting this indicator.
Network equipment provider or association (NEPs)	(Ericsson 2022), (Huawei 2022), (Orange 2021) (Telefonica 2022a)	“Must Have”	GHG scope 3 is quite important for network equipment providers because the supply chain element in GHG scope 3 is identified as very relevant by telecoms operators.
Network operator (Fixed)	(Radonjič 2018)	“Must Have”	GHG scope 3 is an important contributor to the overall carbon emissions, even if it is not the predominant one in a fixed network.
Network operator (Mobile)	(GSMA 2023), (Telefonica 2023), Orange (2023),(TIM 2022),(Orange 2021),(Telefonica 2022a)	“Must Have”	GHG scope 3 is reported by many mobile telecoms operators as the main contributor to carbon emissions, even if the reporting may be more challenging than GHG scope 1 and GHG scope 2.
Software provider or association	(Unpri 2023)	“Must Have”	One reference indicates that GHG scope 3 is responsible for the large majority of carbon emissions in software development companies, but it is not clear if this is valid for specific companies working in the telecoms sector.
Third-party sustainability auditor or association	(EU 2021), (EC 2023).	“Must Have”	GHG scope 3 is one of the climate change indicators present in the standards and methods adopted by auditors (e.g., for CSR).
National Regulatory Authority	(BEREC 2023)	“Must Have”	This indicator has grown in importance for national authorities, as shown in recent reports like (BEREC 2023) but it is not collected at the same level as GHG scope 1 and scope 2. Notably the French NRA ARCEP considers it a priority indicator, even if measuring it is not fully mature. This is why ARCEP included this indicator in its collection of environmental data, encouraging players to work on its measurement.
Consumer/civil society association	(Neumman 2020)	“Should Have”	As with other GHG scope indicators, while consumer awareness on climate change rises, there is no clear evidence that this indicator influences consumers’ provider choices.

Data centre operator or association (this is only for the data centres used for network operations and management including virtual distributed units and centralised units)	(Cao 2022), (Gandhi 2023)	"Should Have"	GHG scope 3 is not reported as GHG scope 1 and scope 2. In some references it is mentioned that most companies report scope 1 and scope 2 but scope 3 is only planned. On the other hand, some stakeholders remarked that given the long value chain of telecommunications networks and the interdependence between the various players in this chain, the GHG scope 3 indicator may increase its priority in the future when some operators will start to collect data for this indicator.

5.2.5.3 Results from the survey

Network components and their relevance: As GHG scope 3 focuses rather on broader value chain aspects than the network itself, the survey results indicated a relatively even distribution of the main contributors: RAN (16%), BB (15%), FAN (14%), Organisation (14%).

Standardisation: In the survey, a large majority of stakeholders (75%) indicated significant standardisation gaps for data analysis (29%) and data collection (36%). Regarding the choice of standards, the majority suggested the GHG Protocol family of standards (33%), ISO (22%) and finally the Global Reporting Initiative (17%).

Audit: A large majority of survey respondents (80%) indicated that they audit GHG scope 3 energy consumption, with more than half (56%) doing so on a voluntary instead of mandatory basis (24%). However, for those for which the audit of this indicator was mandatory, it was mainly done by a third party (20% vs. 4% mandatory self-audit). For the voluntary audit, the respondents used a third party for a 36% and by self-audit for 20%. By summarising the results for voluntary and mandatory third-party auditing, we can conclude that there is a preference for the use of a third-party auditor (56%).

Metrics: The tons of equivalent CO_2 were indicated as the main measurement metric by 72% of the respondents (this is consistent with desktop research). The metric of consumed power was also relevant (18%).

Implementation cost: While only less than one third of all participants answered this question, the ones who did indicated the cost of implementing this indicator was less than 0.1% both for their capital and operative expenditures.

Agreement with proposed ranking: Based on initial research, this indicator was proposed as "Must Have", to which a large majority (76%) of survey respondents agreed, even if it was lower than what was reported for GHG scope 1 and scope 2.

5.2.5.4 Results from the stakeholder workshop

The feedback from the stakeholder workshop confirmed that GHG scope 3 is a "Must Have" indicator. No objections were raised by the audience. Telecoms operators unanimously supported this indicator, as it is used in Corporate Social Responsibility (CSR) reports, and it is one of the main goals of the climate change action plans (e.g., net zero emissions). In fact, GHG scope 3 is often the greatest contributor to carbon emissions for a company. However, it was also reported that this indicator is difficult to collect because it is related to many different activities in the company in the upstream and downstream supply chains. The supply chain aspect was particularly relevant, as companies are defining requirements for their suppliers to lower carbon emissions. As for other carbon emissions indicators, a holistic lifecycle assessment was important for the evaluation of this indicator.

5.2.5.5 Ranking and outlook for a future Code of Conduct

Our analysis has confirmed that GHG scope 3 is a "Must Have" indicator for measuring the sustainability of telecommunications networks. In particular, both desktop research and the workshop findings pointed out that GHG scope 3 is the largest carbon emission contributor among the GHG emissions, and it is important to lower the GHG scope 3 levels of emissions. However, it is challenging to measure this indicator because it is pervasive among the different activities of a company and not always directly related to the network infrastructure itself. From the feedback collected through the desktop research and the workshop, setting requirements on the supply chain seems like a key objective for the telecoms operators, and this may become relevant for a future Code of Conducts and its technical requirements and guidelines.

It was also underlined by some stakeholders that this specific indicator should be given top priority in closing the standardisation gaps. Should those gaps not substantially be closed before the adoption of the first release of the Code of Conduct, reporting on it should be optional and could vary between different companies, as long as the respective underlying methodologies would be made transparent.

5.2.6 Use of renewable energy

5.2.6.1 Definition

This indicator is used to measure the percentage of renewable energy used in the deployment and operation of telecom networks. It is connected to other indicators, namely energy consumption and GHG scopes 1 and 2, because if a telecom network uses renewable energy instead of fossil-based energy, there is a positive GHG and climate impact.

It can be subdivided into other sub-indicators:

- Renewable energy factor (REF) from ISO/IEC 30134-3:2016 and the related amendment.
- Energy reuse factor (ERF), which is used to estimate the reused energy outside the DC divided by the total DC energy. It is defined in ISO/IEC 30134-6:2021.
- Carbon usage effectiveness (CUE), which is the total CO2 emission divided by IT equipment energy. It is derived from ISO/IEC 30134-8:2022.

The indicators and metrics identified in the Energy Efficiency Directive (EED) regarding renewable energy should be also considered[61].

5.2.6.2 Results from desktop research

(IDEA Consult and OKO Institute 2022) reported that renewable energy is a very important indicator because the purchase of renewable energy or the purchase of guarantees of origin is the most prominent tool for achieving GHG reduction targets. In particular, it can be a criterion for the geographic placement of the data centre. (BEREC 2023) reported the high importance of this indicator because the level of support by the companies was evaluated as "high" with 51 companies collecting this indicator. In (BEREC 2023) it is underlined that renewable energy as measured by the companies that replied to the BEREC questionnaire may encompass both the consumed energy (self-consumption) or committed energy (e.g., power purchase agreement). Also, (NGMN 2021) reported that the use of renewable energies, either by direct implementation in the telecom network (e.g., solar panels for base stations) or by procurements with energy vendors, is important to minimise GHG. Therefore, the renewable energy indicator has a high priority for telecom companies. (GSMA 2022a) reported that "as part of the data collection for the regional figures, the GSMA asked operators how much renewable electricity they plan to use by 2030. Operators across every region stated they plan to significantly increase the amount of

[61] Energy Efficiency Directive (EED). Subject matter, scope, definitions and energy efficiency targets.. https://www.europarl.europa.eu/meetdocs/2014_2019/plmrep/COMMITTEES/ITRE/DV/2022/07-13/EED_FinalCompromiseAmendment_EN.pdf.

renewable electricity they use”. Then, the use of renewable energy is also considered of high importance, up to the point that (GSMA 2022a) highlights the significant challenge of obtaining the use of renewable energy sources as they are available in a limited amount.

Regarding the sustainability impact, various sources provide an indication of how important renewable energy is across the different network components of the network. The use of renewable energy is highly correlated with energy consumption, energy efficiency and GHG scopes 1 and 2. Then, the impact is similar to the other indicators regarding this aspect.

In mobile networks, the mobile towers sector is one of the main elements in the network, which can be impacted by using renewable energy, either taken from renewable energy providers or produced by telecom operators (e.g., solar panels) (NGMN 2021), (GSMA 2022a). Similar findings that base stations, or more generally, RANs are mostly impacted by this indicator were suggested some time ago by academics, as in (Hussan 2013), (Zeng 2017). In fixed networks, we can extrapolate the findings for energy consumption and energy efficiency to the use of renewable energy as they are directly related: the digital cross-connect transponders in the optical network consume significant electric power (Tucker 2021). In the fixed access network, the power consumption of DSLAM and amplifiers used for the last km of connectivity can be significant because of the presence of massive amount of copper-based legacy systems (Lange 2015). On the other hand, the deployment of renewable energy solutions and supplies can depend on geographical considerations. For example, wind energy or thermal energy may not be available in the area, or solar panels could not be installed for space reasons, and the optimal deployment of renewable energy sources in a nationwide network may be challenging for the operators (Israr 2021), (Ehsan 2018). On the other hand, (Ehsan 2018) reports that “the power distribution network with high penetration of renewable DGs is becoming prevalent”; in particular, for remote areas where the main power grids may not be available and alternative supplies of energy must be deployed. The considerations presented in the other sub-sections for energy consumption and energy efficiency for data centres can also be applied to this indicator. Because data centres are significant consumers of electric power, the use of renewable energy to power data centres can be quite relevant, even if there are various challenges for the integration of renewable energy in data centres (Oro 2015), (Huang 2020) including the variability of the energy supply (e.g., solar panels or wind). In the specific case of the telecom sector, it is noted that the placement of data centres for the implementation of vDUs and vCUs in telecom networks is constrained by their physical proximity to the network elements (for keeping the communication latency limited), while data centres for ICT application have more freedom in their placement. It is also noted that data centres are not only consumers but also producers of energy as they can be used as heating sources (e.g., for heating buildings), even if such use is not always straightforward (Huang 2020). Regarding consumer choice, we could not find direct evidence that telecommunications consumers would adopt a telecom provider because it uses more renewable energy. Studies like (Neumann 2020) show that while there is a general preference expressed by energy consumers to support sustainability choices, this is not followed by a concrete action by the consumer to change to a telecom provider for this reason. Finally, the powering of the facilities of the telecom operators themselves can also be based on renewable energy.

In this context, the purchase of green certificates or Energy Attribute Certificates (EAC’s) is relevant as this is one of the easiest and most straightforward ways for a company to green their energy supply and allow a company to claim zero carbon emissions on their electricity use in GHG Scope 2 reporting, according to the GHG Protocol. These certificates go by various names in different regions of the world such as Guarantees of Origin (GO’s) in Europe and Renewable Energy Certificates (REC’s) in North America[62]. Such certificates are designed to work as a tracking mechanism for renewable electricity created and used by the telecom operator. The tracking function is needed once the renewable power (e.g., solar or wind farm energy) has been transmitted to the grid, because it becomes indistinguishable from any other form of electricity. The certificates are used to unbundle the renewable aspect from the physical power. This allows for bilateral purchasing of renewable electricity outside the scope of a physical power contract.

Table 14 summarizes the analysis provided in the previous paragraph, with the highlights of the elements where renewable energy can be significant or very significant.

[62] How to Know What Renewable Energy Certificates You're Buying. https://www.flexidao.com/post/how-to-know-what-renewable-energy-certificates-youre-buying.

Table 14 Sustainability impact (qualitative measure)

Source	Type of Networks	RAN	FAN	BB	DC	Organisation	Facility
(NGMN 2021), (GSMA 2022a), (Zeng 2017)	Mobile	Very significant		Significant	Very significant		Significant
(Huang 2020), (Tucker 2021), (Lange 2015)	Fixed		Significant	Significant	Very significant		Significant

Regarding the measurement metric, (BEREC 2023) reported that a large majority of the respondents (27/46 or 59% of the total) measure the quantity of renewable energy consumed or purchased in W or Wh, while another significant percentage of respondents (18/46 or 39% of the total) measure this indicator as the proportion (e.g., percentage) of renewable energy to the total energy consumed or purchased. Reference (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) indicates the share of renewable energies in energy consumption. GSMA in (GSMA 2021) indicated the percentage of renewable energy consumption on the total energy consumption. In (GSMA 2020a), one of the main suggested indicators is the number of mobile towers powered by renewable energy. The temporal trend of this indicator is also considered relevant in (GSMA 2020a): the percentage growth of the towers powered by renewable energy.

Regarding the standard(s) to be adopted to measure the use of renewable energy in the network, we did not identify specific standards for renewable energy. This may be due to the reason that stakeholders apply the same standards used for energy consumption to the measurement of the renewable energy. For example, ISO/IEC 30134-3:2016 (Ademe, Arcep 2022).

Table 15 provides a summary of our assessment on the importance of this indicator for the different types of stakeholders. The assessment if broken down according to the stakeholder category – e.g., telecom operator, or national regulatory authority, or telecom equipment vendor. Across most of the stakeholders' categories, this indicator is considered a "Must Have" (MH).

Table 15 Indicator relevance for categories of stakeholders

Category of stakeholder	References	Priority	Summary
Data centre operator or association (this is only for the data centres used for network operations and management	(Israr 2021), (Ehsan 2018), (IDEA consult and OKO Institute 2022)	"Must Have"	Renewable energy can be used to lower the GHG scope 2. The availability of renewable energy sources can also be a criterion for the placement and design of the data centre. The future application of the Energy Efficient Directive (EED) may impact this indicator for data collection and reporting in data centres.

including virtual Distributed Units)			
National Regulatory Authority	(BEREC 2023)	"Must Have"	The increased use of renewable energy by telecom operators is an important aspect for NRA because telecom operators are significant consumers of electric power.
Network equipment providers or association (NEPs)	(BEREC 2023), (NGMN 2021)	"Must Have"	The use of renewable energy can also lower the GHG scope 2 in the production of network equipment, but this is usually much lower than the operational use of network equipment.
Network operator (Fixed)	(Tucker 2010), (Lange 2015)	"Must Have"	The use of renewable energy can be used to lower the GHG scope 2.
Network operator (Mobile)	(BEREC 2023), (NGMN 2021), (GSMA 2022a), Hussan 2013), (Zeng 2017)	"Must Have"	Renewable energy can be used to lower the GHG scope 2.
Third-party sustainability auditor or association	(BEREC 2023)	"Must Have"	The use of renewable energy is useful to lower GHG scope 2, and it is also relatively easy to evaluate and audit in the reporting by the companies. The use of renewable energy is indicated in the International Life Cycle Data (ILCD) system[63] developed by the JRC, which is used by auditors.
Consumer/civil society association	(Neumman 2020)	"Should Have"	The use of renewable energy is known by the public, but it is not clear if consumers of telecom providers use this aspect in their choice of provider.
Software provider or association		"Nice to Have"	Not really relevant for this category, as we did not find specific references pointing to the relevance of this indicator for software providers or associations.

Some clarifications on Table 15:

Some sources combine the analysis of this indicator with other related indicators like energy consumption or GHG scope 2 (which focuses on the energy supply from energy providers). In this case, the other indicators are mentioned for completeness, but the focus of this section is on the use of renewable energy.

The data centre category is relevant for telecom networks for the trend of softwarisation and virtualisation, which is already happening and is likely to grow in future years. The use of renewable energy for data centres in the telecom sector in comparison to the ICT sector is slightly different because data centres for the telecom

[63] https://eplca.jrc.ec.europa.eu/ilcd.html.

sector should be place in proximity of the telecom networks (e.g., base stations) while for the ICT sector this is not the case.

5.2.6.3 Results from the survey

Network components and their relevance: The survey results confirm similar results obtained for energy consumption and energy efficiency with RAN (18%), FAN (17%) and BB (17%) as most relevant for the use of renewable energy.

Standardisation: In the survey, a majority of stakeholders indicated that there are no (29%) or minor standardisation gaps (29%). A smaller group of respondents indicated standardisation gaps for data analysis (21%) and for data collection (18%).

Regarding the choice of the standards, the three main families of standards were ISO with 27% of the respondents, GHG with 25%, and GRI with 23%. These three families of standards comprise the majority of choices made by the respondents.

Audit: A large majority of survey respondents (71%) indicated that they audit energy consumption, with the majority (48%) doing so on a voluntary instead of mandatory basis (23%). Then, the results are consistent with related indicators like energy efficiency. However, for those for which the audit of this indicator was mandatory, it was mainly done by a third party (19% vs. 4% mandatory self-audit). For the voluntary audit (48%), the respondents used a third party for a 26% and did a self-audit for 22%. In total, among the respondents performing auditing, almost half of them used a third-party auditor (45%) and the remaining perform self-auditing.

Metrics: The survey indicated two predominant metrics (which are also consistent with the findings from the desktop research): the share of renewable energy of total energy consumed (51%) and renewable energy consumed (28%).

Implementation cost: While only less than one third of all participants answered this question, the ones who did indicated the cost of implementing this indicator was less than 0.1% both for their capital and operative expenditures. This low value is probably due to the fact that it is relatively easy and cost-effective to collect and measure this indicator.

Agreement with proposed ranking: Based on initial research, this indicator had been proposed as “Must Have” (‘must have’), to which a significantly large majority (80%) of survey respondents agreed (even if it was slightly lower than similar energy indicators).

5.2.6.4 Results from the stakeholder workshop

The feedback from the stakeholder workshop confirmed that the use of renewable energy is a Must Have (MH) indicator, to which there were no objections from the audience. In addition, the input and key messages from the telecom operators and vendor (Ericsson) were mostly supportive of this indicator in relation to related sustainability indicators like GHG scope 2 and energy consumption. Some stakeholders pointed out that it is important to evaluate the improvements in time of this indicator: if a telecom operator is able to improve the percentage of used renewable energy in comparison to the total used energy year after year. Telecom operators also indicated that it may be challenging to increase this indicator in countries where the supply of renewable energy is limited (see also (GSMA 2022a)).

5.2.6.5 Ranking and outlook for a future Code of Conduct

Our analysis has confirmed that the use of renewable energy is a “Must Have” indicator to measure the sustainability of telecommunications networks.

Both from desktop research and the feedback at the workshop, the increase in the use of renewable energy is seen as an efficient way to reduce the climate impact as it is directly related to GHG scope 2. On the other hand, it was noted that the challenge to find suitable supplies of renewable energy, which may also be different across different regions of Europe, may also cause the issue of unfair comparison among telecom operators as there are local constraints.

It was suggested by some stakeholders (e.g., Arcep) that the CoC should not recommend the use of a ratio-based indicator to monitor the use of renewable energy. These ratios are all too often wrongly used to promote virtuous behaviour over and above what is actually done. Indeed, when an economic player withdraws electricity from the grid, what counts is the real time carbon intensity of the grid (in order to properly address its carbon impact).

However, for the sake of transparency and to recognise the player's effort to contribute to the energy transition, it might be interesting to ask for a breakdown of the energy consumed (i.e. distinguishing between GOs, PPAs financed, electricity actually withdrawn from the grid, etc.) in order to be as transparent as possible.

For this indicator, there is the possibility of reusing standards already defined for energy consumption, or GHG. In particular, the ISO standards (e.g., ISO 50001), GHG and GRI standards seem to be widely accepted and could be considered for a future Code of Conduct. It is noted that the survey respondents indicated no or minor standardisation gaps. The large majority of survey respondents also indicate two measurement metrics.

5.2.7 Distribution or utilisation of recycled/refurbished/reused products

5.2.7.1 Definition

This indicator is related to the distribution or utilization of recycled, refurbished, or reused products used in telecommunications networks. The reuse of refurbished products enables a circular economy where the waste of electronic components is minimized. In addition, the refurbishing and reuse of telecommunications equipment reduces also the problems associated with e-Waste, such as the pollution generated by the disposal of electronic products.

A number of sub-indicators (mostly related to the circular economy concept) have been defined for this indicator as described in (Moraga 2019) and (EC 2018)., including the recycling rate of e-Waste and the percentage of use of refurbished products when deploying telecommunications networks.

Many telecom operators have initiated activities to support the recycling and refurbishing of telecommunications systems and devices, even if most of them are focused on mobile phones and other users' devices, which is out of the scope of this study (GSMA 2023b).

5.2.7.2 Results from desktop research

(BEREC 2023) reports this indicator as a highly relevant indicator in terms of support by the surveyed companies, even if it is reported that only 26 companies are collecting this indicator. In addition, two NRAs (France and Belgium) collect this indicator. On the other hand, (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) reported that 92% of the respondents to the online survey with ECN providers and equipment manufacturers use this indicator for environmental reporting, which is a very high percentage.

Among telecom operators, the importance of this indicator has been underlined by a number of references, including (GSMA 2022c) where refurbishment of network equipment is discussed in relationship to other indicators, like GHG scope 3, e-Waste and raw materials (this indicator can provide positive impacts on the latter indicators). There are many examples of companies setting up refurbishment programmes, as mentioned in (GSMA 2022c). For example, (GSMA 2022c) mentions that "Orange and Nokia have signed an agreement to increase the use of refurbished equipment in telecoms infrastructure. Refurbished network equipment will be offered by Nokia to all Orange subsidiaries via BuyIn, the procurement alliance of Orange and Deutsche Telekom. This joint commitment will comprise radio-based equipment ('Radio Access Network'), with medium- and long-term plans to also encompass other network equipment. The refurbishment process is expected to generate reductions in carbon emissions as opposed to manufacturing new equipment". A similar agreement was reached between Orange and Ericsson (GSMA, 2022c). Moreover, Telefonica has launched MAIA in recent years, which is a platform to promote the reuse of its network equipment (Telefonica 2023c). The MAIA platform allows each operator in the group to publish and display available equipment and to connect with others to encourage reuse.

Among mobile communication providers and vendors, refurbishment of telecom products has started to increase, and a number of vendors are offering refurbished products or implementing the so-called "reverse logistics", where the vendor re-acquires the network equipment from the telecom operator to refurbish it so that it can be re-used. For example, Ericsson has started in 2021 the Ericsson Product Reuse services. The company states that, compared to the manufacturing of new equivalent, product refurbishment reduces supply chain carbon emissions by more than 90 percent (Ericsson 2022b). In a similar way, Nokia has defined an agreement with Orange for refurbished network equipment, as mentioned in (GSMA 2022c).

In the academic sector, the study (Goldey 2010) reports an improvement of the Global Warming Potential (GWP) in terms of kilograms of carbon dioxide equivalents of 88% for the wireline switching products and 60% for the wireless base stations when the refurbished product rather than the initial manufactured one is chosen.

Considering the large amount of electronic equipment used in server farms and processors, this indicator is important for data centres, as also shown in (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022), where it is mentioned that during the survey conducted by the authors there was significant support for this indicator: "When asked what metrics related to the IT equipment data centre operators were actively working on improving, the most popular ones were maintenance, followed by reuse, refurbishment, exchange with secondary markets for components and materials, and finally remanufacturing". Many organisations have started to implement refurbishment programmes and reuse of the products. For example, in (DataCenterDynamics 2023), it is mentioned that in 2020, Microsoft announced Circular Centres, dedicated to reusing and repurposing servers and other hardware in its data centres. Its servers have an average lifespan of around five years, and Microsoft expects the centres to increase the reuse of servers and components by up to 90 percent by 2025. On the other hand, based on the desk research and interviews with stakeholders, it seems that there is a lack of standardisation for data centre circularity, as reported in (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022).

For the auditor category, this indicator does not seem to be a primary indicator included in the ILCD handbook (the International Reference Life Cycle Data system) (EC 2023) and PEF (Product Environmental Footprint) (EU 2021). This indicator has an indirect relationship with resource depletion and resource use as part of the circular economy.

Regarding the sustainability impact, similar considerations to those already described for e-Waste can also be put forward. Refurbishment and reuse of network equipment are somewhat related to all the network equipment and network elements of the telecom infrastructure, and it is also difficult to identify specific impacts because the authors did not find references with detailed data. Based on the authors' experience and the input from the desktop research, the base stations, switches, routers and data centres can be highlighted for their impact because of the large number of base stations, switches, and routers present in the network and the high modularity of the data centres, where server elements can be easily replaced. It should be noted that the reuse of refurbished products is in some way against the logic of upgrading the network to more efficient solutions, and there may be a trade-off between this indicator and the energy efficient indicator.

Concerning the standard(s) to be adopted to measure this indicator in the network, (BEREC 2023) indicated (in Annex I) GRI 306: Effluents and Waste 2020 standard and ISO 14040:2006 and related standards for Life Cycle assessments. The desktop research also suggested ITU-T L.1020 as relevant for this indicator.

Regarding the measurement metrics, (BEREC 2023) indicated various metrics which are mostly based on ratios like kg, or number of second-hand equipment items, the number of recycled devices, and the number of items collected or refurbished units of reused products. The reference (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) also indicates the number of items collected or refurbished units of reused products.

Table 16 provides a breakdown on our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on the category of the stakeholder, e.g., telecom operator, or national regulatory authority, or telecom equipment vendor. For this indicator, we can see that there is a majority of "Must Have" but some categories are also associated to "Should Have".

Table 16 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
Cross-cutting	(BEREC 2023)	"Must Have"	(BEREC 2023) reports e-Waste as a HIGH indicator.

Data centre operator or association (this is only for the data centres used for network operations and management including virtual Distributed Units and centralized units)	(IDEA consult and Öko-Institut for the European Commission DG CNECT 2022), (DataCenterDynamics 2023),	"Must Have"	This indicator is quite important for data centres, as reported in the literature review because of the large number of electronic devices like CPU, GPUs, memory and mass storage units.
National Regulatory Authority	(BEREC 2023)	"Must Have"	(BEREC 2023) mentions that at least two NRAs in Europe are collecting data for this indicator.
Network equipment provider or association (NEPs)	(Ericsson 2022b), (GSMA 2022c)	"Must Have"	Network equipment manufacturers have started various programmes for the distribution and recycling of refurbished products.
Network operator (Fixed)	(Telefonica 2023c)	"Must Have"	Network operators have started programmes and projects for the distribution of refurbished products.
Network operator (Mobile)	(Telefonica 2023c), (GSMA 2022c)	"Must Have"	Various mobile telecom operators have started programmes for the reuse and refurbishment of network equipment.
Consumer/civil society association	(Neumman 2020)	"Should Have"	There is no clear evidence that this indicator influences consumers on the provider choice.
Software provider or association	(No available sources)	"Should Have"	Software companies are not directly involved in the refurbishment process, but they can be customers of refurbished products.
Third-party sustainability auditor or association	(No available sources)	"Should Have"	The authors could not find direct evidence that auditors collect data on this indicator.

5.2.7.3 Results from the survey

Network components and their relevance: In the survey, 19% of the respondents indicated FAN, which was the largest percentage (presumably because of the large amount of copper cables and systems), NSR (18%), BB with 16%, and RAN with 14%.

Standardisation: In the survey, a good majority of stakeholders (59%) contributed to the survey and they indicated significant gaps for data collection (26%) and analysis (33%), while 22% reported minor gaps and 19% reported no gaps. Regarding the choice of standards, it was relatively balanced among ISO (22%), Global Reporting Initiative (20%), and the GHG Protocol (17%).

Audit: The audit on this indicator is mostly done on a voluntary basis, with 55% of respondents indicating this choice. The mandatory option was almost negligible (5%). It is noted that a significant number of respondents indicated No Audit (40%).

Metrics: Three main metrics were identified: Weight of recycled, refurbished, and reused products (25%), share of returned products (23%) and number of refurbished products (21%).

Implementation cost: We did not receive a significant number of answers to this question.

Agreement with proposed ranking: Based on initial research, this indicator was proposed as "Must Have", which was supported by a significant percentage of respondents (67%). 22% indicated it as Should Have and 11% as Nice to Have.

5.2.7.4 Results from the stakeholder workshop

The feedback from the stakeholder workshop confirmed that this indicator can be considered a Must Have (MH) indicator, in particular in relation to the aspects of circular economy. A number of stakeholders confirmed programmes recently started for the refurbishment of products, even if there are still challenges related to standards.

5.2.7.5 Ranking and outlook for a future Code of Conduct

Our analysis has confirmed that the distribution or utilisation of recycled/ refurbished/ reused products is a "Must Have" indicator because of the significant benefits for the environment from supporting a circular economy. On the other hand, there are standardisation gaps and a lack of harmonisation in the metrics, which must be addressed.

5.2.8 E-waste production

5.2.8.1 Definition

e-Waste is also known as waste electrical and electronic equipment (WEEE) and refers to electrical or electronic equipment which has been discarded by its end-user.

e-Waste is also sometimes referred as eWaste, e-waste or E-waste.

5.2.8.2 Results from desktop research

(BEREC 2023) reports e-Waste as a MEDIUM (it is indicated in capital letters in the report) indicator. Even among the MEDIUM indicators, it is the one with the most respondents to the BEREC survey, with 41 companies collecting this indicator. On the other hand, NRAs classify this indicator in the B category, which means that it has not been collected yet by NRAs. However, (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) reported that 92% of the respondents to the online survey with ECN providers and equipment manufacturers use this indicator for environmental reporting, which is a very high percentage.

Among mobile communication providers and vendors, the scope of e-Waste is especially focused on mobile devices or customer premises equipment (CPE) as described in (GSMA 2022b), where it is associated with circularity principles. On the other hand, the coverage of telecom network infrastructure and components is limited. Various telecom operators have undertaken significant actions to reduce e-waste like (Telefonica 2023a), where it is mentioned that in 2022 Telefonica "generated 52,906 tonnes of waste and recycled 98%. In terms of electronic equipment, Telefonica reused around 44% of the total equipment collected and recycled the remaining 56%" but it has to be seen which part of these figures is network infrastructure equipment and which part is mobile devices. Telefonica has recently launched the MAYA platform[64] to promote the use of recycling for network equipment, aiming to achieve the target of Zero Waste by 2030. In a similar way, Orange launched the circular economy program named OSCAR, aiming at achieving Net Zero carbon commitment by 2040. Similarly, the equipment manufacturer[65] Ericsson in (Ericsson 2023b) supported programmes like Ericsson Connected Recycling (ECR), which digitalizes and connects the reverse supply chain to empower circularity. Nokia has committed to reducing the environmental impact of its products, operations, manufacturing, and supply chains[66]. Huawei also developed the E-waste Recycling Program (Huawai 2023b) which seems mostly focused on the e-Waste of smartphones and tablets.

In academic research, (Vishwakarma 2023) also investigated and identified the main sources of e-Waste around the world, with small IT and telecommunications equipment accounting for 4.7 millions of tons of e-Waste in 2019, but again, it is not clear if the majority is due to mobile phones, desktop and laptop computers, and CPEs. (Islam 2018) reviewed the literature on e-Waste, identified the current actions for e-Waste, circular economy, and described the processes for the closed-loop supply chain of e-waste. However, most of the cited references are focused on mobile phone rather than network equipment.

E-waste in data centres is particularly important considering the large amount of electronic equipment used in server farms. In (Hoosain 2023), it is discussed how a circular economy can be implemented to support the concept of sustainable data centres. For economies of scale, data centres are based on commodity equipment that can be easily disassembled, refurbished, replaced, or reused. Other sources (Supermicro 2019) indicate that data centres may account for 2 million tons of e-waste each year.

The aspect of e-waste in data centres are also discussed in (ITU 2021a), where it is pointed out end-of-life management companies face many challenges in recovering critical raw materials and rare earth elements from infrastructure equipment, particularly the viability of technology and economic recovery, and these are compounded by the falling value of e-waste, meaning there is less value to extract. It is also noted in (ITU 2021a) that data centres use high-grade circuit boards and backplanes that have, on average, a higher precious metal content than the typical circuit boards from individual consumer or small IT devices.

For the auditor category, e-Waste does not seem to be a primary indicator included in the ILCD handbook (the International Reference Life Cycle Data System) (EC 2023) and PEF (Product Environmental Footprint) (EU 2021). There is an indirect relationship between resource depletion and resource use as part of the circular economy concept.

(Rajesh 2023), (Andersen 2022) analysed the e-Waste impact in telecom networks and remarked that e-Waste of telecommunications products is still a limited portion (less than 5%) of the overall e-waste. Even in this 5%, e-Waste is also mostly related to end user equipment like phones or Customer Premise Equipment (CPE) rather than network equipment.

Regarding the sustainability impact, e-Waste is related to all the network equipment and network elements of the telecom infrastructure. Then, it has a general impact on all the components of the network infrastructure. It is also difficult to identify specific impacts because the authors of this report did not find references with clear

[64] https://www.telefonica.com/en/communication-room/press-room/telefonica-launches-maia-a-platform-to-promote-the-reuse-of-its-network-equipment/

[65] https://www.orange.com/en/newsroom/news/2021/net-zero-carbon-commitment-circular-economy-heart-our-network-infrastructure

[66] https://www.nokia.com/networks/services/circular-products-and-services/

and specific values. The European Parliament infographics on e-waste[67], the Global E-waste Statistics Partnership[68] funded by ITU, United Nations University – Sustainable Cycles (UNU-SCYCLE), the International Solid Waste Association (ISWA) and the European Court of Auditors[69] report aggregated data from which it is not possible to decouple the impact of telecom network equipment. Based on the authors' experience, the base stations and data centres can have a great impact on e-Waste because of the large number of base stations, which must be replaced (2G, 3G) in the near future, and the fast technological cycle of the data centres. The disposal of a large number of legacy copper access networks can also have a considerable impact.

Concerning the standard(s) to be adopted to measure e-Waste in the network, (BEREC 2023) indicated (in Annex I) GRI 306: Effluents and Waste 2020 standard. The authors of this report also identified ITU-T L.1020 as relevant for this indicator.

The weight of e-Waste materials produced by the companies has been indicated by (BEREC 2023) as the measurement metric since it was reported as the most used indicator. It can be expressed in kg, tons or megagrams. The reference (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) also used the metric tons of e-Waste as the main indicator together with the Electronics Disposal Efficiency (EDE) indicator, which shows the responsible (in terms of controlled e-Waste) disposed weight in comparison to the overall total weight disposed.

Table 17 provides a breakdown of our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on the category of the stakeholders, e.g., a telecom operator, or national regulatory authority, or a telecom equipment vendor. For this indicator, we can see that there is no predominance of "Must Have" and many categories are also associated with "Should Have".

Table 17 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
Data centre operator or association (this is only for the data centres used for network operations and management including virtual Distributed Units and centralized units)	(Hoosain 2023)	"Must Have"	E-Waste is quite important, as the fast technology cycle and the massive use of computing equipment in data centres are very significant contributors to e-waste.
Network equipment provider or	(GSMA 2022b), (Telefonica 2023a), (Huawai 2023b)	"Must Have"	Network equipment manufacturers are primarily involved in e-waste as they are one of the main actors in the circularity process.

[67] https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93325/e-waste-in-the-eu-facts-and-figures-infographic
[68] https://globalewaste.org/
[69] https://www.eca.europa.eu/lists/ecadocuments/rw21_04/rw_electronic_waste_en.pdf

association (NEPs)			
Software provider or association	(No available sources)	"Must Have"	While software companies are not directly involved in e-waste because their product is software, they are increasingly involved in the production of software tools to improve the performance in e-waste production and processing.
Consumer/civil society association	(Neumman 2020)	"Should Have"	There is no clear evidence that this indicator influences consumers' provider choices.
Cross-cutting	(BEREC 2023)	"Must Have"	(BEREC 2023) reports e-Waste as a MEDIUM indicator. On the other hand among the MEDIUM indicators, it is the one with the most responses to the BEREC survey, with 41 companies collecting this indicator.
National Regulatory Authority	(BEREC 2023)	"Should Have"	This indicator has grown in importance for national authorities, as shown in recent reports like (BEREC 2023) but it is not collected at the same level as GHG scope 1 and scope 2.
Network operator (Fixed)	(Rajesh 2023), (Andersen 2022)	"Should Have"	E-waste from telecommunications products is still a limited portion (less than 5%) of the overall e-waste. It is also mostly related to end user equipment like broadband CPEs. We note that mobile phones and user equipment, in general, are out of the scope of this study.
Network operator (Mobile)	(Rajesh 2023), (Andersen 2022), (GSMA 2022b), (Telefonica 2023a), (Huawai 2023b)	"Should Have"	E-waste from telecommunications products is still a limited portion (less than 5%) of the overall e-waste. It is also mostly related to end user equipment, like mobile phones. We note that mobile phones and user equipment in general are out of the scope of this study.
Third-party sustainability auditor or association	(Rajesh 2023), (Andersen 2022), (BEREC 2023)	"Should Have"	It is very challenging for auditors to monitor the reporting of e-waste by telecom companies. At the moment, it is not clearly indicated in the references as an important indicator.

5.2.8.3 Results from the survey

Network components and their relevance: In the survey, 22% of the respondents indicated FAN, which was the largest percentage (presumably because of the large amount of copper cables and systems), BB with 18%, and RAN with 15%. Data centres (Server Farms or SF) were indicated at 11%.

Standardisation: In the survey, stakeholders indicated no standardisation gaps for 27%, while another 41% indicated the presence of standardisation gaps cumulatively for data collection (27%) and data analysis (15%), showing contradictory views of the respondents. A significant percentage (27%) also indicated minor gaps. Regarding the choice of standards, the majority suggested the GHG Protocol family of standards (24%), the ISO (24%) and the ETSI (20%).

Audit: A significant majority of survey respondents (60%) indicated that they audit energy consumption, with 44% doing so on a voluntary basis rather than a mandatory basis (16%). However, for those for which the audit of this indicator was mandatory, it was mainly done by a third party (12% vs. 4% mandatory self-audit). We note that 27% of the respondents did not perform audits. Regarding the voluntary audit, 31% of the respondents used third party companies, and 23% performed self-audit. Summarizing the results for voluntary and mandatory third party auditing, it can be concluded that there was not a majority of respondents, who use a third party auditor (43%).

Metrics: The weight of produced e-waste was predominant among the respondents, at 87%.

Implementation cost: We did not receive a significant number of answers to this question.

Agreement with proposed ranking: Based on initial research, this indicator was proposed as “Must Have”, to which a large majority (80%) of survey respondents agreed.

5.2.8.4 Results from the stakeholder workshop

The feedback from the stakeholder workshop confirmed that e-Waste can be considered a Must Have (MH) indicator, in particular in relation to aspects of the circular economy. On the other hand, the reporting and collection of data on this indicator is still in the preparation or planning phase, and it is not actually implemented by NRAs or telecom operators, as shown in the desktop research and the results of the survey, i.e., no audit by 27% of the respondents. It seems that the current main focus is on the e-Waste of mobile phones, where many telecom operators have already started various e-recycling programmes.

5.2.8.5 Ranking and outlook for a future Code of Conduct

Our analysis has confirmed that e-Waste is a “Must Have” indicator for measuring the sustainability of telecommunications networks, but significant work is needed to define processes for e-Waste data analysis and collection. The weight of e-Waste is suggested in the survey as the predominant metric (87% of respondents), but it would also be useful to measure the Electronics Disposal Efficiency (EDE) indicator expressed as responsible disposed weight in comparison to the overall total weight disposed.

5.2.9 Recycled/refurbished/reused components (also the excavated mass) used in products

5.2.9.1 Definition

This indicator can be defined as the amount of recycled, refurbished, or reused materials in relation to the amount of primary materials used as the input to production (ITU-T L.1410).

This indicator is different from the indicator Distribution or utilisation of recycled/ refurbished/ reused products, which focuses on the recycling or refurbishing of the entire product (e.g., mobile network equipment). Instead, this indicator (‘Recycled/refurbished/ reused components (also the excavated mass) used in products’) focuses on the recycling of the components inside the product. In the case of a mobile phone (even if mobile phones are not considered in this study), the camera, display, and potentially the battery and charger could be extracted from the phone and reused to build a new mobile phone. Both indicators belong to the circular economy paradigm, which is also related to the reparability and recyclability indicators.

5.2.9.2 Results from desktop research

(BEREC 2023) reports this indicator as a highly relevant one in terms of support by the surveyed companies because 22 respondents are collecting this indicator and 35 of them consider it very relevant. On the other hand, no NRA is collecting this indicator at this moment, and thus it is allocated to group B in the BEREC report (BEREC 2023), which is the group where no NRA is collecting data on the indicator but there is significant support by companies.

Among telecom operators, the importance of this indicator has been underlined by a number of references, including (GSMA 2022b) where it is mentioned as part of the circular economy paradigm. On the other hand, the main focus is on mobile devices and less on network equipment. Report (GSMA 2022b) mentions the difficulty of establishing supply chains and reverse supply chains with the vendor and manufacturer where the components of the network equipment can be reused. In (GSMA 2022b), it is mentioned the case study of the Optus company, a producer of telecommunications modems, where it is claimed that more than 95% of the modem components (except 5G models) are extracted and recycled. A discussion on the challenges of establishing a circular economy in the ICT domain is also provided in (MacArthur, E. 2013) where it is mentioned that the design of the ICT equipment must be changed and improved to facilitate the extraction and reuse of components. This is not the case for most of the companies in the telecom sector today. One problem (Note of Authors) in the telecommunications sector is that it is difficult to reuse electronic components like filters or processing units from one generation of telecom networks to the next because the design standards and modulation schemes may differ. In addition, thanks to Moore's law, the CPUs of older generations have much lower performance than those of the next generation rendering them unsuitable to support the enhanced processing requirements of newer protocols, services, and applications.

Nevertheless, this indicator has a great potential for network equipment manufacturers because they would be the main entities responsible for the design of their equipment and can support component extraction and reuse with an inverse supply chain. Various companies defined recycle and reuse processes like the Ericsson Connected Recycling (Ericsson 2023b) and the E-waste Recycling Program in Huawei (Huawai 2023b) which seems to include the components as well as the whole products although the main focus is still on the mobile phones.

Considering the large amount of electronic equipment used in server farms and processors this indicator is important for data centres, as also shown in (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022), where the authors found significant support for this indicator in their survey: "When asked what metrics related to the IT equipment data centre operators were actively working on improving, the most popular ones were maintenance, followed by reuse, refurbishment, exchange with secondary markets for components and materials, and finally remanufacturing". Many organisations have started to implement refurbishment programmes and reuse of products and components. For example, in (DataCenterDynamics 2023), it is mentioned that in 2020, Microsoft announced Circular Centres, dedicated to reusing and repurposing servers and other hardware in its data centres. Its servers have an average lifespan of around five years, and Microsoft expects the centres to increase the reuse of servers and components by up to 90 percent by 2025. Similarly, the same reference (DataCenterDynamics 2023) mentions that "Google is also a major proponent of hardware re-use and refurbish programmes. In 2020, 23 percent of the data centre hardware components used in server upgrades were refurbished inventory, and 8.2 million components were resold into the secondary market. The refurbishment percentage has stayed around that figure for the last few years, but the number of components resold has increased from 2.1 million in 2016". On the other hand, based on the desk research and interviews with stakeholders, it seems that there is a lack of standardisation for data centre circularity, as reported in (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022). The same reference also provides an estimate of the main components of the data centres, which can be reused: Hard Disk Drive have a reuse-rate of 47.7 % and memory cards of 40.1 %.

For the auditor category, this indicator does not seem to be a primary indicator included in the ILCD handbook (the International Reference Life Cycle Data system) (EC 2023) and PEF (Product Environmental Footprint) (EU 2021). It has an indirect relationship with resource depletion and resource use (which are instead in the PEF as part of the circular economy).

Regarding the sustainability impact, similar considerations to those already described for e-Waste and refurbishment of products (rather than components) can also be put forward. Refurbishment and reuse of network equipment are somewhat related to all the network equipment and network elements of the telecom infrastructure, and it is again difficult to identify specific impacts because the authors did not find references with detailed data. Based on the authors' experience and the input from the desktop research, the base stations, switches, routers, and data centres can be highlighted for their impact because of the large number of base stations, switches, and routers present in the network and high modularity of data centres where server elements, hard disks and memory can be easily extracted from the server. In fixed access networks, it should also be considered a significant excavated land mass.

The results are presented in Table 18.

Table 18 Sustainability impact (qualitative measure)

RAN	**FAN**	**BB**	**DC**	**Organisation**	**Facility**
Relevant for the large number of electronic components.	Relevant for the excavate mass.	Less relevant due to the long lifetime and lower possibility of reuse.	Relevant for the large number of components like hard disks and memories.	N/A	N/A

Concerning the standard(s) to be adopted to measure this indicator in the network, the authors have similar recommendations to the ones already suggested for the other indicators in the Circular economy (e.g., e-Waste). (BEREC 2023) indicated (in Annex I) GRI 306: Effluents and Waste 2020 standard and ISO 14040:2006 and related standards for Life Cycle assessments. The desktop research also suggested ITU-T L.1020 as relevant for this indicator.

Regarding the measurement metrics, (BEREC 2023) indicated various metrics, which are mostly based on the number of items refurbished, the number of devices and weight in tons, and total tons or percentage of product components/mass. The reference (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) also indicates the percentage of used electronics recycled.

Table 19 provides a breakdown of our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on the category of the stakeholder, e.g., telecom operator, or national regulatory authority, or telecom equipment vendor. For this indicator, we can see that there is a majority of "Must Have" but some categories are also associated with "Should Have".

Table 19 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
Data centre operator or association (this is only for the data centres used for telecom network operations and management including virtual Distributed Units and centralized units)	(IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022), (DataCenterDynamics 2023)	"Must Have"	This indicator can be important for data centres as reported in the literature review.

Network equipment provider or association (NEPs)	(Ericsson 2023b), (GSMA 2022c), (Huawai 2023b)	"Must Have"	Network equipment manufacturers have started various programmes for the distribution and recycling of refurbished components, even though they are now mostly focused on mobile phones.
Consumer/civil society association	(Neumman 2020)	"Should Have"	There is no clear evidence that this indicator influences consumers on the provider choice.
Cross-cutting	(BEREC 2023)	"Should Have"	(BEREC 2023) reports recycled/refurbished/reused components (also the excavate mass) used in products as a medium indicator, which corresponds to "Should Have" in this report.
National Regulatory Authority	(BEREC 2023)	"Should Have"	No NRA is collecting this indicator at this moment, and it is allocated to group B in the BEREC report.
Network operator (Fixed)	(No available sources)	"Should Have"	The authors of this report did not find specific references for the reuse of components in products. On the other side, the extensive fixed access networks requires excavation of land mass.
Network operator (Mobile)	(Telefonica 2023c), (GSMA 2022c)	"Should Have"	Various mobile telecom operators have started programmes for the reuse and refurbishment of network equipment, but it is not clear how much of it is related to the components of the network equipment rather than end-user products and mobile devices.
Software provider or association	(No available sources)	"Should Have"	The authors of this report did not find specific references.
Third-party sustainability auditor or association	(No available sources)	"Should Have"	The authors could not find direct evidence that auditors collect data on this indicator, even if it is related to the Circular Economy.

5.2.9.3 Results from the survey

Network components and their relevance: 19 responses were received, which were quite balanced among the different items.

Standardisation: 13 responses were received, with ITU-T and ISO predominant with 31% each, followed by ETSI (16%), GHG (8%), GRI (8%), and Other (8%). There are significant standardisation gaps for data collection (46%) and data analysis (46%). One response indicated minor standardisation gaps (8%).

Audit: 6 responses mostly mentioning No audit (83 %) or Voluntary third party audit (17%).

Metrics: 10 responses were received. Number of recycled/refurbished/reused components in products (30%) Percentage (%) of recycled/refurbished/reused components used in products (20%) Weight (kg, tons) of recycled/refurbished/reused components in products (50%).

Implementation cost: we received 6 responses, all indicating that this information is not available.

Agreement with the proposed ranking: 59% agreed with the "should have" ranking. This value is not a predominant confirmation as with other indicators, but it should be considered that the other two choices had almost the same score, around 20%.

5.2.9.4 Results from the stakeholder workshop

The feedback from the stakeholder workshop confirmed that this indicator can be considered a Should Have (SH) indicator, in particular in relation to the aspects of circular economy. A number of stakeholders confirmed programmes recently started for the refurbishment of products, but less so on components, as this may be complex to implement in the supply chains.

5.2.9.5 Ranking and outlook for a future Code of Conduct

Our analysis has confirmed that the recycled/refurbished/ reused components (also the excavate mass) used in products is a "Should Have" indicator because of the significant benefits for the environment by supporting a circular economy. On the other hand, the implementation of reverse supply chains to improve the reusability of components may be challenging (GSMA 2022b).

5.2.10 Expected lifetime

5.2.10.1 Definition

Expected lifetime is the lifetime of operation of a product or service or end-user device or mobile network element. The useful life is usually expressed in years. Methodology and technical tools are needed, so that the telecom companies can collect this indicator since there are some limitations, such as a lack of criteria, the granularity of the required data due to the varying products and the elements of each network type and segment.

In (EC 2021), the expected lifetime is linked to the concept of extending a product lifetime due to reuse or refurbishment of a product. This may result in two situations:

Resulting in a product with the original product specifications (providing the same function). In this case, the product lifetime is extended to a product with the original product specifications (providing the same function) and shall be included in the reference flow. The user of the PEF method shall describe how reuse or refurbishment is included in the calculations of the reference flow and the full life cycle model, taking into account the "how long" of the FU.
Resulting in a product with different product specifications (providing another function).

5.2.10.2 Results from desktop research

(BEREC 2023) reports the 'Expected lifetime' as an indicator having a medium support from the respondents with only 10 companies collecting this indicator. On the other hand, in (BEREC 2023) 31 respondents mentioned very relevant as an indicator and 37 somewhat relevant. The NRAs involved in the study indicated recyclability as belonging to group A, which represents the indicators already collected by an NRA. In this case, France is collecting this indicator.

Among mobile communication providers and vendors, the improvement of the expected lifetime of network equipment (in particular mobile devices) is one of the action where telecom operators and vendors aim to improve the current situation (GSMA 2022b). Some case studies of companies starting programmes to improve the lifespan of the network equipment are mentioned in (GSMA 2022b). In particular, Telefónica has developed and deployed the VICKY initiative in Brazil to extend the recyclability and lifespan of network equipment even if the initiative is mostly related to mobile devices and CPE and it is not clear if it is intended to be extended to network equipment (GSMA 2022b). It should be noted that the lifespan of mobile networks is relatively long (5-15 years) (ITU 2020). Then, the possibility to extend the lifespan of mobile networks could bring a strong benefit to telecom operators.

Regarding fixed networks, whose lifespan is quite long (30-50 years) as described in (Europacable 2021), optical cables are already designed for a long lifespan in particular the ones used for access networks because their replacement can be quite costly in terms of physical cable deployment. Other components like the backbone switches and routers are also designed and deployed to have a long lifespan of 10-15 years.

For data centres, reparability and the possibility to extend the lifespan may be important considering the large amount of electronic equipment used in server farms and the recent regulatory actions in EU member states and France. In (Swinhoe 2022), it is discussed how various companies are promoting initiatives to expand the life time of the equipment in data centres including a higher degree of reparability. In (Hoosain 2023), it is discussed how a circular economy can be implemented to support the concept of sustainable data centres. Previously, (ITU 2020a), has observed a lack of transparent or clear quantitative data in the public domain regarding the composition, lifespan, volume and end-of-life management of equipment generated by data centres (and other networking equipment). Therefore, it is difficult to make an assessment. It should also be noted that data centres have a short lifecycle of 3-5 years (ITU 2020a). Therefore, the impact of lifespan for some components, which must be replaced with new more powerful computing platforms, may be limited in data centres themselves however they can be deployable in other products (situation 2, in the definition above).

For the category of auditors, expected lifetime is not one of the main indicators included in the European Environmental Footprint (EF) but it is mentioned in (EC 2021) (Expected Product lifetime).

Regarding the actual sustainability impact of recyclability, we did not find specific data on the distribution of this indicator across the network elements (as also pointed out in (ITU 2020a) but we can summarise the key findings from the paragraphs above. Due to the long requested lifespan of RAN components or cabling components in FAN, this indicator may be quite important for those components. Even if there are companies promoting initiatives to extend the lifespan of data centres, the short lifecycle of data centres (3-5 years) may limit the impact of this indicator.

Table 20 provides an overview of the sustainability impact for this indicator.

Table 20 Sustainability impact (qualitative measure)

RAN	**FAN**	**BB**	**DC**	**Organisation**	**Facility**
Very relevant due to the long required lifespan of the network equipment.	Very relevant due to the long required lifespan of the network equipment.	Very relevant due to the long required lifespan of the cabling, switch and routers.	Relevant because there are companies proposing actions for this indicator but the DC upgrade lifecycle is usually short.	N/A	Relevant because the lifespan of facilities is expected to be long.

Concerning the standard(s) to be adopted to measure this indicator in the network, it is proposed to use the same standards of reparability, (BEREC 2023) indicated (in Annex I) GRI 306: Effluents and Waste 2020 standard. (GSMA 2022b) also indicated ITU-T Standard L.1023 Assessment method for circular scoring.

Regarding the measurement metric, (BEREC 2023) indicated the lifetime in years.

Table 21 provides a breakdown on our assessment of the importance of this indicator for the different types of stakeholders. It is also based on the category of the stakeholder, e.g. telecom operator or national regulatory authority or telecom equipment vendor. Across most of the stakeholders' categories, it can be seen that this indicator is considered as a "Should Have" indicator.

Table 21 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
National Regulatory Authority	(BEREC 2023)	"Must Have"	This indicator is in the Group A of indicators where at least one country (France) is collecting information.
Consumer/civil society association	(Laitala 2021), (EC 2018), (EC 2020)	"Should Have"	There were some studies, which show that consumer may be willing to pay more for products that are easier to repair, have an extended lifespan and are labelled with this information. On the other hand, these products are mostly mobile devices and other electronic appliances used directly by the consumers rather than the network equipment in the telecom network infrastructure.
Cross-cutting	(BEREC 2023)	"Should Have"	The level of strong support from the surveyed companies is based only on 10 companies.
Data centre operator or association (this is only for the data centres used for network operations and management including virtual Distributed Units and centralized units)	(Swinhoe 2022), (Hoosain 2023), (ITU 2020a),	"Should Have"	Relevant because there are companies proposing actions for this indicator but the DC lifespan is usually short, which may reduce the impact of this indicator.
Network equipment providers or association (NEPs)	(Ericsson 2023b) (Huawei 2023b) (ITU 2020a)	"Should Have"	Network equipment vendors have set up programmes for circular economy but they seem to be mostly focused on the user equipment like mobile phones and customer premise equipment (CPE).
Network operator (Fixed)	(ITU 2020a)	"Should Have"	Network operators have started programmes for circular economy but it is not clear if they are focused only on network equipment or customer premise

	(Unger 2008) (Rene 2021) (Flik 2021)		equipment (CPE). On the other hand, the lifecycle of network equipment in large telecom infrastructure is quite long (10-15 years), hence this indicator may be quite beneficial.
Network operator (Mobile)	(GSMA 2022b)	"Should Have"	Mobile telecom operators have started programmes for circular economy but the main focus at the moment is about mobile phones and their components rather than the network equipment. On the other hand, the lifecycle of network equipment in large mobile telecom infrastructure is quite long (10-15 years) and this indicator may be quite beneficial.
Software provider or association	(ITU 2020)	"Should Have"	Software updates can improve significantly the lifespan of network equipment.
Third-party sustainability auditor or association	(BEREC 2023), (EC 2021)	"Should Have"	It is not one of the main indicators included in the European Environmental Footprint (EF), but it is proposed in PEF.

5.2.10.3 Results from the survey

Network components and their relevance: The 25 responses were spread across various components of the network infrastructure with 25% indicating data centres and network equipment each. The BB collected 24% of the responses as well. Another 16% suggested RAN and 16% suggested FAN. Finally, Organisation and facility was indicated by 4% whereas 4% of the responses did not know what to suggest.

Standardisation: On the 18 responses, 28%, suggested GRI, 17% suggested ITU-T, 17% suggested ETSI, 17% suggested GHG and one answer used the Other option suggesting LCA PEF 3.0. There were 11 responses to indicate the standardisation gaps with 36% stating that there are standardisation gaps for data collection and data analysis (both of them) and another 27% stating that there are minor standardisation gaps. Hence, there is a need for actions to address gaps in standardisation.

Audit: Out of the 8 answers, 88% responded that they do not perform audit (No audit) whereas 12% perform mandatory third-party audit.

Metrics: There were 11 responses with 6 responses (54%) pointing out to Years, 4 responses (36%) to Months and one (Other category) "Real Lifetime".

Implementation cost: There were 6 responses with 5 indicating N/A and one stating <0.1 % both for OPEX and CAPEX.

Agreement with proposed ranking: A majority 63% of the responses supported "Should Have" but it should be also considered that a significant part (28%) suggested "Must Have". Only 9% indicated "Nice to Have".

5.2.10.4 Results from the stakeholder workshop

Extended lifespan was discussed only in a limited way in the workshop and mostly in the context of circular economy and its relationship with other indicators like reparability. It was highlighted that there may be trade-offs between this indicator and other indicators because an extended lifespan of network equipment goes against the logic of upgrading the network with equipment, which may be more energy efficient.

5.2.10.5 Ranking and outlook for a future Code of Conduct

This indicator is mostly indicated as "Should Have" indicator but it is in the Group A of indicators collected by NRAs (BEREC 2023) and it may grow in importance because some network components (RAN, FAN) have a long renewable lifecycle. Metrics are well defined, but there are still significant standardisation gaps. In addition, it may be difficult to collect data considering the massive amount of network equipment present in a large network infrastructure.

5.2.11 Recyclability

5.2.11.1 Definition

Recyclability is defined in ITU-T L.1022 as the ability of a product to be recycled at its end-of-life stage. In substance, recyclability is the ability of a material to regain its valued properties through a recycling process or the capability of a product being reusable at the end of its useful life to minimize waste, pollution, and resource use.

5.2.11.2 Results from desktop research

(BEREC 2023) reports recyclability as an indicator with a medium support from the respondents, with 20 companies supporting this indicator. The NRAs involved in the study indicated recyclability as belonging to group B, which represents the indicators not yet collected by the NRAs but supported by the industry.

Among mobile communication providers and vendors, recyclability is supported by various actions, and this information can be derived from the same or similar references also used for the e-Waste indicator. One potential issue is that recyclability is quite often related to users' devices, like mobile phones or customer premise equipment (CPE), and the relation to network equipment of the telecom infrastructure is not clear (GSMA 2022b). Various telecom operators have undertaken significant actions to improve recyclability, like (Telefonica 2023a), where it is mentioned that in 2022 Telefonica "generated 52,906 tonnes of waste and recycled 98%. In terms of electronic equipment (even if it has to be evaluated it these numbers are related to mobile devices or network equipment with the latter more difficult to recycle). Telefonica reused around 44% of the total equipment collected and recycled the remaining 56%", but it has to be seen which part of these numbers is network infrastructure equipment and which part is mobile devices. The equipment manufacturer[70] Ericsson in (Ericsson 2023b) supported programmes like Ericsson Connected Recycling (ECR), which digitalizes and connects the reverse supply chain to empower circularity. Huawei also supports also recyclability and has developed the E-waste Recycling Program (Huawei 2023b), although it seems mostly focused on the recyclability of smartphones and tablets.

For data centres, recyclability could be an important indicator considering the large amount of electronic equipment used for their design and implementation. As described in (DCD 2022), various companies aim to improve reuse and recyclability in data centres like Microsoft: "In 2020, Microsoft announced Circular Centres, dedicated to reusing and repurposing servers and other hardware in its data centres. Its servers have an average lifespan of around five years, and Microsoft expects the centres to increase the reuse of servers and components by up to 90 percent by 2025". In the same article, it is stated by Oracle that 99.6% of the company's electronic waste was reused or recycled in full year 2021. In a similar way, Google reports that 23% of the data centres hardware components were refurbished inventory and 8.2 million components were resold into the secondary market (DCD 2022), (Miller 2023). Amazon Web Service is also reported in (Miller 2023) to have facilities around the world to manage its hardware refurbishing process, which is called reverse logistics. Each reverse logistics hub consists of an information technology (IT) asset disposition centre that receives server racks and individual components from data centres and a failure analysis lab (FA lab) that tests and repairs used components. All these companies develop and operate "generic" data centres for ICT applications, where the word *generic* means that it is not specific for telecom virtualised infrastructure. The authors of this report did not find specific

[70] https://www.orange.com/en/newsroom/news/2021/net-zero-carbon-commitment-circular-economy-heart-our-network-infrastructure

references discussing telecom data centres for vDU and vCU but it can be assumed that actions in the telecom sector can follow the ones described above.

For the category of auditors, recyclability is not one of the main indicators included in the PEF (Product Environmental Footprint) from (EU 2021) and used by all standard LCA reports[71]. As in the case of e-Waste, there may be an indirect relationship between the circular economy and resource depletion.

Regarding the actual sustainability impact of recyclability, the authors of this report did not find data for the specific elements of the network. On the basis of the experience of the authors, data centres can be impacted mostly by this indicator because of the large amount of components like memory and computing components, which can be recycled. In the case of RAN, it would be difficult to effectively implement recyclability because of the upgrade of the cellular technologies from one generation to another (4G->5G), which requires new components and systems. Also, for fixed networks, upgrades to new protocols and hardware components supporting higher transmission rates make it difficult to effectively implement recyclability. Indeed, it may not always be economical and energy-efficient to recycle and reuse equipment (ITU 2020b) Concerning the basic materials, in fixed access networks, the traditional copper cables can be greatly recycled (Rene 2021). Components of base stations also contain rare materials like Gallium and Tantalum, while fibre optics contain Erbium. There are a number of challenges to recyclability that have been highlighted by recent reports like (GSMA 2022b), which could be reformulated as regulatory actions.

Concerning the standard(s) to be adopted to measure recyclability, the same standard as for e-Waste and indicated in (BEREC 2023) in Annex I can be used, i.e., GRI 306: Effluents and Waste 2020. The authors of this report suggest also that the ITU-T L.1022 can be used for the indicator´s assessment.

Regarding the measurement metric, (BEREC 2023) indicated various measurement metrics, including the number of recycled devices, the number of units in percentage on the number of total units, the kgs of recycled waste tonnes and the percentage of recycled products on the total electronic waste.

Table 22 provides a breakdown of our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on the category of the stakeholder, e.g., telecom operator, or national regulatory authority, or telecom equipment vendor. Across most of the stakeholders' categories, it can be seen that this indicator is considered as a "Should Have" indicator.

Table 22 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
Cross-cutting	(BEREC 2023)	"Should Have"	The level of support from the surveyed companies is medium with 20 companies collecting this indicator.
Network equipment providers or association (NEPs)	(Ericsson 2023b) (Huawai 2023b)	"Should Have"	Some of the network equipment vendors have set up programmes for recyclability and circular economy but they seem to be mostly focused on the users' equipment like mobile phones and customer premise equipment (CPE).
Network operator (Fixed)	(Telefonica 2023a)	"Should Have"	Network operators have started programmes for e-Waste and recyclability, but it is not clear if they are focused on network equipment or customer premise equipment (CPE).

[71] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32021H2279

Network operator (Mobile)	(GSMA 2023)	"Should Have"	It seems that the main focus at the moment is on the recyclability and reuse of mobile phones and their components rather than the network equipment.
Software provider or association	(No references available)	"Nice to Have"	The authors of this report did not find references for the relevance of this indicator for software providers.
Third-party sustainability auditor or association	(No references available)	"Should Have"	At the moment, it is not clearly indicated in the references as an important indicator, apart that it can be used to support the circular economy.
Consumer/civil society association	(Neumman 2020)	"Nice to Have Have"	There is no clear evidence that this indicator influences consumers' provider choice.
Data centre operator or association (this is only for the data centres used for network operations and management including virtual Distributed Units and centralized units)	(DCD 2022), (Miller 2023).	"Must Have"	Many data centres companies have started programmes to support recyclability. Even if these companies operate in the general ICT domain, similar programmes can be adopted in the telecommunications domain.
National Regulatory Authority	(BEREC 2023)	"Should Have"	This indicator is not collected today by NRAs but it is supported by the industry, even if it is not clear if such support is focused on the recyclability of mobile phones or network equipment in the network infrastructure.

5.2.11.3 Results from the survey

Network components and their relevance: RAN (19%), FAN (19%), BB (14%), SF (14%), NSR (19%), Organisation (5%), Do Not Know (5%). Total answers: 21. The results are well balanced across the different components of the network infrastructure.

Standardisation: For this item, the survey reported 13 answers with significant standardisation gaps for data collection and data analysis, with 46% in each category. Another 8% declared minor standardisation gaps. ITU was indicated by 50% of the responses with GHG protocol and GRI both at 25%.

Audit: The survey reported only 6 answers with 83% declaring that no audit is performed in their organisation and 17% implementing a voluntary audit by a third party.

Metrics: The survey reported only 10 answers, with 30% using the number of recycled network elements, 20% using the percentage of the recycled network elements on all the network elements, and 50% using the weight of the recycled network elements.

Implementation cost: No responses were received.

Agreement with proposed ranking: 72% supported the allocation of this indicator to "Should Have", 20% to "Must Have" and 9% to "Nice to Have".

5.2.11.4 Results from the stakeholder workshop

The feedback from the stakeholder workshop confirmed that recyclability is a "Should Have" (SH) indicator, to which there were no objections from the audience. This indicator was mostly discussed in the context of the circular economy, and it is associated with other environmental indicators like e-Waste or raw materials. From the discussions at the workshop, it seems that most of the current efforts of the telecom vendors and products are focused on the recyclability of mobile phones rather than the network equipment of the network infrastructure. There was a debate at the workshop about the trade-off of reusing or recycling old equipment (this indicator) with the need to deploy high performance network equipment (related to the energy consumption and energy efficiency indicators).

5.2.11.5 Ranking and outlook for a future Code of Conduct

This is a second priority indicator in comparison to the "Must Have" indicators, and most of the stakeholders present at the workshop and providing input to the survey confirmed its classification to the "Should Have" category. Together with other indicators focused on the disposal of network equipment (e-Waste, distribution of recycled, refurbished, or reused products), some actions can be activated to improve the recyclability of network equipment in the telecom infrastructure rather than just the users' equipment, as is the current situation. Possible actions include the creation of "reverse logistics" supply chains so that telecom operators and vendors can improve the recyclability of network equipment. The authors of this report also note that full reuse of network equipment may not be possible in some cases because the network equipment must be upgraded to provide better performance than the existing equipment (e.g., 4G and 5G).

5.2.12 Reparability

5.2.12.1 Definition

Repairing is one of the most relevant strategies within the Circular Economy (CE) concept since it contributes to waste prevention and extends products and components' lifespans. Reparability can be defined as a measure of the degree to which a product can be repaired and maintained.

Repair should be considered as a crucial part of the circular economy through its contribution to increased product service lifespans and, thus, better resource utilisation and less waste (Laitala 2021). Then, it is linked to other environmental indicators like e-Waste and expected lifetime.

Besides the positive effects on the environment, the possibility of repairing a product increases the awareness of the impact of product choices on the climate and environment and may lead to more sustainability-friendly customer choices.

5.2.12.2 Results from desktop research

(BEREC 2023) reports that reparability has a medium level of support from stakeholders participating in the survey, with 13 of them collecting this indicator but the other 12 planning to do it in the future. 27 respondents consider this indicator very relevant, while 41 of them consider it somewhat relevant. On the other hand, NRAs classify this indicator in the B category, which means that it has not yet been collected by NRAs.

Among mobile communication providers and vendors, reparability is discussed as part of the circular economy. (GSMA 2022b) discusses the role of reparability and the potential actions that can be taken by telecom operators, such as the application of Eco-Design principles, the need to improve the supply chain among operators and vendors, and the need to increase partnerships with repair workshops, resellers, and consumers. However, the focus of the analysis in (GSMA 2022b) seems mostly oriented to the reparability of the mobile devices (smartphones and tables) rather than the network equipment. Telefonica has also triggered an initiative called the European Green Passport to promote the reuse and reparability of electronic equipment used in the mobile telecommunications industry (Telefonica 2022b) but it seems again mostly focused on mobile devices for final users[72].

Reparability in data centres is important considering the large amount of electronic equipment used in server farms and the recent regulatory actions in the EU and France[73]. In (Swinhoe 2022), it is discussed how various companies are promoting initiatives to expand the lifetime of the equipment in the data centres including a higher degree of reparability. In (Hoosain 2023), it is discussed how a circular economy can be implemented to support the concept of sustainable data centres. It needs to be noted, though, that most of the mentioned initiatives are mostly focused on other related indicators like e-Waste and the increase in life-span rather than improving reparability.

For the auditor category, reparability does not seem to be a primary indicator included in the ILCD handbook (the International Reference Life Cycle Data System) (EC 2023) and PEF (Product Environmental Footprint) (EU 2021). There is an indirect relationship between resource depletion and resource use as part of the circular economy concept.

Regarding the sustainability impact, reparability is related to all the network equipment and network elements of the telecom infrastructure, even if network elements more exposed to adverse environmental conditions (e.g., rain) may be more prone to failures (e.g., both RAN and FAN), requiring repairs. Malfunctions in air conditioning in server farms (e.g., data centres) or in cabinets hosting network equipment (switches, routers) can also generate failures and thus the need for repairs.

Concerning the standard(s) to be adopted to measure this indicator in the network, (BEREC 2023) indicated (in Annex I) GRI 306: Effluents and Waste 2020 standard. (GSMA 2022b) also indicated the ITU-T Standard L.1023 Assessment method for circular scoring.

Regarding the measurement metrics, (BEREC 2023) indicated the reparability index, number of devices repaired, and percentage of repaired units on the overall number of units. Academics also indicated the reparability index (Louis-Pastor 2023) and the ease of repair of a product (Flipsen 2016).

Table 23 provides a breakdown of our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on the stakeholder category, e.g., telecom operator, or national regulatory authority, or telecom equipment vendor. This indicator is not grouped in the "Must Have" ones, and most categories of stakeholder have included it in the "Should Have" indicators.

Table 23 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
Data centre operator or association (this is only for the data centres used for network operations and	(Hoosain 2023), (Swinhoe 2022)	"Must Have"	Reparability is important in large data centres composed of a large number of computing systems.

[72] : https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=PI_COM:Ares(2022)6031464
[73] https://www.ecologie.gouv.fr/indice-reparabilite,

management including virtual Distributed Units and centralized units)			
Consumer/civil society association	(Laitala 2021), (EC 2018)	“Should Have”	There were some studies that show that consumers may be willing to pay more for products that are easier to repair and are labelled with this information. On the other hand, these products are mostly mobile devices and other electronic appliances used directly by consumers rather than equipment in the network infrastructure.
Cross-cutting	(BEREC 2023)	“Should Have”	(BEREC 2023) reports reparability as a MEDIUM indicator.
National Regulatory Authority	(BEREC 2023)	“Should Have”	This indicator has grown in importance for national authorities, as shown by recent reports, e.g., (BEREC 2023), but it is not collected at the same level as GHG scope 1 and scope 2. It is assigned to group B, which means that it is not collected by NRAs but is supported by industry. In addition, in some countries, like France, there are regulatory actions to support this indicator. Reparability is a score ranging from 0 to 10, assigned to electronic devices since January 1, 2021, with the aim of raising consumer awareness to the possibility of extending the useful life of devices. Especially by directing consumers towards products that are much more repairable, while encouraging them to repair their equipment and allowing them to compare different products to make the right choice.
Network equipment provider or association (NEPs)	(GSMA 2022b),	“Should Have”	Vendors have started programmes to improve reparability, but they seem mostly focused on mobile devices rather than network equipment.
Network operator (Fixed)		“Should Have”	The authors of this report did not find supporting evidence to date that this indicator is important to fixed network operators.
Network operator (Mobile)	(GSMA 2022b), (Telefonica 2022b)	“Should Have”	Telecom operators have started programmes to improve reparability, but such programmes seem mostly targeted at mobile devices.
Third-party sustainability	(BEREC 2023)	“Should Have”	At the moment, it is not clearly indicated in the references as an important indicator, but regulatory

auditor or association			actions like the one in France may support auditing activities regarding this indicator.
Software provider or association	(No references available)	“Nice to Have”	The authors of this report did not find references to support this indicator among software providers.

5.2.12.3 Results from the survey

Network components and their relevance: Number of answers: 16. FAN (25%), RAN (19%), BB (19%), SF (12.5%), NSR (12.5%), Organisation (6%), Do Not Know (6%).

Standardisation: The number of answers was 8. Significant standardisation gaps for data collection (50%), significant standardisation gaps for data analysis (38%), minor standardisation gaps (8%). For the indicated standard, the number of answers was 9: GRI (33%), GHGP (22%), ITU (22%), ISO (11%), and other 11%.

Audit: Number of answers: 6. No audit is done (100%).

Metrics: Number of answers: 11. Percentage of repaired devices: 54%. Reparability index 36%. Number of repaired devices 6%.

Implementation cost: N/A

Agreement with the proposed ranking: 72% confirmed the “Should Have” ranking, but 24% proposed “Must Have” and 4% “Nice to Have”.

5.2.12.4 Results from the stakeholder workshop

Feedback from the stakeholder workshop confirmed that reparability can be considered as a Should Have (SH) indicator, even if recent regulatory actions for sustainability (in particular in France) may raise the importance of this indicator in future. Reparability is linked to other environmental indicators for the circular economy.

5.2.12.5 Ranking and outlook for a future Code of Conduct

Our analysis has confirmed that reparability is a “Should Have” indicator for measuring the sustainability of telecommunications networks, and it is linked to other “circular economy” indicators like e-Waste. Even if the measurement metrics are already defined, it may be difficult to estimate the degree of reparability of network equipment. These aspects require further analysis for the definition of appropriate guidelines.

5.2.13 Raw Materials/Resources depletion

5.2.13.1 Definition

Resource depletion is the consumption of a resource beyond its rate of replacement. Resource depletion refers mostly to minerals and water. In the analysis of this report, only raw materials are considered.

The impact of material resource depletion and the relevant elementary flow are allocated to the life cycle that depletes the material resource (e.g., dumping material in landfills). Consequently, if the assessed ICT product system is wasting materials, it shall carry this burden fully and cannot share it with other product systems (definition from [ITU-T L.1410]).

This indicator refers to raw materials in general. However, there are two categories of raw material that are of greater concern and that are widely used in telecommunications equipment: rare-earth elements and critical raw materials.

Rare-earth elements are typically dispersed in nature and are not often found concentrated in rare-earth minerals. Thus, to achieve usable purity, the processing of enormous amounts of raw ore at great expense is required, hence the name "rare" earths.

Critical raw materials are of strategic importance. The European Commission identified critical raw materials on the basis of their economic importance and supply risk[74]. Supply risk accounts mainly for geopolitical and economic risks related to the supply chain, and thus the sustainability aspect related to the availability or scarcity of nature is only indirectly considered.

JRC maintains a Raw Materials Information System[75] and provides analysis of the use of raw materials in different sectors, including ICT[76].

5.2.13.2 Results from desktop research

(BEREC 2023) reports raw materials depletion as an indicator with medium support from respondents with only 6 companies collecting it. However, in the same survey (BEREC 2023), 14 respondents mentioned that this is a very relevant indicator, and 21 mentioned that it was somewhat relevant. The NRAs involved in the study indicated raw material depletion as belonging to group A, which represents indicators already collected by NRAs. In this case, France is collecting this indicator.

Among mobile communication providers and vendors, raw materials depletion (or actually the mitigation of the depletion) is supported by various actions, even If the greatest focus is on mobile devices (GSMA 2022b). (GSMA 2022b) notes that the reduction of raw materials also has ethical aspects because the mining of important materials (cobalt, gold) may be based on child labour or pollute the environment. Thus, it is important to reduce the depletion of raw materials and limit their mining through recycling or other activities (repairing, increasing lifetime). In this context, there is a strong relationship to other indicators like recyclability. As pointed out in other sections of this report, both telecom operators and vendors can help reduce raw material depletion by improving recyclability. For example, in (Telefonica 2023a), it is described how, in 2022, Telefonica “generated 52,906 tonnes of waste and recycled 98% of the waste. In terms of electronic equipment, Telefonica reused around 44% of the total equipment collected and recycled the remaining 56%”. The equipment manufacturer Ericsson supports programmes like Ericsson Connected Recycling (ECR), which digitalizes and connects the reverse supply chain to empower circularity (Ericsson 2023b). Huawei also supports recyclability and has developed the E-waste Recycling Program (Huawei 2023b), although it seems mostly focused on the recyclability of smartphones and tablets. In (ITU 2020b), it is discussed how radio access network equipment uses critical materials that are difficult to replenish through mining, like gold, indium, germanium, and gallium, making the radio access infrastructure a source of raw material recovery. On the other hand, mobile cellular networks have a long lifetime (10-15 years) which may not contribute to the mitigation of raw materials depletion.

Regarding fixed networks, the greatest opportunity is the extraction of copper from existing copper-based cabling in fixed access networks (Unger 2008), (Rene 2021), even if it is estimated that 25% of telecommunications wiring is recycled, and 75% is treated as waste (Unger 2008). Optical components may be more difficult to recycle (Unger 2008) but they contain rare earth elements, that are scarce in nature, like Erbium, Ytterbium, Germanium and other rare earths (Flik 2021).

For data centres, raw material depletion may be quite important because there is growing demand for raw materials for the manufacture of new data centre equipment; because their refresh rates can vary between 1 and 5 years; and the recycling and materials reclamation infrastructure for electronic equipment is severely underdeveloped. In addition to widely-used metals such as iron, copper, and aluminium, only precious metals (e.g., gold) and a small number of critical materials are being recovered. In addition, the procedure is chemically

[74] https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en
[75] https://rmis.jrc.ec.europa.eu/eu-critical-raw-materials
[76] https://rmis.jrc.ec.europa.eu/techprofiles/ind/12

burdensome as equipment at its EoL (end-of-life) undergoes numerous mechanical and chemical separation processes. Due to the use of hazardous chemicals for material recovery, the process itself has a negative impact on the environment, together with the loss of large volumes of materials (Kerwin 2022). As described in (DCD 2022), various companies aim to improve reuse and recyclability in data centres like Microsoft or Oracle, and details on the recyclability aspects are provided in the related sub-section. (Laurent 2020) and (Whitehead 2014) discuss how energy consumption and efficiency were the primary indicators for data centres, but there should be more attention on raw material use because this can be quite significant for large data centres. On the other hand, they may be mostly common materials (e.g., steel, copper, aluminium) and polymers, while 10 critical raw materials typically make up 0.2 per cent of components (Andrews 2019), which may not enable significant recovery of critical materials from obsolete data centre equipment. In fact, only 1% of wasted electronic equipment is reported to be used for material extraction (ITU 2020b).

In the category of auditors, the resource of metals and minerals is one of the main indicators included in the European Environmental Footprint (EF), which are also included in all reference environmental databases (e.g., Ecoinvent, Sphera, CODDE, etc.). Therefore, this indicator is quite relevant for auditors.

Regarding the actual sustainability impact of raw materials depletion, no specific data on the distribution of this indicator across the network elements was found, but a summary of the key findings from the paragraphs above is provided in Table 24. In the FAN, this indicator can be quite relevant for the extraction of a large amount of copper from existing copper cabling infrastructure. The extraction of critical materials like rare earths from optical networks in particular makes this indicator relevant for the BB. Various materials, including gold, can be extracted from the radio access network, but we need to take into consideration the long lifecycle of RAN.

Table 24 Sustainability impact (qualitative measure)

RAN	**FAN**	**BB**	**DC**	**Organisation**	**Facility**
Relevant for gold and rare earth metals but long lifecycle	Very relevant for copper	Relevant for rare earth metals	Very Relevant for common metals due to the fast technological evolution	N/A	N/A

Concerning the standard(s) to be adopted to measure recyclability, the same standard as for e-Waste and indicated in (BEREC 2023) in Annex I can be used, i.e., GRI 306: Effluents and Waste 2020. The authors of this report also suggest that ITU-T L.1022 can be used for the indicator´s assessment. We also suggest EN 50625 and EN 50614 and standards from ITU-T study group 5 (ITU-2020).

Regarding measurement metrics, (BEREC 2023) indicated the two main metrics of kg and equivalent tons of CO_2.

Table 25 provides a breakdown of our assessment of the importance of this indicator for different types of stakeholder. The breakdown is also based on stakeholder category, e.g., telecom operator, national regulatory authority, or telecom equipment vendor. Across most of the stakeholder categories, it can be seen that this indicator is considered a “Should Have” indicator.

Table 25 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
Data centre operator or association (this	(DCD 2022),	“Must Have”	The fast lifecycle of data centres (3-5 years) and the large amount of electronic equipment (servers, switches) can strongly support this indicator, although

is only for the data centres used for network operations and management, including virtual distributed units and centralized units)	(Kerwin 2022), (Laurent 2020), (Whitehead 2014), (Andrews 2019)		it is reported that most of the potential raw materials are of common type (copper, aluminium).
National Regulatory Authority	(BEREC 2023) direct feedback at the workshop	"Must Have"	This indicator belongs to Group A of indicators with at least one country (France) collecting information on it.
Third-party sustainability auditor or association	(BEREC 2023), direct feedback at the workshop	"Must Have"	This is one of the main indicators included in the European Environmental Footprint (EF).
Cross-cutting	(BEREC 2023)	"Should Have"	The level of support from the surveyed companies is based only on 6 companies.
Network equipment providers or association (NEPs)	(Ericsson 2023b) (Huawei 2023b) (ITU 2020b)	"Should Have"	Some of the network equipment vendors have set up programmes for recyclability and circular economy, but they seem to be mostly focused on user equipment, like mobile phones and customer-premise equipment (CPE). There could be an opportunity to mitigate raw materials depletion, also considering that rare earthls (which are critical raw materials) are present in telecommunications equipment. On the other hand, the lifecycle of network equipment in large telecom infrastructure is quite long (10-15 years).
Network operator (Fixed)	(ITU 2020b) (Unger 2008) (Rene 2021) (Flik 2021)	"Should Have"	Network operators have started programmes for e-Waste and recyclability, but it is not clear if they are focused on network equipment or Customer Premises Equipment (CPE). There could be an opportunity to mitigate raw materials depletion considering that rare earths (which are critical raw materials) can be recovered from optical networks and copper can be extracted from the extensive access network copper cabling infrastructure. On the other hand, the lifecycle of network equipment in large telecom infrastructure is quite long (10-15 years).

Network operator (Mobile)	(GSMA 2022b) (Telefonica 2023a)	"Should Have"	It seems that the main focus at the moment is on recyclability and reuse of mobile phones and their components rather than network equipment. On the other hand, the lifecycle of network equipment in large mobile telecom infrastructure is quite long (10-15 years).
Consumer/civil society association	(Neumman 2020)	"Nice to Have Have"	There is no clear evidence that this indicator influences consumers' provider choice.
Software provider or association	(No references available)	"Nice to Have"	The authors of this report did not find references for the relevance of this indicator for software providers.

5.2.13.3 Results from the survey

Network components and their relevance: Answers were numerous (23), and were quite balanced with a significant percentage of RAN, FAN and backbone network: RAN (17%), FAN (17%), NSR (17%), BB (13%), SF (13%), Organisation (9%), Facility (9%), Organisation (9%), Other (4%).

Standardisation: Only 10 answers pointed out mostly to ISO (40%), then ITU-T (20%), ETSI (20%) and Other (20%). On the responses (6) for standardisation gaps, the following information was provided: significant standardisation gaps for data collection (44%), significant standardisation gaps for data analysis (44%), and no gaps (12%).

Audit: There were few answers (4) for audit. No audit (50%), Voluntary third party (25%), Other (25%).

Metrics: 10 answers were provided, with a significant percentage pointing out weight (kg, tons) (50%) and 10% suggesting tons of carbon dioxide equivalent (tCO2e). 4 responses (40%) indicated other metrics, or provided specific comments. One response claimed that "The main impact on this indicator will be at the network equipment manufacturing stage. The weight of the equipment is not a good indicator, as metals with a high environmental impact may have a low weight in relation to the weight of the overall equipment. Interesting metrics would be, for example, the number of CPUs, RAMs, GPUs...". One other response indicated kg Sb eq, kg MIPS. One indicated Abiotic depletion potential elements (ADPe) & Abiotic depletion potential fossil (ADPf) and one indicated MIPS. MIPS is material input per service unit.

Implementation cost: N/A

Agreement with proposed ranking: 65% confirmed the "Should Have", with 20% indicating "Nice to Have" and the rest "Must Have".

5.2.13.4 Results from the stakeholder workshop

Most of the participants in the stakeholder workshop confirmed that raw material depletion is a "Should Have" (SH) indicator, but one stakeholder (French representative) notified us that this indicator should be "Must Have" indicator, considering also that it is in Group A of the BEREC study. This indicator was mostly discussed in the context of the circular economy, and it is associated with other environmental indicators like e-Waste or recyclability.

5.2.13.5 Ranking and outlook for a future Code of Conduct

This indicator could be raised to the "Must Have" level considering that it is supported by at least one NRA and by auditors. On the other hand, telecom vendors (e.g., Ericsson) pointed out that this indicator is quite difficult to measure and report and that this will not be a differentiating KPI between operators. It should also be noted that telecommunications equipment uses many rare earth elements (e.g., Erbium) and critical materials (e.g., Germanium, Gallium). The lack of plans for their retrieval could impact the economic security of the European

Union regarding these metals[77], which are usually mined and processed outside the EU. On the other hand, it should be considered that the long lifecycle of mobile and fixed networks may hamper actions focused on this indicator. There is no fragmentation in the used metrics or standards; consequently, its definition in a future Code of Conducts should not be overly complex.

5.2.14 Waste heat recovery

5.2.14.1 Definition

Waste Heat Recovery (WHR) is a low-carbon, environmentally-friendly technique, that recovers heat from industrial processes to produce energy or to heat households, businesses, industrial spaces, and even sports facilities (e.g., swimming pools). It is relevant mostly to data centres and units of measurement include tons of carbon dioxide equivalent [tCO2e] and kWh.

5.2.14.2 Results from desktop research

(BEREC 2023) reports waste heat recovery as an indicator with medium support from survey respondents, with 10 of them supporting this indicator. In addition, in (BEREC 2023) only 7 respondents mentioned that this is a very relevant indicator and 30 said it was somewhat relevant. The NRAs involved in the study indicated that WHR belongs to group B, i.e., indicators not collected by NRAs but with some support by companies.

Regarding telecom operators, the main application of waste heat recovery is in data centres and server farms used in telecom networks for virtualisation, cloudification, and operations (e.g., configuration management, fault management). In this context, the heat produced by electronic equipment (e.g., servers) can be reused for heating buildings (e.g., offices) co-located with server farms or other facilities. Consequently, GHG scope 2 and GHG scope 3 emissions can be lowered because there is less need for generating heating. The study (Laine 2020) has shown that GHG scope 3 can be more predominant than GHG scope 2, but this depends on how the company uses generated waste heat. This indicator is related to scope 3 because there is less need for heating of facilities. Adoption of this strategy is mainly the responsibility of telecom operators; depending on the placement of server farms and data centres the produced heat can benefit personnel of the company by warming up office facilities (e.g., placement of the personnel offices in the same building as the data centres) (Montagud-Montalvá 2023). Besides data centres, this technology can also be applied to base stations. For example, Nokia implemented liquid-cooled base station technology where waste heat was collected into liquid and transported over distances for other use cases, such as circulating the waste heat for building heating (Telecom Review 2022).

For the category of auditors, this is not one of the main indicators included in the European Environmental Footprint (EF). Nevertheless, re-use of waste heat can reduce GHG scopes 2 and 3 because it may lower the need for heating in offices and facilities.

Regarding the actual sustainability impact of this indicator, data centres are the main network elements, but also base stations in the RAN can be impacted (Telecom Review 2022) as shown in Table 26. Facilities are impacted because they are beneficiaries of waste heat.

Table 26 Sustainability impact (qualitative measure)

RAN	FAN	BB	DC	Organisation	Facility

[77] This is important given than two critical raw materials, i.e., Gallium used for RF and optoelectronic equipment and Germanium used for optical fibers, are now subject to unilateral export restriction by China.

Relevant			Very relevant	N/A	Beneficiary of the waste heat.

Concerning the standard(s) to be adopted for the measurement of WHR, the GHG protocol calculation tool for emissions in Scope 3 could be used because the recovery of waste heat can be used to lower GHG scopes 2 and 3.

Regarding the measurement metric, (BEREC 2023) indicated tons of carbon dioxide equivalent [(tCO2e] and saved kWh.

Table 27 provides a breakdown of our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also grouped by stakeholder category, e.g., telecom operator, or national regulatory authority, or telecom equipment vendor.

Table 27 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
Data centre operator or association (this is only for the data centres used for network operations and management including virtual distributed units and centralised units)	(Montagud-Montalvá 2023)	“Must Have”	Waste Heat recovery is mostly related to data centres.
National Regulatory Authority	(BEREC 2023)	“Should Have”	This indicator is in Group B, where no NRA is collecting information, but it has some support by companies (4 companies at the moment).
Third-party sustainability auditor or association	(BEREC 2023)	“Should Have”	This is not one of the main indicators included in the European Environmental Footprint (EF) but it has a positive impact on GHG scope 3, which is included in the EF.
Cross-cutting	(BEREC 2023)	“Should Have”	The level of support from the surveyed companies is based only on 10 companies.
Network equipment provider or	(No references found)	“Nice to Have”	No references for the relevance of this indicator for this category found.

association (NEPs)			
Network operator (Fixed)	(GSMA 2022)	"Should Have"	Network operators may have data centres.
Network operator (Mobile)	(Telecom Review 2022)	"Should Have"	Network operators may have data centres. In addition, heat can also be recovered from base stations.
Consumer/civil society association	(No references available)	"Nice to Have"	The authors of this report did not find references for the relevance of this indicator for consumers.
Software provider or association	(No references available)	"Nice to Have"	No references for the relevance of this indicator for software providers found.

5.2.14.3 Results from the survey

Network components and their relevance: 2 answers: RAN (50%), SF (50%).

Standardisation: 3 answers: ITU-T (33%), ETSI (33%), ISO (33%).

Audit: There were 3 answers indicating no audit.

Metrics: 3 answers: Tons of waste going to heat recovery treatment (33%), Tons of carbon dioxide equivalent (tCO2e) (33%), Recovered energy (kWh, MWh) (33%).

Implementation cost: One answer, with x < 0.1% for CAPEX and OPEX.

Agreement with proposed ranking: 74% of the survey respondents confirmed the "Nice to Have" classification.

5.2.14.4 Results from the stakeholder workshop

Most of the stakeholder workshop participants confirmed that waste heat recovery is a "Nice to Have" (NH) indicator. There could be possibilities for waste heat recovery in the network infrastructure, but it depends on local conditions.

5.2.14.5 Ranking and outlook for a future Code of Conduct

This indicator is not one of the main indicators at this moment, as NRAs are not collecting it and only a few companies are collecting it. This indicator is mostly related to data centres or large base stations that are co-located or in proximity of facilities that can benefit from heat reuse. Since heat reuse can lower energy consumption and GHG emissions scopes 2 and 3, techniques of heat reuse can be implemented to improve the other indicators.

5.2.15 Water usage / Water consumption

5.2.15.1 Definition

According to PEF (EC 2021), this indicator represents the relative amount of available water remaining per area in a watershed after the demand of humans and aquatic ecosystems has been met. It assesses the potential of water deprivation for either humans or ecosystems, building on the assumption that the less water remains available per area, the more likely another user will be deprived.

For telecommunications networks, this indicator mainly refers to the consumption of water for manufacturing equipment and cooling of operating equipment.

5.2.15.2 Results from desktop research

(BEREC 2023) reports water usage and consumption as an indicator with medium support from respondents but with a very significant number of companies supporting it, i.e., 35. In addition, in (BEREC 2023) 9 respondents mentioned that this is a very relevant indicator and 31 said it was somewhat relevant. The NRAs involved in the study indicated water usage and consumption as belonging to group A, which represents the indicators already collected by NRAs. In this case, both France and Belgium are collecting this indicator from companies or asking companies to report on it.

Among mobile communication providers and vendors, the authors of this report did not find specific references documenting water use. For example, it was reported that in 2022, the Chinese enterprise Huawei used 17 million metric tons of water, but it was mostly used to maintain the gardens of Huawei's properties, in the company's canteens, and for air conditioning (Statista 2023). Thus, it is difficult to have figures on the actual water consumption of network infrastructure. In a similar way, the authors of this report did not get data for the fixed network.

For data centres, they can use a significant quantity of water for cooling and humidity control. The reduction of water usage is an important indicator (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) because data centres are huge consumers of water. In (Time 2020), it is reported that in 2019 alone, Google requested, or was granted, more than 2.3 billion gallons of water for data centres in three different states, according to public records posted online and legal filings. Reference (Al Kez 2022) also reported that data storage alone can have a footprint of 5 l/GBytes in data centres and Microsoft used 3.96 Gigalitres (GL) of water in 2020, while Google utilized 21.5 Gl in 2021. Similar figures were provided in (Mytton 2021), which shows that a good percentage of water can be potable water (a company called DigitalReality reports consumption from potable water of 57 in 2019). In addition, (Mytton 2021) mentions that there are no such requirements for reporting water usage, and some companies do not want to disclose this information for competitiveness reasons. In the Data Centre Code of Conduct (EC JRC 2021a), optional measures are suggested, such as metering and use of “grey water” or rainwater. It was also noted in (ITU 2021a) that a large number of data centres are placed near largely populated areas, where the data is being consumed, and it is not rare that some of these data centres are located in areas already affected by draughts and high stress in aquifers needed for the people’s consumption, having to compete with the demand of large data centres.

For the category of auditors, water usage is one of the main indicators included in the European Environmental Footprint (EF), which is also included in all reference environmental databases (e.g., Ecoinvent, Sphera, CODDE, etc.). Therefore, this indicator is quite relevant for auditors.

Regarding the actual sustainability impact of water usage and consumption, we did not find specific data on the distribution of this indicator across the network elements, but from the previous references, it can be inferred that data centres and facilities are the largest consumers of water, while according to the knowledge of the authors of this report, other elements of the network are not reported in the literature. The summary on the impact is shown in Table 28.

Table 28 Sustainability impact (qualitative measure)

RAN	**FAN**	**BB**	**DC**	**Organisation**	**Facility**
Not reported	Not reported	Not reported	Very Relevant for the large water consumption	N/A	Can be quite relevant depending on the type of facility.

Concerning the standard(s) to be adopted to measure water usage, reference EN 50600-4-9 is suggested in (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022).

Regarding the measurement metric, (BEREC 2023) indicated that out of the 32 undertakings providing details on the measurement unit, 22 refer to cubic meters (m^3), whereas only 5 mention litres. 9 undertakings report difficulties, mostly related to lack of real-time data, the necessity to derive data from bills, or having no access at all to the water consumption of their suppliers. Only one respondent supported the indicator water usage effectiveness (WUE) (L/kWh) for cooling performance, which is also identified in (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022). This metric is also indicated in the EU Code of Conduct for DCs Best Practices[78]. WUE is also suggested by academics in (Mytton 2021).

Table 29 provides a breakdown of our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on stakeholder category, e.g., telecom operator, or national regulatory authority, or telecom equipment vendor.

Table 29 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
Data centre operator or association (this is only for the data centres used for network operations and management including virtual Distributed Units and centralized units)	(IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) (Time 2020) (Al Kez 2022) (Mytton 2021),	"Must Have"	Data centres are huge consumers of water, including potable water. Even if this indicator is not reported by telecom operators specifically for the telecom infrastructure, it would be useful to support such reporting.
National Regulatory Authority	(BEREC 2023) direct feedback at the workshop	"Must Have"	This indicator is in Group A of indicators, where at least two countries (France, Belgium) are collecting information.
Third-party sustainability auditor or association	(BEREC 2023), direct feedback at the workshop	"Must Have"	This is one of the main indicators included in the European Environmental Footprint (EF).
Cross-cutting	(BEREC 2023)	"Should Have"	The level of support from the surveyed companies is based only on 35 companies.
Network equipment providers or	(No references available)	"Should Have"	No data available.

[78] Data centres Code of Conduct, https://e3p.jrc.ec.europa.eu/communities/data-centres-code-conduct

association (NEPs)			
Network operator (Fixed)	(No references available)	“Should Have”	No data available.
Network operator (Mobile)	(No references available)	“Should Have”	No data available.
Consumer/civil society association	(No references available)	“Nice to Have”	There is no clear evidence that this indicator influences consumers on the provider choice.
Software provider or association	(No references available)	“Nice to Have”	The authors of this report did not find references for the relevance of this indicator for software providers.

5.2.15.3 Results from the survey

Network components and their relevance: From the survey, this indicator is distributed across different elements including the data centres of SF, with 17%, BB and FAN, with 17%.

Standardisation: ISO (28%) and ITU-T (24%) standards are predominant among the other standards. For standardisation gaps (8 responses), 38% indicated both significant standardisation gaps for data analysis and collection and 12% minor standardisation gaps.

Audit: Only 4 answers were provided, with half of them indicating voluntary audit.

Metrics: With 13 provided responses, the most important were Water Usage Effectiveness (38%), Cubic meters (m^3) (31%), Megaliters (24%) and Others (7%).

Implementation cost: All the provided responses were N/A.

Agreement with proposed ranking: A significant but not predominant number of respondents supported the assignment of this indicator to “Should Have”, with 59% of the responses. On the other hand, the other two recommended categories were almost evenly split between “Must Have” (21%) and “Nice to Have” (20%).

5.2.15.4 Results from the stakeholder workshop

Most participants in the stakeholder workshop confirmed that water use depletion is a “Should Have” (SH) indicator. Water use/depletion was not discussed in detail like other indicators, but it was reported that this indicator is relevant both for auditors and NRAs.

5.2.15.5 Ranking and outlook for a future Code of Conduct

The water usage/consumption indicator is primarily important for data centres considering their massive use of water. At the moment, companies owning and running data centres do not need to report this indicator. When it is reported, it is shared with more conventional use of water in the organisation facilities (e.g., offices), making it difficult to understand the actual impact of the telecom network. On the other hand, with the increased virtualisation and softwarization of telecom networks, the impact of data centres in telecom networks is likely to grow, rendering this indicator more important in future.

5.2.16 Land use

5.2.16.1 Definition

Land use is the size of land occupied or the area of buildings.

In the telecom sector, this indicator is mostly collected at company level, although it has also been reported in product and service level. It is also referring to the surface of the company's data centre or the surface that office buildings occupy.

For activities related to electronic communications, sustainability of the land use is typically high, since efficient network planning, use of existing infrastructure, practical implementation constraints (e.g., in urban areas), restrictions in deployment by local construction, and environmental legislation are examples of limiting land use in the telecom sector.

According to ISO 14031, land use can be reported as an energy environmental performance indicator and can be defined as the area or land used to produce one unit of energy. For the telecom sector, this can be translated as the area or land used per cell site, or per bitrate, or per mobile connection. This could provide some uniformity in this indicator and make it more relevant for the telecom sector.

5.2.16.2 Results from desktop research

The aim of this subsection is to report on findings for the land use indicator from desktop research, notably on 1) its prioritisation by different sources, indicating also the stakeholders providing the recommendation, 2) measuring or estimating its actual sustainability impact in the network, and 3) standards suggested by the desktop research for its assessment.

(BEREC 2023) reports land use as an indicator with medium support from the survey respondents, with 10 of them supporting this indicator. In addition, in (BEREC 2023) only 7 respondents mentioned that this is a very relevant indicator and 30 said it is somewhat relevant. The NRAs involved in the study indicated that land use indicator belongs to group B, i.e., the indicator is not collected by NRAs but has some support from companies.

Efficient land use by network infrastructures can have a positive impact on sustainability indicators too (i.e., the indicators can be related). For example, in (World Bank 2022), it is indicated that during network deployment, sharing existing physical infrastructure (such as ducts, poles, and masts) and microtrenching for fibre deployment can reduce the carbon footprint. Reduction of cooling and, thus, power consumption is another benefit of efficient land use. As mobile telecom operators often share building infrastructure like towers (Amponsah 2023), this indicator may be important for them. For example, Telefonica shares infrastructure to reduce land use (Telefonica 2023c).

This indicator is also important for data centres, whose facilities may occupy significant land for hosting server farms (Whitehead 2014).

For the category of auditors, land use is one of the main indicators included in the European Environmental Footprint (EF), which is also the one included in all reference environmental databases (e.g., Ecoinvent, Sphera, CODDE, etc). In addition, (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022) mentions that an amendment of the Eco-Management and Audit Scheme (EMAS Annex IV Amendment) regulation (EU Commission Regulation EU 2018/2026), which dates from January 9th 2019, defined the core indicators in the following key environmental areas: energy, material, water, waste, land use with regard to biodiversity, and emissions. Thus, this indicator is quite relevant for auditors.

Regarding the actual sustainability impact of land use, we did not find specific data on the distribution of this indicator across network elements, but from the previous references, it can be inferred that RAN, FAN, data centres and facilities are the most relevant network elements for this indicator, as shown in Table 30 below.

Table 30 Sustainability impact (quantitative measure)

RAN	**FAN**	**BB**	**DC**	**Organisation**	**Facility**
Very relevant because of towers	Relevant for deployment of the main access	Relevant for hosting switches and	Very relevant for large data centres	N/A	Can be quite relevant depending on

for mobile telecommunications	nodes whereas most of the cabling is underground	routers and optical nodes			the type of facility

Concerning the standard(s) to be adopted to measure land use, reference EN50600 is suggested in (IDEA Consult and Öko-Institut for the European Commission DG CNECT 2022).

Regarding the measurement metric, (BEREC 2023) indicated "building area, size of the land occupied", square meters, and number of building units.

Table 31 provides a breakdown of our assessment of the importance of this indicator for different types of stakeholders. The breakdown is also based on the stakeholder category, e.g., telecom operator, or national regulatory authority, or telecom equipment vendor.

Table 31 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
Network operator (Mobile)	(Amponsah 2023), (Telefonica 2023c)	"Must Have"	The large number of towers for base station support makes this indicator very relevant for mobile telecom operators.
Third-party sustainability auditor or association	(BEREC 2023), direct feedback at the workshop	"Must Have"	This is one of the main indicators included in the European Environmental Footprint (EF).
Consumer/civil society association	(Siegrist 2005)	"Should have"	Placement of mobile base stations can have an impact on landscape and visual impact, especially in areas of historic, artistic, and naturalistic value. Besides this, civil associations are mostly concerned by electromagnetic fields (EMFs).
Cross-cutting	(BEREC 2023)	"Should Have"	The level of support from the surveyed companies is based only on 10 companies.
Data centre operator or association (this is only for the data centres used for network operations and management including virtual Distributed	(Whitehead 2014).	"Should Have"	Large data centres may occupy a significant amount of land. In the case of telecom operators, the data centre may not be as large as those of Amazon or Google, but they may still rely on large data centres, and the number of vDUs and vCUs can be significant.

Units and centralized units)			
National Regulatory Authority	(BEREC 2023) direct feedback at the workshop	"Should Have"	This indicator is in Group B, where no NRA is collecting information, but some companies are supporting it.
Network operator (Fixed)	(World Bank 2022)	"Should Have"	Hosting of large switches and routers can occupy land. Last km access networks are also quite extensive, but most of the cabling is underground and does not occupy land.
Network equipment provider or association (NEPs)	(No references available)	"Nice to Have"	The authors of this report did not find references for the relevance of this indicator for this category.
Software provider or association	(No references available)	"Nice to Have"	The authors of this report did not find references for the relevance of this indicator for software providers.

5.2.16.3 Results from the survey

Network components and their relevance: The responses were not decisive. One for each component.

Standardisation: Only one answer refers to ISO standards. Significant standardisation gaps were confirmed both for data collection and analysis (40%).

Audit: No audit is reported**.**

Metrics: Square meters or square kilometers based on 2 responses**.**

Implementation cost: Not available.

Agreement with the proposed ranking: 74% of the responses confirmed the attribution to "Nice to Have".

5.2.16.4 Results from the stakeholder workshop

Most stakeholder workshop participants confirmed that land use is a "Nice to Have" (NH) indicator. Mobile telecom operators discussed the need for infrastructure sharing for base stations, especially in urban areas, as a way to also mitigate land use.

5.2.16.5 Ranking and outlook for a future Code of Conduct

Land use is not included in the main indicators at this moment, as NRAs are not collecting it. Companies are supporting this indicator to minimize costs associated with the construction of new towers for mobile communication. Network infrastructure sharing is a means to reduce the land use impact in RAN deployment. Currently, there are two trends that can negatively impact land use. 5G networks using the 3.6 GHz frequency band and millimetre wave may need a higher number of base stations, especially in urban environments, due to limited coverage and high blockage of the radio signal. Also, virtualization of telecommunications networks may require an increase in the number of data centres or their resources.

5.2.17 Eco toxicity

5.2.17.1 Definition

The emission of substances, such as heavy metals, can have an impact on the ecosystem, including biodiversity and water pollution. Assessment of toxicity is based on maximum tolerable concentrations for ecosystems.

Regarding the telecom sector, eco toxicity has been reported using several metrics, such as the occupancy of protected areas, the percentage of sites located in these areas, and the number of m^2 of facilities in these areas. The listing of sites in the Natura 2000[79] network of Europe's most valuable and threatened species and habitats can be used to define the protected areas. Other metrics include the concentration of substances and the volume of wastewater (m^3).

5.2.17.2 Results from desktop research

The aim of this subsection is to report on findings for the eco toxicity indicator from desktop research, notably on 1) its prioritisation by different sources, indicating also the stakeholders providing the recommendation, 2) measuring or estimating its actual sustainability impact in the network, and 3) standards suggested by the desktop research for its assessment.

(BEREC 2023) reports eco toxicity as an indicator with low support from survey participants, with only 8 respondents supporting it and 35 respondents not collecting it. In addition, in (BEREC 2023) only 5 respondents mentioned that this was a very relevant indicator and for 23 respondents it was not relevant. The NRAs involved in the study indicated eco toxicity as belonging to group C, which represents the indicators not collected by NRAs and with low support from companies. In addition, in (BEREC 2023), the eco toxicity indicator is disregarded as not having a relevant impact on the sector by 17 survey responders.

From the point of view of telecom operators, most of them have not collected this indicator so far. This indicator is also related to other "Must Have" indicators like e-Waste in relation to the disposal of network equipment. For telecom operators, this indicator can also be related to land use in the placement of base stations and facilities for routers, switches and data centres, and it is partially addressed by the land use indicator.

In (NGMN 2021b), it is also reported that "The material toxicity footprint for the ICT and Entertainment & Media sectors was estimated to represent about 3% of the impacts related to the global use of the selected materials (including also cement)". Eco-toxicity can be relevant to the RAN due to the potential use of protected areas (but this impact may be limited because protected areas do not have a high density of customers).

On the other hand, from the point of view of network equipment manufacturers, the production of electronic equipment and its final disposal may have potential to pollute the environment, and this can be related to this indicator (Pino 2017). A lifecycle assessment of network equipment may provide valuable information on the impact of this indicator for each phase. (Pino 2017) reports on such an assessment for a BSP 8100 cabinet (*BSP 8100* is a data centre infrastructure produced by Ericsson).

For the category of auditors, this is one of the main indicators included in the European Environmental Footprint (EF) especially for freshwater pollution.

Data centres can be significant consumers of water (e.g., for cooling purposes), but they do not necessarily pollute it. The impact on the use of water is already addressed by the water usage indicator (Murino 2023).

It is difficult to provide an estimate of the sustainability impact across all the network elements of the telecom infrastructure because this indicator is mostly related to the manufacturing and disposal of network equipment.

Table 32 provides a breakdown of our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on the category of the stakeholder, e.g., telecom operator, or national regulatory authority, or telecom equipment vendor.

[79] https://natura2000.eea.europa.eu/.

Table 32 Indicator relevance for categories of stakeholders

Category of stakeholder	References	Priority	Summary
Third-party sustainability auditor or association	Feedback from the workshop	"Must Have"	This is one of the main indicators included in the European Environmental Footprint (EF).
Data centre operator or association (this is only for the data centres used for network operations and management including virtual Distributed Units and centralized units)	(Murino 2023)	"Should Have"	Potential for water pollution or disposal of electronic equipment, which can be potentially polluting.
Network equipment provider or association (NEPs)	(GSMA 2022b)	"Should Have"	Network equipment vendors could be impacted by this indicator, especially in relation to the production phase of the lifecycle assessment.
Consumer/civil society association	(NGMN 2021b)	"Nice to Have"	There is a growing perception among consumers and citizens about eco-toxicity, but (NGMN 2021b) reports that ICT accounts for only 3% of the overall eco-toxicity impact.
Cross-cutting	(BEREC 2023)	"Nice to Have"	There are only 8 respondents supporting this indicator and 35 respondents not collecting it from (BEREC 2023).
National Regulatory Authority	(BEREC 2023)	"Nice to Have"	This indicator is in Group C where no NRA is collecting information and there is limited support from companies.
Network operator (Fixed)	(No available references)	"Nice to Have"	No reported data on this indicator.

Network operator (Mobile)	(No available references)	“Nice to Have”	No reported data on this indicator.
Software provider or association	(No available references)	“Nice to Have”	The authors of this report did not find references for the relevance of this indicator for software providers.

5.2.17.3 Results from the survey

Network components and their relevance: For this indicator there was a limited number of answers: only 10 answers with a predominance for the backbone and the fixed access network. BB (20%), FAN (20%), RAN (10%), Facility (10%), SF (10%), NSR (10%), Organisation (10%), Do not know (10%).

Standardisation: To identify the standards families, there were 3 answers: GRI (33%), GHG protocol (33%) and ISO (33%). For the standardisation gaps, there were 7 answers: significant standardisation gaps for data collection (43%), significant standardisation gaps for data analysis (29%) and no standardisation gaps (29%). The majority indicated that there are significant standardisation gaps.

Audit: There were 3 answers indicating no audit.

Metrics: 6 answers: area (m^2, km^2) of installations in areas protected or of high biodiversity (33%), percentage (%) of sites in areas protected or of high biodiversity (17%) and cubic metres (m^3) of waste water (17%). Other (33%)

Implementation cost: 3 answers with N/A.

Agreement with the proposed ranking: 74% of the survey respondents confirmed the “Nice to Have”.

5.2.17.4 Results from the stakeholder workshop

This indicator was scarcely discussed at the workshop.

5.2.17.5 Ranking and outlook for a future Code of Conduct

This indicator is not one of the main indicators at this moment, as NRAs are not collecting it, and only very few companies are collecting it. In addition, some potential impact of this indicator can also be addressed by other indicators like e-Waste, water consumption, or land use.

5.2.18 Human toxicity

5.2.18.1 Definition

The emission of substances (e.g., heavy metals) can have an impact on human health. Assessment of toxicity is based on concentrations of those substances in the air, soil, and water. The tolerable daily intake and acceptable daily intake for human toxicity are set in international guidelines.

For the telecom sector, human toxicity can include data on concentrations of substances and the volume of air pollutants (e.g., the Carbon Dioxide Equivalent in tons (tCO2e)). Moreover, exposure to electromagnetic fields (EMF) is also reported as an indicator of human toxicity.

5.2.18.2 Results from desktop research

(BEREC 2023) reports human toxicity as an indicator with low support from survey participants, with only 7 respondents supporting this indicator and 41 respondents not collecting it. In addition, in (BEREC 2023) only 4 respondents mentioned that this was a very relevant indicator and 26 were not relevant. The NRAs involved in the study indicated water usage and consumption as belonging to group C, which represents indicators not collected by NRAs and with low support from companies.

From the point of view of telecom operators, most have not collected this indicator so far. For the EMFs, most if not all operators mention that they are compliant with regulation and policy on EMFs, which would be within the scope of a precise and specific regulation.

For the category of auditors, this is one of the main indicators included in the European Environmental Footprint (EF): Human toxicity and Human health. EMFs in radio frequencies are non-ionizing radiations, which are investigated in regulatory frameworks around the world, which define maximum emission levels (ICNIRP 2020).

Regarding the actual sustainability impact of this indicator, EMFs are emitted from the RAN, i.e., the radio links between users and base stations, and the radio links which replace fixed links in rural areas. For pollution aspects, telecommunications equipment should already be environment-compliant, and their disposal is already addressed in the e-Waste indicator. The summary of the sustainability impact is shown in Table 33.

Table 33 Sustainability impact

RAN	FAN	BB	DC	Organisation	Facility
Relevant (EMF)	N/A	N/A	N/A	N/A	N/A

Concerning the standard(s), no standards were indicated either in (BEREC 2023) or other references. The feedback from the survey was also quite limited.

Regarding the measurement metric, (BEREC 2023) indicated tons of air pollutants (e.g., NOx, SO_2, etc.) emitted, EMF measurements, and kg or ton of CO_2 equivalent.

Table 34 provides a breakdown of our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on the stakeholder category, e.g., telecom operator, national regulatory authority, or telecom equipment vendor.

Table 34 Indicator relevance for categories of stakeholders

Category of stakeholder	References	Priority	Summary
Consumer/civil society association	(Jung 2015)	"Must Have"	There is a growing perception among consumers and citizens for EMF, and this has become a sensitive topic.
Network operator (Mobile)	(ICNIRP 2020)	"Should Have"	Compliance with EMF regulations is relevant for mobile telecom operators, but this is already addressed in other regulatory processes.
Third-party sustainability auditor or association	Feedback from the workshop	"Must Have"	This is one of the main indicators included in the European Environmental Footprint (EF).
Cross-cutting	(BEREC 2023)	"Nice to Have"	There are only 7 respondents supporting this indicator and 41 respondents not collecting it from (BEREC 2023).

Data centre operator or association (this is only for the data centres used for network operations and management including virtual Distributed Units and centralized units)	(No available references)	“Nice to Have”	No reported data on this indicator.
National Regulatory Authority	(BEREC 2023)	“Nice to Have”	This indicator is in Group C where no NRA is collecting information and there is limited support from companies.
Network equipment providers or association (NEPs)	(No available references)	“Nice to Have”	Network equipment vendors must be compliant with environmental regulations in general, but the authors of this report did not manage to find relevant material.
Network operator (Fixed)	(No available references)	“Nice to Have”	No reported data on this indicator. Theoretically, the EMF aspects could be related to the rare fixed radio links used in rural areas of the fixed telecommunications infrastructure.
Software provider or association	(No available references)	“Nice to Have”	The authors of this report did not find references for the relevance of this indicator for software providers.

5.2.18.3 Results from the survey

Network components and their relevance: The survey got 10 answers with RAN and FAN with 20% and the other components at 10%.

Standardisation: Only 3 answers: GHG protocol (33%), GRI (33%), ISO (33%). 6 responses were provided for the standardisation gaps. There were significant standardisation gaps for data analysis and collection at 33%.

Audit: There were only 2 answers, split between no audit and voluntary self audit.

Metrics: 6 responses: Tons of Air Pollutant (33%), Tons of water pollutant (50%), Emitted electromagnetic field (17%)

Implementation cost: Only three answers.

Agreement with the proposed ranking: 72% of the survey respondents confirmed “Nice to Have”.

5.2.18.4 Results from the stakeholder workshop

This indicator was scarcely discussed at the workshop.

5.2.18.5 Ranking and outlook for a future Code of Conduct

This indicator is not one of the main indicators at this moment, as NRAs are not collecting it and only a few companies are collecting it. EMF aspects are relevant, but they are already addressed by international, European, and national regulations.

5.2.19 Eutrophication

5.2.19.1 Definition

As defined by the European Environmental Agency, eutrophication is a process of pollution that occurs when a lake or stream becomes overly rich in plant nutrients. As a consequence, it becomes overgrown with algae and other aquatic plants. The plants die and decompose. Due to decomposition processes, the plants remove oxygen from the water and the lakes, rivers, or streams become lifeless. Nitrate fertilizers, which drain from farmland, and nutrients from animal waste and human sewage are the primary causes of eutrophication. Emissions of ammonia, nitrates, nitrogen oxides and phosphorous to air or water all have an impact on eutrophication.

5.2.19.2 Results from desktop research

(BEREC 2023) reports eutrophication as an indicator with low support from the survey participants, with only 1 respondent supporting this indicator and 31 respondents not collecting it. In addition, in (BEREC 2023) only 3 respondents mentioned that this was a very relevant indicator and 31 mentioned that this was not relevant. The NRAs involved in the study indicated eutrophication as belonging to Group C, which represents the indicators not collected by NRAs and with low support from companies. In addition, in (BEREC 2023), eutrophication is disregarded as not having a relevant impact on the sector by 31 undertakings.

From the point of view of the telecom operators, most of them have not collected this indicator so far. This indicator is also related to other higher priority indicators like e-Waste in relation to the disposal of network equipment to avoid pollution. Data on eutrophication can be reported at company level, although the telecom sector contribution to eutrophication can be considered minimal (GreenIT 2021). Even academic studies like (Sheck 2013) show that the eutrophication impact of telecommunications networks is less than 1% when compared to the other indicators in the LCA.

From the point of view of network equipment manufacturers, the production of electronic equipment and its final disposal may have the potential to pollute the environment, but in general, this is unrelated to nitrate fertilizers, and other forms of pollution are addressed by other indicators like eco-toxicity.

For the category of auditors, this is one of the main indicators included in the European Environmental Footprint (EF).

Data centres can be significant consumers of water, but they do not necessarily pollute it regarding nitrate fertilizers. Other pollutants related to the disposal of IT equipment (in particular their metal components) are possible (Flucker 2018) but these pollutants are discussed in other indicators like e-Waste, eco-toxicity and human toxicity. The impact on the use of water is already addressed by the water usage indicator.

It is difficult to provide an estimate of the sustainability impact across all the network elements of telecom infrastructure because this indicator is mostly related to the manufacturing and disposal of network equipment.

Table 35 provides a breakdown of our assessment of the importance of this indicator for the different types of stakeholders. The breakdown is also based on the stakeholder category, e.g., telecom operator, national regulatory authority, or telecom equipment vendor.

Table 35 Indicator relevance for categories of stakeholders

Category of stakeholder	**References**	**Priority**	**Summary**
Third-party sustainability auditor or association	Feedback from the workshop	"Must Have"	This is one of the main indicators included in the European Environmental Footprint (EF).
Data centre operator or association (this is only for the data centres used for network operations and management including virtual Distributed Units and centralized units)	(Flucker 2018)	"Should Have"	Potential for water pollution or disposal of electronic equipment, but these aspects are mostly addressed in other indicators like e-Waste, eco-toxicity, and human toxicity.
Network equipment provider or association (NEPs)	(Sheck 2013)	"Should Have"	Network equipment vendors could be impacted by this indicator, especially in relation to the production and disposal phases of the lifecycle assessment.
Consumer/civil society association	(NGMN 2021b)	"Nice to Have"	There is a growing perception among consumers and citizens about eutrophication, but the authors of this report did not find specific references to the impact of telecommunications systems on eutrophication.
Cross-cutting	(BEREC 2023)	"Nice to Have"	There is only 1 respondent supporting this indicator and 31 respondents not collecting it from (BEREC 2023).
National Regulatory Authority	(BEREC 2023)	"Nice to Have"	This indicator is in Group C where no NRA is collecting information and there is limited support from companies.
Network operator (Fixed)		"Nice to Have"	No reported data on this indicator or reported minimal impact.
Network operator (Mobile)	(No available references)	"Nice to Have"	No reported data on this indicator or reported minimal impact.

Software provider or association	(No available references)	"Nice to Have"	The authors of this report did not find references for the relevance of this indicator for software providers.

5.2.19.3 Results from the survey

Network components and their relevance: Low number of responses: 9, and they were spread across various network components. BB (11%), FAN (22%), RAN (11%), Facility (11%), SF (11%), NSR (11%), Organisation (11%), do not know (11%).

Standardisation: Only 4 answers, GHG Protocol (25%), ISO (50%), Global Reporting Initiative (25%).

Audit: Only 2 responses indicate no audit.

Metrics: Only 6 answers: pH, biological oxygen demand (BOD), chemical oxygen demand (COD) (17%), dissolved oxygen (17%), total nitrogen, total phosphorus, suspended solid (mg/l) (33%), weight (kg) of phosphate (PO_4) equivalent (33%).

Implementation cost: N/A

Agreement with the proposed ranking: 80% of the responses confirmed the "Nice to Have" ranking.

5.2.19.4 Results from the stakeholder workshop

This indicator was scarcely discussed at the workshop.

5.2.19.5 Ranking and outlook for a future Code of Conduct

This indicator is not one of the main indicators at this moment, as NRAs are not collecting it and only a few companies are collecting tit. In addition, some potential impact of this indicator can also be addressed by other indicators like e-Waste, eco-toxicity, and human toxicity.

6 Conclusions for the indicators and recommendations for a future EU Code of Conduct for the sustainability of telecommunications networks

This study has reviewed a wide range of possible indicators for representing the sustainability of telecommunications networks and assessed their impact along energy, climate and environmental dimensions as well as aspects of practical feasibility regarding the collection and calculation of reporting data. The selection of the most appropriate indicators took into account ongoing activities in this area and parallel studies (especially the sustainability indicators study led by BEREC) as well as various stakeholder positions and reports, including from telecommunications operators, vendors, auditors and national authorities. On the basis of a targeted survey conducted in May-June 2023, additional desktop research, and a comprehensive stakeholder workshop on 10 October 2023, the report prioritised the main indicators that could be considered to track the sustainability impacts of telecommunications networks and support the development of a Code of Conduct by 2025.

The below lists key recommendations for a future Code of Conduct based on the results of the analyses in this report.

- Initial focus on “Must Have” indicators but openness to change: The first release of the Code of Conduct should be focused on the "Must Have" indicators with no major standardisation gaps, in order to select the most appropriate standards and processes to be followed by stakeholders to collect data and report sustainability information. Other indicators (such as the ones labelled “should have” and “nice to have” in this report) could be provided by the adhering parties on an optional basis. As standardisation evolves and the challenges of the data collection are overcome, the Code of Conduct could be updated and additional indicators included. Stakeholders should continue to strive developing processes and standards to close gaps and improve transparency.
- Role of specific network elements and their technological evolution: The use of standards to collect data from the network components for each indicator should take into consideration that different network components may require different sets of standards (e.g., data centres from base stations in the RAN of a cellular network). The Code of Conduct should prioritise those standards that capture best the connectivity sector’s transition towards cloud-edge architectures that are increasingly managed through algorithms.
- Links to policy initiatives: The future Code of Conduct should drive the connectivity sector to measure and follow KPIs as well as to implement best practices for taking action to reduce the sustainability footprint. Thus, it could serve as a reference point for policy initiatives in the field (e.g., on emission reduction targets and trajectories, EU Taxonomy, eco-design of equipment, transparency towards end-users to alter purchasing and usage patterns, etc.).
- Other indicators and interrelations: While this report sought to map the main indicators relevant for the sustainability of telecommunications networks, there may be others that merit a more in-depth analysis. An example is raw material depletion, as briefly mentioned in section 5.2.13. Moreover, the interdependence between indicators could be taken more into account, to ensure that improving on certain indicators does not have a negative impact on others (for example, energy efficiency in relation to equipment lifespan, reconditioning or reparability).

Stakeholders are invited to react on the substance of this report with a view to preparing the ground for a Code of Conduct, which should be finalised by the end of 2025. There is no time to lose for additional efforts to drive down the sustainability impact of telecommunications networks.

Annex A. Report on the Stakeholder workshop on Identifying common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs)

A. 1 Location of the workshop

This was a hybrid meeting with the physical location in Brussels, 10 October 2023

Conference room AB / 2.B, Albert Borschette Conference Center Rue Froissart 36, Brussels, Belgium and the remote webmeeting tool WebEX.

A.2 Executive summary of the stakeholders' workshop

The workshop provided a forum to discuss the preliminary study findings with stakeholders. Stakeholders overall agreed with the proposed indicator ranking but provided additional nuances, such as for the renewable energy indicator and the role of power purchase agreements. Stakeholders pointed to a discrepancy between indicators, which are established and for which data can relatively easily be collected and indicators, which are not (yet) established but have an impact on sustainability (e.g., indicators on raw materials and multi-criteria Life Cycle Assessments (LCAs)). Other trade-offs related to the role of legacy infrastructures (e.g., higher energy use of such infrastructures versus positive environmental impact when extending their lifetime). EU harmonisation activities in telecoms sustainability would be welcome, but stakeholders pointed to difficulties when comparing different geographies (currently, operators would mainly compare with themselves in a given geography). Smaller operators mentioned that they may find it difficult to gather data on some 'must have' indicators that large operators are able to gather (e.g., scope 3 emissions and recyclable products, where there would still be standardisation gaps). Some stakeholders underlined the need to work on quantifying the enabling effect of telecoms on other sectors, which is however not in scope of the study underlying the workshop. As a lesson learned from the existing Data Centre Code of Conduct, auditors mentioned that its wording had to be changed to make it auditable.

It was also noted the need to define a methodology across different indicators. From this point of view, ADEME has put together and applied to the French telecoms (under the anti-waste (AGEC) law) a very good example of PCR, which could be eventually extended at EU level with additional contributions from other member states.

A.3 Detailed report of the workshop

Number of participants

Approximately 80 in total (30 physical and 50 online.

Background

This stakeholder workshop on sustainability indicators was a milestone in the study currently done by DG CNECT and DG JRC to identify the most suitable indicators for telecommunications networks.

The workshop aimed at collecting input and feedback from the stakeholders in the telecommunications sector on a number of questions including: Which should be considered the most relevant sustainability indicators for reporting? What are the main challenges for stakeholders for the implementation of these indicators? How could the work by auditors be supported? The workshop also had the objective of providing a perspective on the various parallel studies conducted by stakeholders or stakeholder associations (e.g., BEREC, GSMA), which would be useful for the Commission to move towards a Code of Conduct for the telecommunications sector by 2025.

The study builds on the results of an EU survey conducted by DG JRC from 26 May to 23 June 2023 where similar feedback was collected. The results of the survey were presented in this workshop.

Agenda

The agenda of the workshop is presented below. The key elements of the workshop were the presentations by DG CNECT, DG JRC, BEREC (which is conducting a similar study on sustainability indicators on telecommunications networks) and the two panel sessions: the first one with telecom operators and vendors, and the second one with government representatives and auditors.

Time	Presenter	Topic
09:00-09:05	DG CNECT Coordinator	Welcome remarks
09:05-9:15	Johannes THEISS, Team Lead – Policy Coordination, Future Connectivity Systems, DG CNECT	Setting up the context for the identification of sustainability indicators for the provision of electronic communications services (ECSs)
09:15-09:40	DG JRC	Detailed presentation of the study findings
09:40-10:00	Participants	Q&A on the study findings.
10:00-10:30	Break	
10:30-11:50	First Panel Session (moderated by DG JRC)	Panel session with the perspective from operators and vendors. Panellists: • Daniel Alberto Maniega (Telefonica-GSMA) • Sølvberg Tina Hageberg (Telenor) • Azeddine Gati (Orange) • Mats Pellbäck Scharp (Ericsson) • Pinar Serdengecti (ECTA)
11:50-13:30	Lunch break	
13:30-13:45	Presentation by BEREC representative Sandrine Elmi Hersi	Presentation on the ongoing work on sustainability indicators
13:45-14:00	Participants	Q&A on presentation by BEREC
14:00-15:20	Second Panel Session (moderated by DG CNECT)	Panel session on the perspective from national authorities and stakeholders beyond telecoms. Panelists: • Lois Ponce (ARCEP) • Julia Meyer (ADEME) • Martin Michelot (TIC-COUNCIL) • Gillo Malpart (Mavana) • Bernd Sörries (WIK-Consult)
15:20-15:50	DG CNECT and DG JRC	Interactive debate among workshop participants on:

		1) How to select the optimal indicators for measuring the sustainability of telecoms networks (also using web interactive tools like slido) 2) Identifying the potential pitfalls/challenges for the deployment of indicators 3) Gathering recommendations for the development of a future Code of Conduct
15:50-16:00	DG CNECT and DG JRC	Closure of the meeting and next steps

Goals of the workshop

The workshop had the goal to:

- Identify the key sustainability indicators for telecommunications networks and/or consolidate the recommendations from the survey and the report on priority indicators.
- Collect input and feedback from the main stakeholders, who were present at the workshop on how to go forward on a Code of Conduct for telecommunications networks in the 2025 timeframe, which can be complementary to the already published Codes of Conduct (mostly coordinated by the JRC) for data centres and broadband equipment.
- Identify key standardisation or metric gaps, which can hamper the work by auditors or telecom operators to report on sustainability indicators in the future.
- Identify ongoing activities in this area and parallel regulatory actions to create synergies and avoid overlaps.

Introductory Remarks

The workshop started with the keynote speech by the Deputy Head of Unit of DG CNECT.E.1, Agustin Diaz-Pines, who introduced the context of the joint work of DG CNECT and DG JRC, the objectives of the workshop and the agenda. Then, Johannes Theiss of DG.CNECT.E1 described in detail the main objectives of the ongoing study and the plan towards the definition of a Code of Conduct for sustainability indicators in telecommunications networks.

Detailed presentation of the study findings

Following the agenda, Gianmarco Baldini (DG JRC) presented the key findings from the study, with a particular focus on the results from the EU Survey, which ran from 26 May to 23 June 2023, where the feedback from 44 participants from different categories of stakeholders was provided. The survey participants mostly confirmed the initially proposed ranking of the sustainability indicators, which had built on a study by the Body of European Regulators for Electronic Communications (BEREC) (BEREC 2023), which was published on 12 October (two days after this workshop). The parallel BEREC study helped to narrow down the list of sustainability indicators on which the analysis should focus. In addition, for each sustainability indicator, the survey results provided insights concerning aspects such as the standardisation gaps for each indicator, which metrics are used most, and what types of audits are conducted (if any). In addition, the JRC presented their own analysis of each indicator, which was based on the input from other sources (including BEREC, GSMA, World Bank) and an evaluation of on the challenges to implement each indicator according to different evaluation criteria.

There were a number of questions and answers on the study findings. In particular:

- Question from the audience: *Why are scopes GHG 1,2,3 considered in the study*? Answer: The different scopes were considered because they can be less or more relevant for a telecommunications network (some scopes are related to an organisation overall). Moreover, each scope provides a different perspective on the GHG emissions of telecommunications networks (e.g., energy consumption of the network components or GHG produced by the maintenance personnel). A participant pointed out that justifications to be included as key indicator are weaker for GHG scope 3.

- Question from the audience: *How to define a target for energy consumption*? Answer: This is not for the study to define, and it may not even be in scope of the Code of Conduct in the 2025 timeframe.
- Question from the audience: *Why establish rankings between Must Have (MH), Should Have (SH) and Nice to Have (NH) indicators*? Answer: There is a need to assess the feasibility as well as the relevance for telecom, and focus the number of indicators accordingly.
- Question from the audience: *How does the new code of conduct relate to the existing code of conduct regarding equipment vs. network?* Answer: The existing codes of conduct (CoC) cover on-site equipment and data centres. The new CoC should complement and not duplicate the existing CoCs, because its focus will be on networks. There is a potential overlap between the data centres used at the application layer (including for 5G applications) and the new computational resources (e.g., in server farms) deployed for supporting 5G network operations.
- Question from the audience: *Were avoided emissions considered in the list of indicators?* Answer: The question is not entirely clear. If the objective of the question is related to the positive sustainability impact of the services provided by the network, this is not in scope of the study.
- Question from the audience: Why is toxicity of hardware a nice to have indicator, or more in general, why are R-strategies (indicators related to refurbished, repaired equipment) only at should have level? Answer: This survey captures survey respondents' priorities. When addressing some indicators, other indicators may be covered indirectly. Some prioritisation is necessary to focus the analysis. This does not mean that these indicators are not important. The question is rather, if we can measure certain indicators and if their sustainability impact matters for telecoms networks.

Question from the audience: *Questions in the survey on indicator ranking were not open questions, but leading questions?* Answer*:* The questions related to ranking sought to validate ranking results by other studies (notably BEREC 2023), complementing instead of repeating them. Stakeholders could choose between agreeing with the preliminary ranking or propose a different ranking per indicator.

First Panel Session (moderated by DG JRC)

The panel sessions were structured in such a way that each panellist could provide a key message of short duration (5 minutes). The rest of the time (which was the majority of the panel session time) was based on interactive discussions with questions proposed alternatively by the EC (DG CNECT/DG JRC) and the audience (both virtual and online).

- Opening statement from the GSM Association or GSMA (Daniel Alberto Maniega from Telefónica)

The GSMA is a non-profit industry organisation that represents the interests of mobile network operators worldwide.

GSMA explained that sustainable finance is a key aspect for telecoms operators. As such the link to the EU taxonomy is understandable, but a prioritisation of the main indicators is needed (e.g., ecotoxicity may not be very relevant). The reason why it is important to focus on 'must have' indicators is because each large telecom operator has to maintain a huge number of sites. Telefónica has 6000 buildings and 40000 base stations. The data collection and analysis for many indicators would be unmanageable even for a large company, which requires focus. The GSMA metrics defined for mobile would include: carbon 'must have' indicators, as identified in the study, which are well defined, power usage efficiency, and ESG indicators (which have been defined by GSMA and are close to 'must have' indicators identified in the study). Indicators not included in the 'must have' category would not be clearly defined and quite difficult to track.

- Opening statement from Telenor (Sølvberg Tina Hageberg)

Telenor is a Norwegian telecom operator. Telenor highlighted that it is important to measure the actual impact (seen by the sector as a whole) of the identified indicator. There would also be a need to support more and incentivise the allocation of resources and efforts towards a circular economy throughout the lifecycle. For example, deployment methods in telecoms networks could also be relevant: microtrenching or plowing would have a lower carbon footprint in comparison to other methods quite commonly used, like deep excavation (e.g., microtrenching generates 6 or 7 times less carbon than deep excavation).

- Opening statement from Orange (Azeddine Gati):

Orange is a French telecom operator. According to Orange, many telecoms operators are going forward towards initiatives like the CDP (Carbon Disclosure Project). One key request was that KPIs have to be precise (e.g., it would not be clear what is behind the proposed renewable energy indicator and what has to be measured) and harmonised across countries. This latter aspect can be quite difficult, because comparing the performance of the sustainability indicators across networks is difficult, as legislation differs across Member States (e.g., need for different battery capacity per node in France vs. Slovakia). The support for research would also be important and it could be a KPI itself. Eventually, it would be important for government agencies to formulate proper incentives to reduce GHG emissions (in particular scope 3).

- Opening statement from Ericsson (Mats Pellbäck Scharp):

Ericsson is a Swedish telecom equipment vendor. Regarding the energy efficiency indicator, Ericsson pointed out that measuring energy efficiency at network level is more effective than comparing hardware equipment, because the actual energy consumption and energy efficiency depends on how the equipment is used in the network. Ericsson also pointed out that ITU and IEA use Ericsson and Telia data, so the EU should use that research as well.

Another key aspect was that it is quite difficult to compare networks with each other, especially if they are in different Member States (with different topographies or climate). Using the same KPIs may yield different results that are dependent on the measuring environment. Despite attempts to compare by organisations like the GSMA, there would clearly be a standardisation gap to harmonise between different networks and geographies. The definition of a CoC should take this aspect into consideration and not penalise telecoms operators for aspects outside their control (e.g., geography and orography of the land, users' density and distribution).

Ericsson recommended to focus on a few key indicators (among which energy efficiency and emission reduction scopes 1-3), also to keep the burden of reporting proportionate for telecoms operators. From this point of view, the identification of the "must have (MH)" indicators in the study is quite useful.

- Opening statement from European Competitive Telecommunications Association or ECTA (Pinar Serdengecti).

ECTA is a pan-European telecoms association representing alternative (i.e. non-incumbent) operators and promoting market liberalisation and competition in the sector.

ECTA agreed with most of the proposed MH indicators, apart from GHG scope 3 and recyclable products, which would not yet be sufficiently standardised but may increase in importance going forward. The following indicators were considered the most important for ECTA: energy consumption, energy efficiency, carbon emissions scope 1 and 2, use of renewable energy, eWaste production. ECTA suggested that focusing for the first release of the Code of Conduct to the MH indicators with no major standardisation gaps and to make all the remaining indicators voluntary would be key in mitigating a market imbalance between big players on one hand and medium and small players on the other and to enable all parties to adhere to the new Code of Conduct.

Another aspect important for ECTA was to assess how the indicators could contribute to making other sectors more sustainable (enabling effect). According to ECTA, the Commission should work with BEREC on this. As regards the final study report, it should clarify the source of the feedback by stakeholder category (national regulator, consumer association, fixed operator, mobile operator, equipment vendor, national institution, etc.) to provide insights on the level of agreement among them. Moreover, the first release of the CoC should focus on the MH indicators without standardisation gaps. Finally, ECTA highlighted that its members have been in the frontline to support the sustainability, many following the science-based targets initiative, but the Commission could play an important coordinator role to involve all relevant parties in the discussion.

Questions/answers for the panel

Beyond the key messages, the following questions/answers and topics were discussed among the participants:

- What is a typical percentage of renewables in terms of self-generation? The answer from Telefónica was that it is usually low, i.e. around 2-3%.
- Sustainable Digital Infrastructure Alliance (SDIA): SDIA mentioned that Power Purchase Agreements (PPAs) for renewable energy should be local to not divert scarce renewable energy from other destinations to telecoms/digital. Local/physical PPAs should at least be rewarded. Ericsson mentioned that PPAs (on renewable energy) by telecoms operators could also drive the growth of renewable

energy in a country. Telenor noted that renewable energy can be created even in places where it was assumed that the output will be low, giving the example of solar panels beyond the Arctic circle.

- Telefónica asked on the extent to which data centres would be covered by the study: DG CNECT/JRC pointed out that, while the virtualisation and softwarization of networks would increase the importance of server farms and data centres in telecommunications networks, the study does not intend to replicate work already ongoing on this aspect, for instance, in the context of the revised Energy Efficiency Directive (EED). Stakeholders were invited to flag any inconsistencies and overlaps.
- How are Eco-design and Life Cycle Assessments (LCAs) considered in this study? Eco-design and other initiatives could be used to support the sustainability indicators in the telecommunications sector. The study seeks to provide an overview of the different sustainability regulatory initiatives and actions.
- Telenor pointed out that circularity and the role of minimum shares of recycled or reused materials when building new base stations could be important. There are however trade-offs with circularity (as pointed out by Telefonica, Telia and Ericsson). Requiring telecom operators to reuse 4G equipment for 5G (or maintaining copper cables instead of replacing them with fibre) may have a positive environmental impact but would increase energy consumption, because 5G or fibre are more energy efficient than 4G or copper.
- Another comment mentioned that life cycle aspects should be taken more into consideration because, some of the proposed indicators are not only valid in the operational phase, but also in the production and deployment phases, where a significant amount of GHG may occur.
- Measurability challenges: Orange pointed out that measuring energy efficiency is not as easy as it may seem, giving the example of tower companies with different tenants. There would be a need for a conceptual framework to transform the impact into carbon equivalents in these cases.
- What is the difference between GHG scope 2 and energy consumption? JRC answered that interdependencies and potential overlaps will be highlighted by the study.
- Nokia asked how renewable energy use would be rewarded? Ericsson pointed to an ITU standard that can be used to define and measure renewable energy.
- Telefónica pointed out that it would be useful to do a materiality assessment before reporting , as under in the Corporate Sustainability Reporting Directive.
- Telefónica also recommended using the best environmental practices and management practices in ICT defined by the JRC in 2021, with a special focus on telecommunications networks.
- Which points are crucial towards the Study's finalization? Ecta has suggested that providing a more detailed view of how the code of conduct would fit with respect to the reporting to the National Regulatory Authorities which has been foreseen already in some Member States (France just to name one) and to the Science Based Targets initiative which foresees a significant data collection and reporting activity for the adhering companies.

BEREC presentation by Sandrine Elmi Hersi

The Body of European Regulators for Electronic Communications (BEREC) is the body in which the national regulatory authorities (NRAs) of the telecommunications markets in the EU work together. It is supported by the European Commission through its the BEREC office. Daily activities and studies are conducted by Working Groups co-chaired by two national representatives.

Sandrine Elmi Hersi co-chair of the sustainability working group of BEREC from ARCEP (the French NRA) provided a presentation of current BEREC activities on sustainability indicators for telecommunications networks and services.

BEREC published in 2022 its first report on sustainability "Assessing BEREC's contribution limiting the impact of the digital sector on the environment" (BEREC 2022) which focuses on the following elements: 1) data availability and accuracy and definition of common indicators for the telecom and ICT sector, 2) use of existing regulatory tools for sustainability purposes, 3) encouraging environment-friendly and sober practices of digital players in collaboration with other relevant bodies, and 4) contributing to the empowerment of end-users through information on ICT products (data-driven regulation).

With regard to telecommunications sustainability indicators, BEREC conducted a survey in October 2022, where 81 participants provided their feedback (including 59 companies as telecom operators). The survey asked if the companies were collecting data and reporting on a list of sustainability indicators. In addition, BEREC also collected input from national regulatory authorities on the same list of sustainability indicators. This input and the feedback obtained from the consulted organisations allowed the definition of three main categories in order of priority. Group A included the following indicators: Energy consumption; Carbon emissions - Direct emissions - Energy indirect emissions- Other indirect emissions; Energy efficiency; Use of renewable energy (rate); Distribution or utilisation of recycled/refurbished/reused products; Expected lifetime; Water usage/consumption; Raw materials depletion (minerals). Group B included the following indicators: E-waste production; Recycled/refurbished/ reused components (also the excavate mass) in products; Recyclability; Reparability; Land use; Waste heat recovery. Group C included the following indicators: Eco toxicity (including incidence on biodiversity, water pollution…); Human toxicity (including air pollution); Eutrophication (terrestrial, freshwater, marine).

Most respondents said they used SBI (science-based targets initiative) to support the data collection and analysis of sustainability indicators. BEREC acknowledged that relevance was not clearly defined in their report, so the results can be interpreted in different ways. De facto, relevance seems to reflect industry acceptance to implement the data collection and analysis of a specific sustainability indicator.

BEREC’s final study report on “Sustainability Indicators for Electronic Communications networks and Services” (BEREC 2023) formulated a number of key findings in three different areas:

1. Investing in environmental transparency tools: This area included the monitoring and support of regulatory actions, the implementation of lifecycle assessment analyses for the most important indicators and the need to collect data from telecoms operators to support science-based analysis.
2. Supporting efforts within the industry: This area included actions to support the coordination and harmonisation among industry players (telecom operators and vendors) to rationalise efforts and foster transparency, avoiding to overburden the industry and creating market and effort imbalances between larger and smaller players. Also remaining technical challenges should be addressed.
3. Defining the role of national regulatory authorities: This area related to how NRAs can harmonise the collection and analysis of relevant data and define harmonised best practices and guidelines that can be tailored to the specific context of their country.

The future work of BEREC is represented in the figure below:

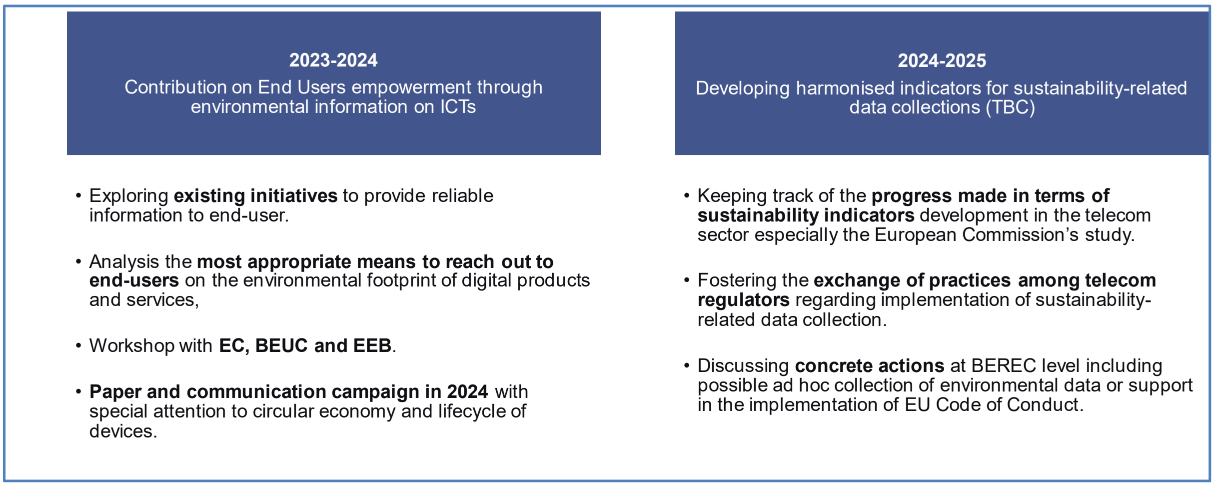

Figure 9 Future planned actions by BEREC on sustainability indicators.

The BEREC Report on sustainability indicators for ECN/ECS was published on October 12th, 2023.

JRC highlighted that the report for CNECT builds on and seeks to complement BEREC’s findings.

After the presentation by the BEREC representative, there were a number of questions from the audience:

- Ericsson highlighted that they have performed Life Cycle Assessments for a long time (since the 90s) and inquired about the purpose of the new BEREC study? BEREC answered that they are looking at the Product Environmental Footprint (PEF) framework, not LCA in general, to assess the real environmental impact of the deployment, operation, and deactivation of telecoms networks.
- Orange asked about the trade-offs between environment and energy or between performance and sustainability. For example, would the performance of the networks degrade if some sustainability practices were implemented to decrease energy consumption? BEREC replied that they did not investigate this specific aspect in their report, but that this could be an aspect to be explored in the DG CNECT/JRC study.

Open Fiber enquired if BEREC had focused on legacy networks and copper switch off. The concept is to see if there is a positive sustainability impact by replacing legacy networks, and in particular the copper-based lines for the fixed access network. BEREC acknowledged that the deployment of new networks with new technologies would improve energy efficiency. JRC would also look at this aspect in the report for DG CNECT, even if the LCA analysis would yet have to be completed.

Second Panel Session (moderated by DG CNECT)

The panel sessions were structured in such a way that each panellist could provide a key message of short duration (5 minutes). Then, the rest of the time (which is the majority of the time) is based on interactive discussions with questions proposed alternatively by the EC (DG CNECT/DG JRC) and the audience (both virtual and online).

- Opening statement from ARCEP (Loïs Ponce)

The Autorité de Régulation des Communications Électroniques, des Postes et de la Distribution de la Presse (ARCEP or Arcep) is an independent French agency in charge of regulating telecommunications, postal services, and print media distribution in France.

The main focus of the presentation of ARCEP was on the task of environmental data collection. ARCEP started with a small number of indicators from the four main telecom operators in France, then extended data collection in 2022 to more players (device manufacturers, data centre operators) and covering more indicators, addressing all components of the digital sector. ARCEP highlighted that selecting indicators with high relevance in terms of sustainability (like the GHG-related indicators) would be important, despite difficulties regarding measurability and data collection. NRAs would have on-the-ground expertise, but an explicit legal mandate could help them to collect data in a more precise and detailed way in their jurisdiction (but such a mandate would not be indispensable).

- Opening statement from ADEME (Julia Meyer)

ADEME is the French agency for ecological transition. Ademe highlighted that there is an increasingly strong French regulatory framework to limit the environmental impact of digital technology. For example: 1) the AGEC law, which states that from 1 January 2024, telecom operators must communicate their carbon footprint to subscribers, based on ADEME's methodology; 2) the Climate & Resilience law, which puts forward a decarbonisation roadmap by 2050 for the digital sector, to feed into the national low-carbon strategy (SNBC). ADEME's mission on the sustainability of digital networks is based on: 1) studies (ADEME published a study on the impact of fixed and mobile networks in France at the end of 2023, 2) LCA-based methodology for Internet access provisioning (published in 2022) and 3) data. ADEME plans to have a life cycle inventory (LCI) database in the timeframe 2022 to 2025. Rebound effects should be accounted for, since more network availability would also imply an increased use of the related services. ADEME also highlighted that it is often difficult to collect LCA data on the equipment, as it is not available. Also, the sharing of the physical infrastructure makes it more difficult to estimate some indicators for specific operators. The ADEME representative confirmed the list of proposed must have indicators but also highlighted that the consumption of raw materials is missing (e.g., Gallium/Germanium mainly imported from China is important for fibre and radio frequency equipment and is now under export control restrictions from China) and should be reflected in the 'must have' indicators. Also, the importance of multi-criteria LCAs was underlined.

- Opening statement from TIC-Council (Martin Michelot)

The TIC Council is an international association representing independent testing, inspection, and certification companies. Sustainability has become an important activity for auditors in recent years. The TIC Council representative described the lessons learned from their experience in making the existing Data Centre Code of Conduct (CoC) auditable. The wording had to be completely changed to turn it into an assessment framework. In particular, pass/fail criteria are essential, but it may be difficult to formulate them. According to the TIC Council, audit firms work on the basis of standards, which should be harmonised as much as possible. Even when standards are mature, there could be the challenge that different companies use different standards. The Commission could work with standardisation agencies towards harmonised standards for auditing by engaging different categories of stakeholders.

- Opening statement from Mavana (Gillo Malpart)

Mavana is an independent digital and environmental consulting company based in France. Specializing in assessing the environmental, financial and social impacts of digital technologies, Mavana assists organisations in identifying, evaluating and sometimes implementing digital solutions to reduce operational and environmental costs. Their main customers are governmental bodies, municipalities, telecom operators (especially in France), but they also work with corporations and SMEs interested in assessing their carbon footprint and improving their eco-design practices. According to Mavana, the relevance of the sustainability indicators should take precedence over the availability. It would also be interesting to evaluate the enabling effect of the telecommunications networks in other domains, for instance, improve energy efficiency through digitalisation. DG JRC clarified that, while this was an important point, it would go beyond the scope of the study. Mavana pointed to research done by the University of Leuven to compare LCA databases, which could provide insights on measuring sustainability impacts and improving comparability (Pirson 2023). ITU standards seem mainly used in auditing. LCA is useful not only for networks but also for devices themselves, even if it may be difficult to analyse their LCA in the context of networks. A recommendation to the European Commission was to set minimum requirements and provide a blueprint or gold standard for assessing telecommunications networks, which could be used in auditing, taking into consideration the difficulty to compare networks.

Networks are part of wider systems that encompasses in particular the devices at both user end and data centers end. LCA is used to assess the environmental impacts of both types of terminals (users and servers), and these LCAs are considering datasets that are more and more standardised (using PEF). Unfortunately, these LCAs cannot be considered complete unless networks are able to provide figures on the same dataset. It is therefore very important that networks are able to align their indicators on the ones used by other sectors of the digital industry (and more widely the sectors who are relying on telecoms).

- Opening statement from WIK-Consult (Bernd Sörries)

WIK-Consult is a consulting company working with the German digital ministry on a sustainability study for telecommunications networks. In particular, WIK-consult is looking at the interplay between infrastructure competition, resilience and sustainability. They had organised a workshop related to the study in September 2023. Its focus is on the deployment of fibre optical cables and 5G/6G in a way that sustainability can be increased. They are particularly interested to see if there are trade-offs with other areas (competition, decommissioning of legacy networks, security, etc.). Thereby, the study does not seek to compare operators but rather to facilitate the deployment assess the behaviour of the end-consumer (e.g., in the context of in-building wiring). In line with other panellists WIK-Consult recommended to focus on a few selected indicators to be harmonised across Member States, also to avoid overburdening small operators with diverging reporting obligations.

Questions/answers for the panel

Then, after the key messages, there were a number of questions/answers for the panel:

- Mavana mentioned that attributional LCA is useful to assess how sustainability indicators of one single stakeholder evolve over time. However it does not help comparing different telecom operators (because the conditions are different, perimeters might be different, assumptions are different etc.). On the other hand, consequential LCA is useful to evaluate the consequences of a change in the stakeholder infrastructure.
- Orange mentioned that the LCA ISO standards (ISO 14001, 14040) allow for diverging methodologies and databases. ITU would be working on streamlining this.
- A number of representatives from telecoms operators pointed to the difficulty to compare networks. It would be better to compare a network against a gold standard or evaluate if there have been improvements over time. Eventually, this could only be done for equipment.
- Telefónica highlighted the considerable efforts in performing an LCA for their subsidiaries in Spain, Brazil and Germany. The subsidiaries had to be compared each with their own development and not with the subsidiaries from the other counties. As a consequence, LCA should not feature among 'must have' indicators in Telefónica's view.

Concluding remarks of the workshop

After the end of the panel sessions, DG JRC and DG CNECT summarised the key points:

- There was a general agreement on the 'must have' indicators identified in the survey, with the exception of the indicator related to raw materials, which was also suggested as important by some stakeholders during the meeting. On the other hand, telecom operators and vendors stressed the importance of focusing on a few indicators, because the data collection, analysis, and reporting for even a few indicators could be a significant effort for a large telecom operator (and even more so for a smaller one).
- LCA was mentioned as an important aspect to evaluate the sustainability impact in the different phases of the network and the equipment. The work already done by the JRC could support the analysis in this regard (notably the JRC Science for Policy Report: Best Environmental Management Practice in the Telecommunications and ICT Services sector JRC121781 EUR 30365 EN).
- For auditing purposes, it would be important to set a harmonised conceptual framework, which can facilitate the analysis by the auditor. In addition, it was mentioned that it is quite difficult to compare networks from different member states, and it would be more effective to evaluate the sustainability indicators over time for the same network, as it evolves. The creation of a blueprint or gold standard of a telecom network would be useful for auditing purposes.
- There were some aspects related to the renewable indicator (notably the role of PPAs), which should be analysed more in detail, because there is a risk of creating imbalances among stakeholders (e.g., some telecom operators may have an easier access to renewable energies than others).
- Smaller operators may have difficulties gathering data on some 'must have' indicators that large operators are able to gather (e.g., scope 3 emissions and recyclable products, where there are still standardisation gaps). It would be important to avoid a market imbalance for the data collection and analysis of sustainability indicators, which may penalise the smaller companies in comparison to the larger ones.
- There were trade-offs regarding the role of legacy infrastructure and how it is accounted for in sustainability (e.g., trade-offs between higher energy use vs. longer lifetime).
- There were a number of potentially interesting initiatives mentioned, which could further support the analysis, for instance the Science-based targets initiative (SBI) and the Carbon Disclosure Project (CDP).
- It would be useful in the design and drafting of the Code of Conduct (CoC) to describe the responsibility across stakeholders involved in the sustainability processes for data collection, analysis, and reporting.
- There should be a minimal set of requirements for the CoC, as it may become difficult to elaborate on different values for different contexts.
- Some stakeholders underlined the need to work on quantifying the enabling effect of telecoms on other sectors (not in the scope of this study but done in other fora, such as the European Green Digital Coalition).
- The EU Taxonomy could be a useful link to the work on telecoms sustainability indicators. Even if there are no formal regulatory relationships at the moment between two areas in the telecom sector, the study on telecoms indicators could inform future iterations of the taxonomy.

- Feedback from past activities on existing CoCs. For example, the wording and terms of the Data Centre CoC had to be completely changed by auditors to make it auditable, in particular, as regards pass/fail criteria.

Annex B. Complementary results from the survey

B.1 Introduction.

During the period from the 26th of May to the 23rd of June, a questionnaire in the format of EU Survey was created to collect inputs on sustainability indicators from stakeholders involved in the design, development, deployment, and operation of telecommunications networks providing electronic communication services to both commercial and residential customers.

More specifically, this survey was an essential instrument for the identification of common indicators for measuring the sustainability of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs).

The main results (tables and figures) were already presented in the main body of the report. This annex complements the content in the technical report with additional figures and tables.

B.2 General figures not related to specific indicators

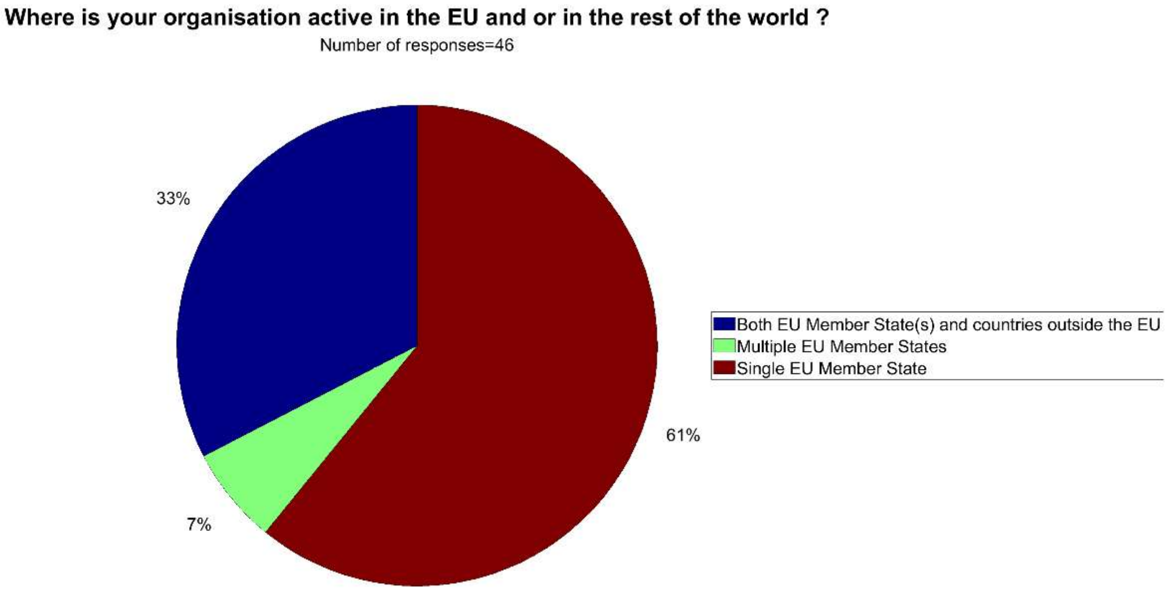

Figure 10 Location of the participant.

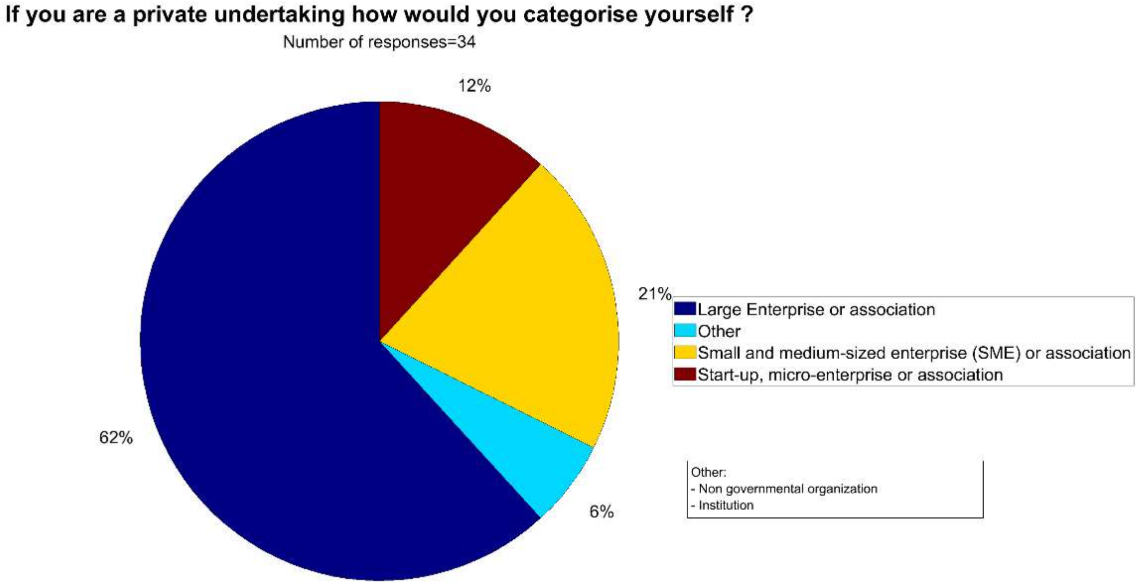

Figure 11 Categorization of the private undertaking.

B.3 Energy Consumption

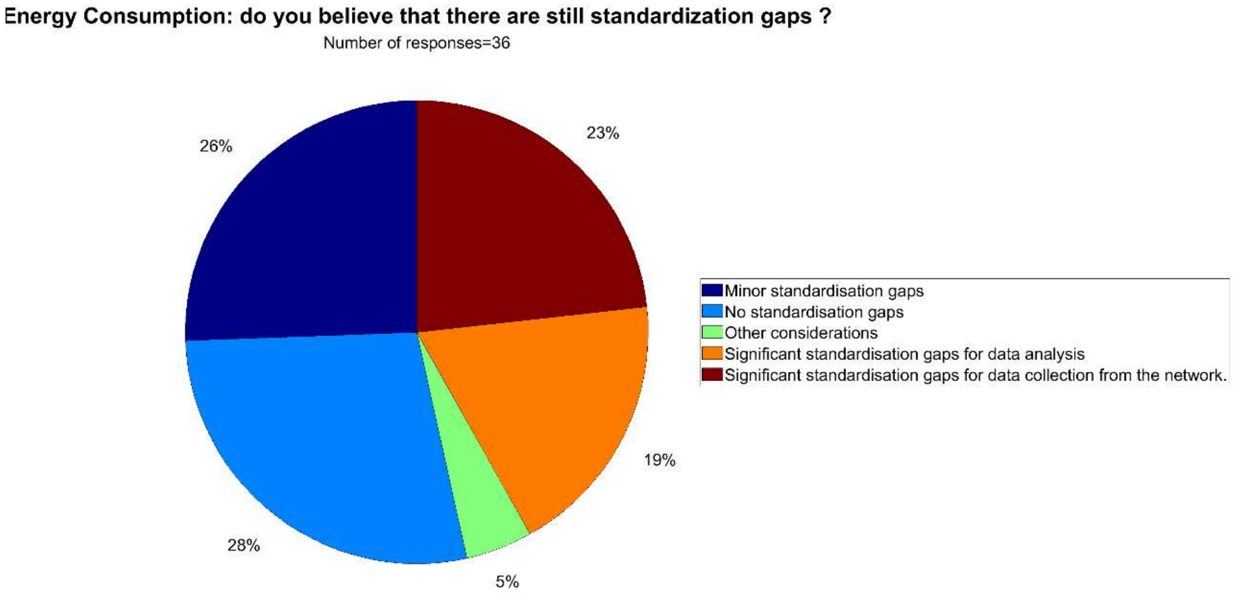

Figure 12 Standardisation gaps in the Energy Consumption indicator.

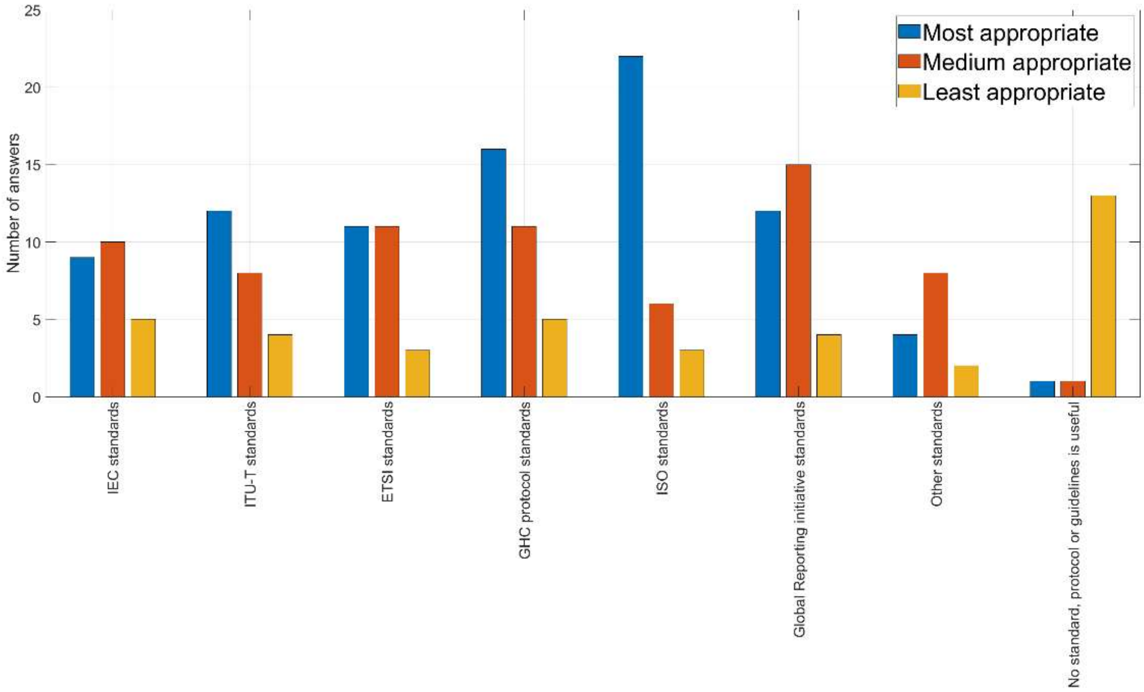

Figure 13 Standards relevant for the Energy Consumption indicator.

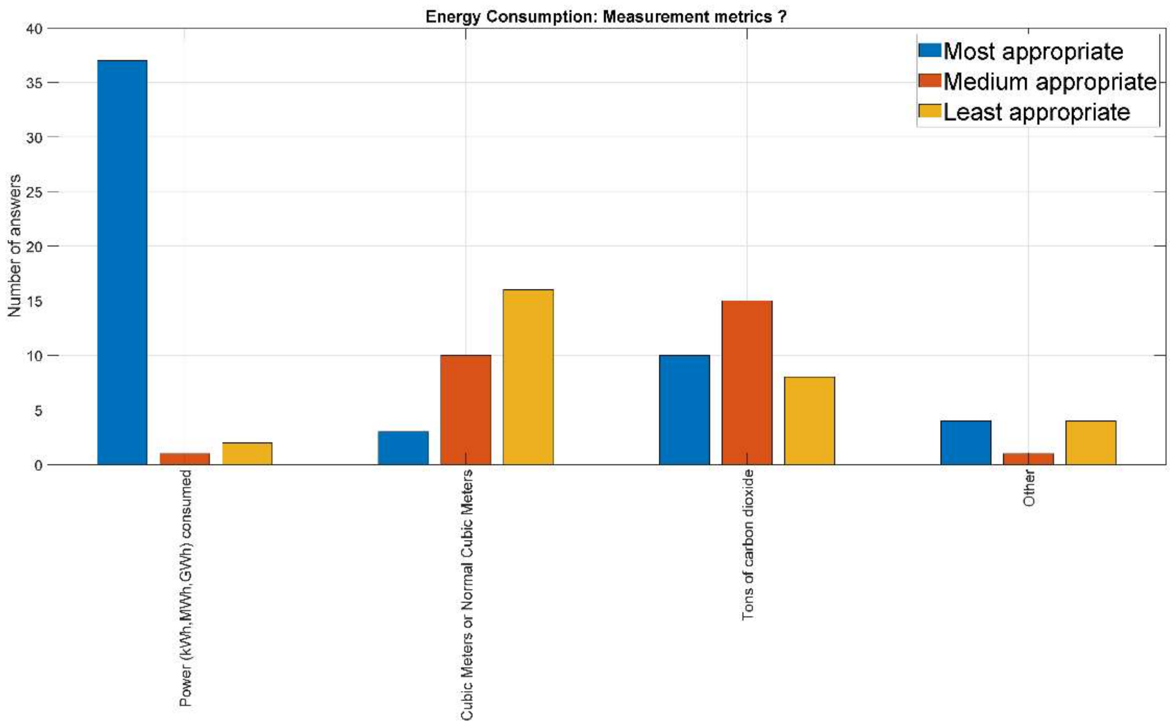

Figure 14 Measurement metrics used in the Energy Consumption indicator.

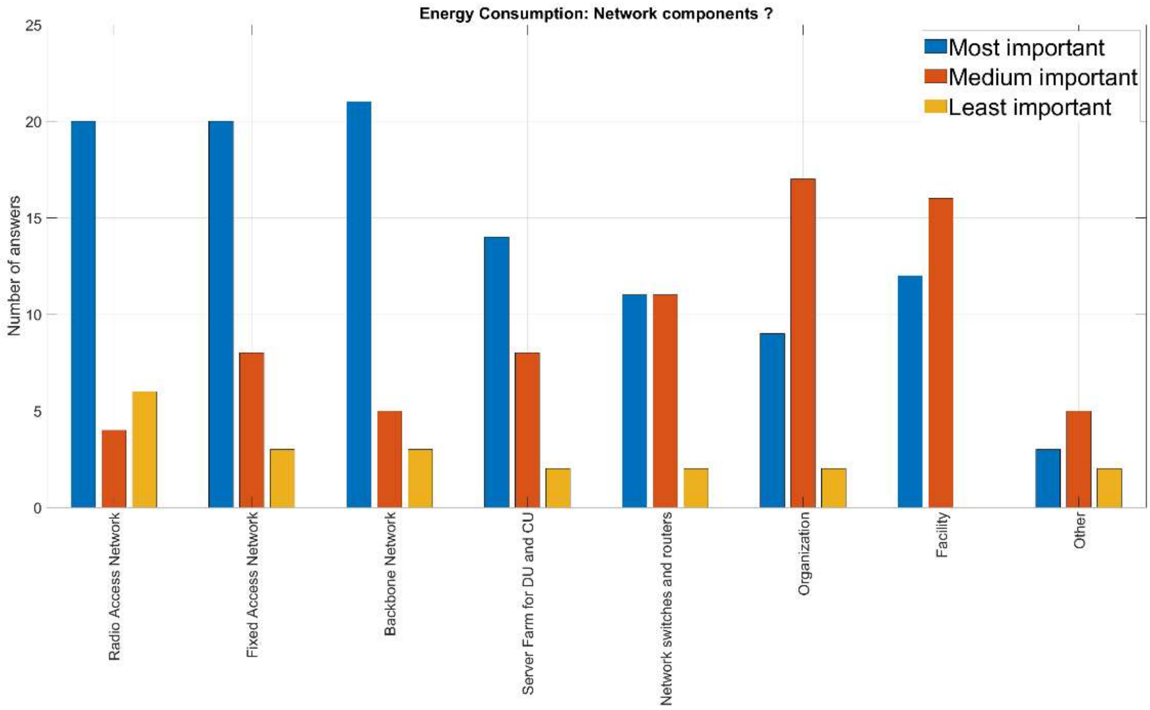

Figure 15 Relevance of the network components for the Energy consumption indicator.

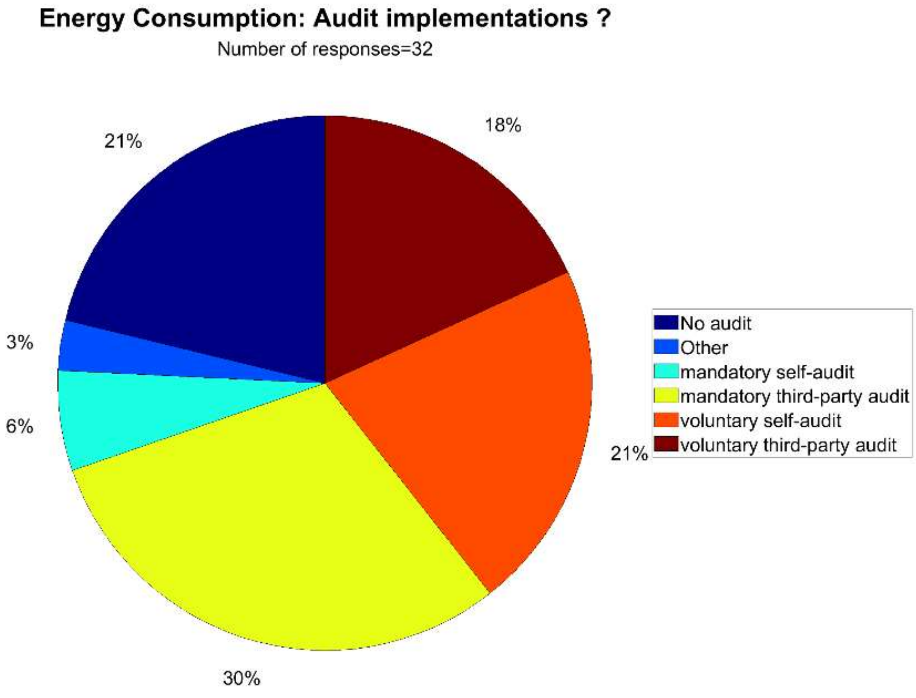

Figure 16 Audit implementations for the Energy consumption indicator.

B.4 Energy Efficiency

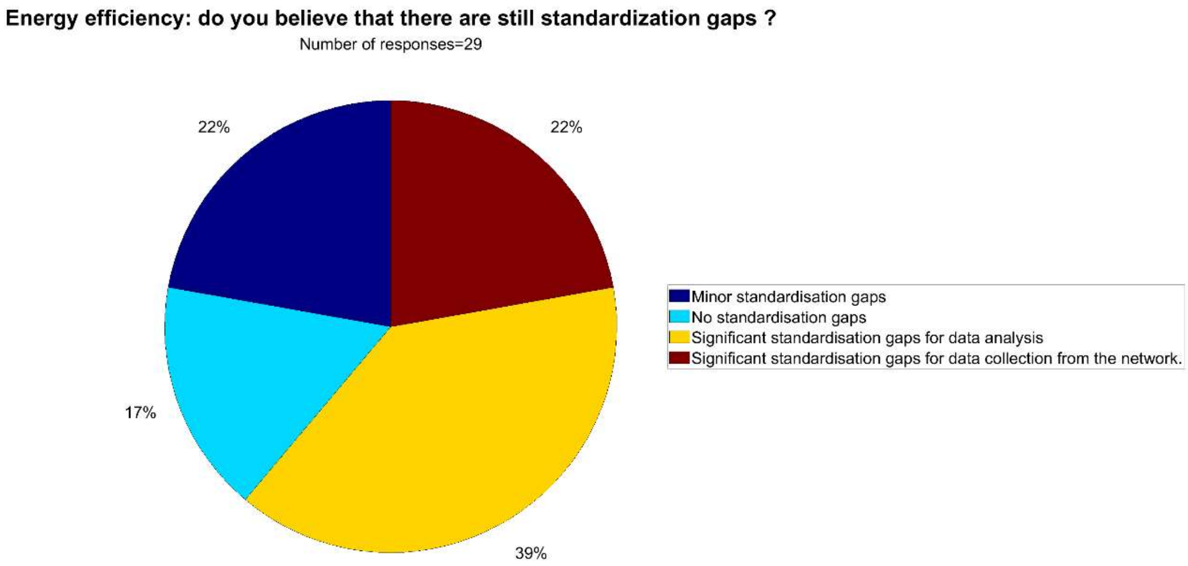

Figure 17 Standardisation gaps in the Energy efficiency indicator.

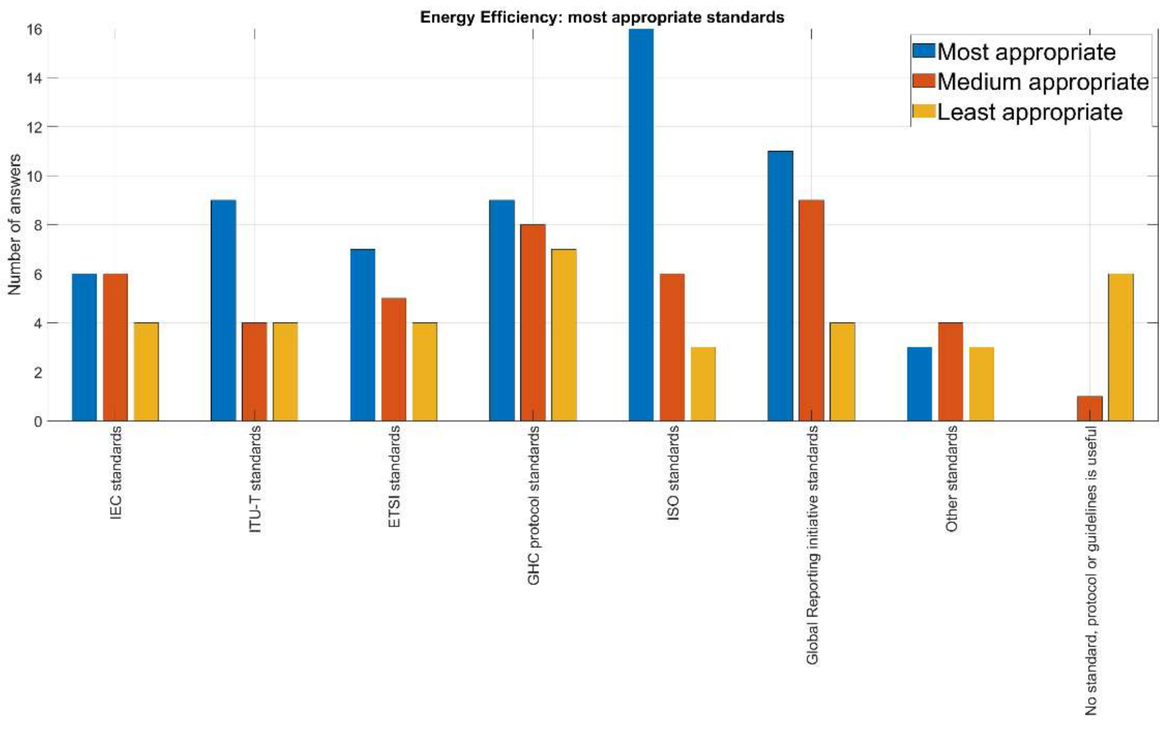

Figure 18 Standards relevant for the Energy efficiency indicator.

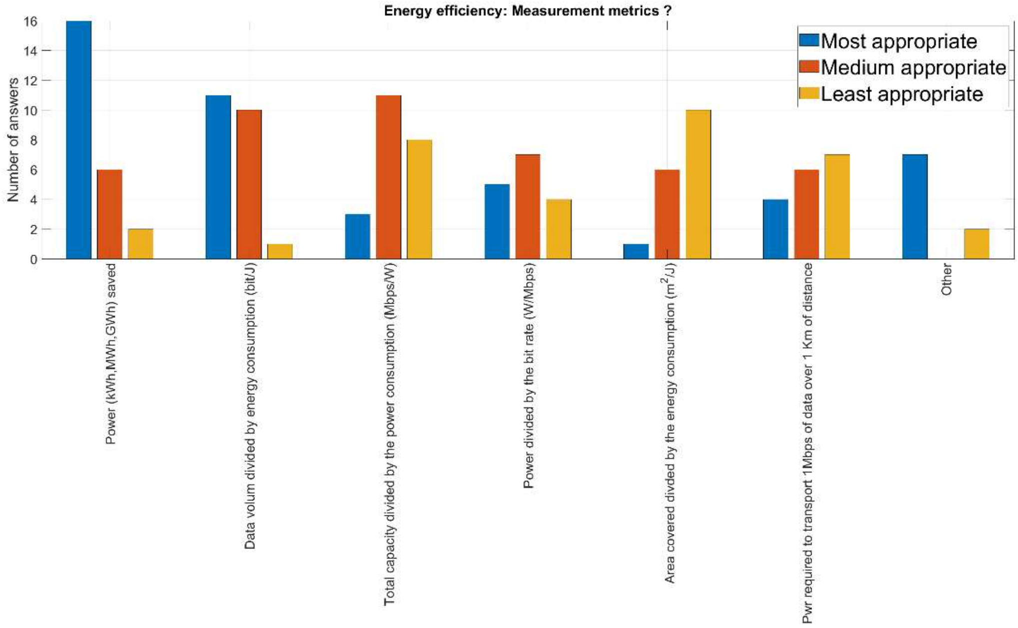

Figure 19 Measurement metrics used in the Energy efficiency indicator.

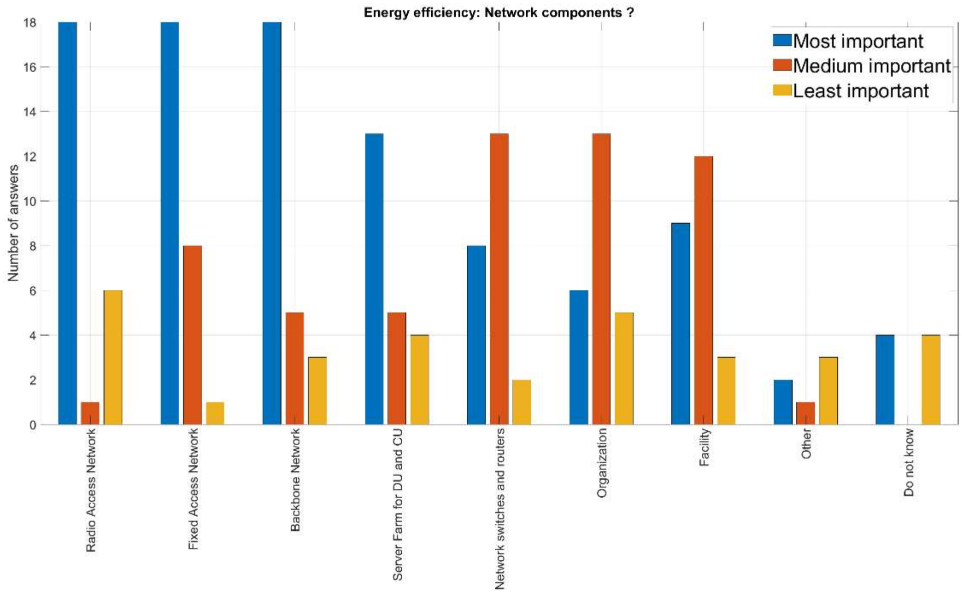

Figure 20 Relevance of the network components for the Energy efficiency indicator.

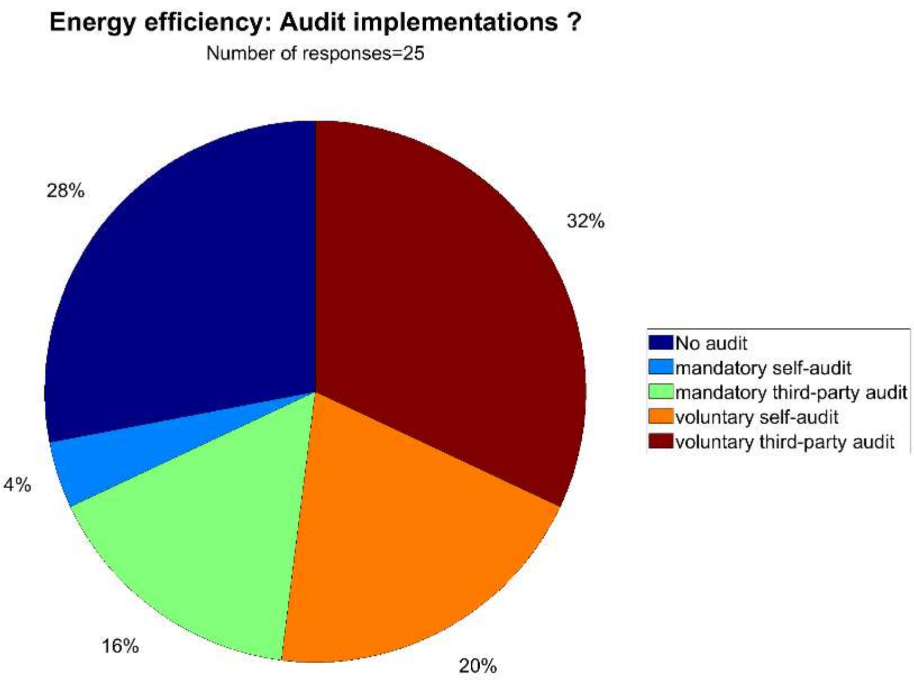

Figure 21 Audit implementations for the Energy efficiency indicator.

B.5 Use of renewable energy indicator

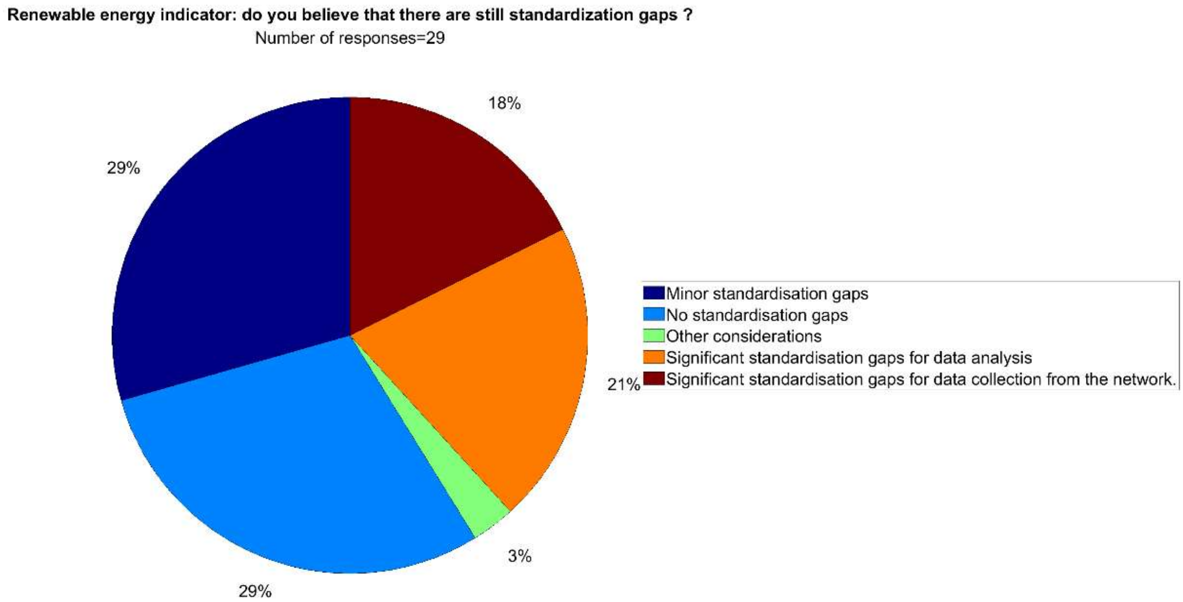

Figure 22 Standardisation gaps in the Renewable energy indicator.

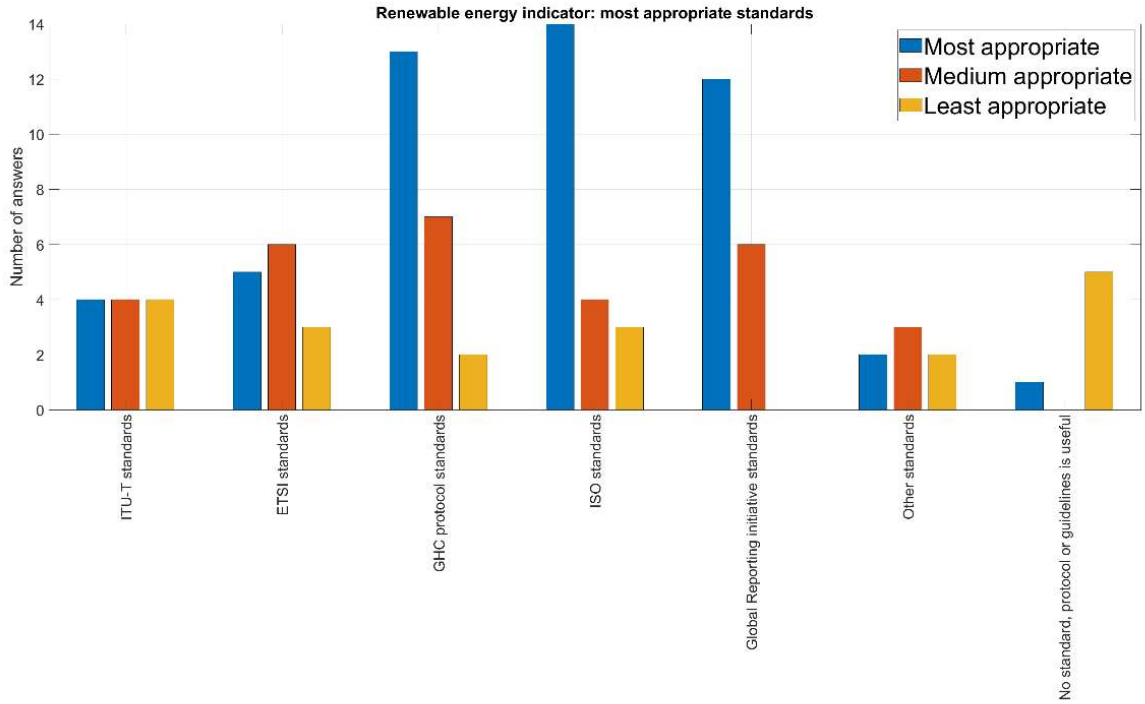

Figure 23 Standards relevant for the Renewable energy indicator.

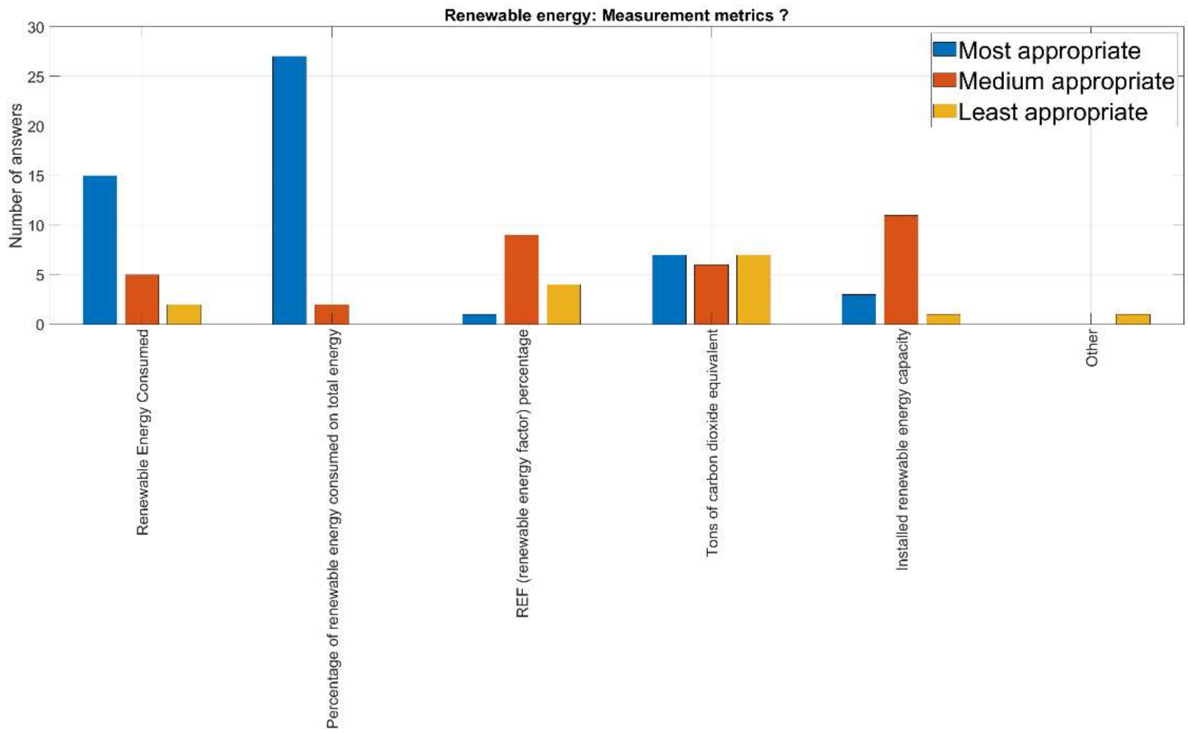

Figure 24 Measurement metrics used in the Renewable energy indicator.

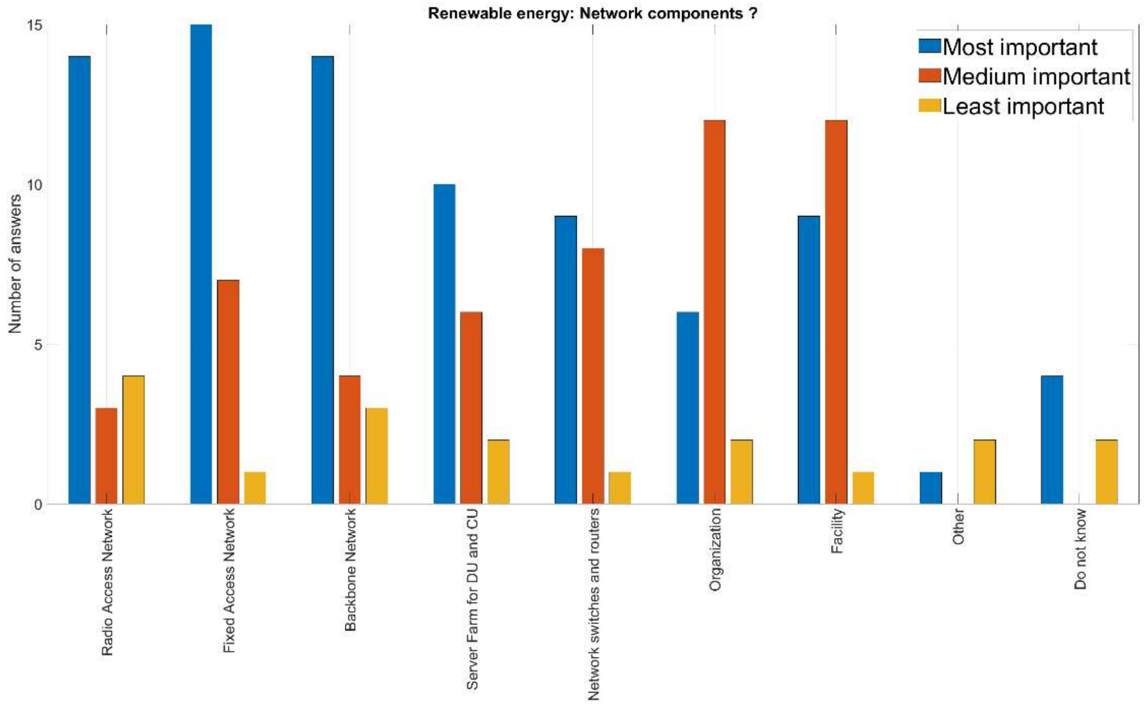

Figure 25 Relevance of the network components for the Renewable energy indicator.

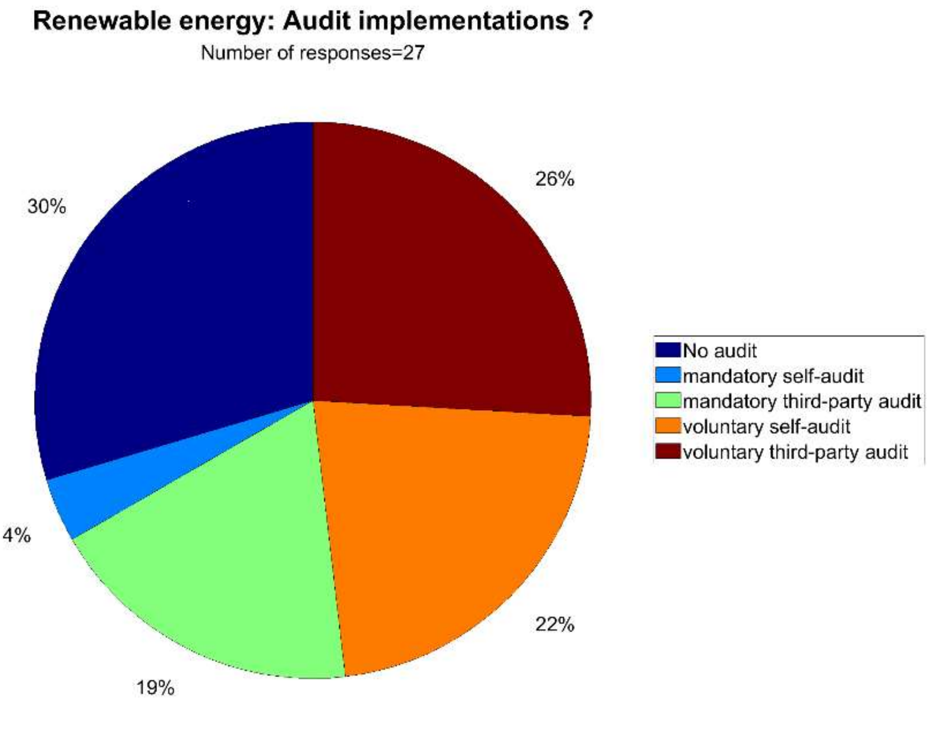

Figure 26 Audit implementations for the Renewable energy indicator.

B.6 Carbon Emission (Scope 1) indicator

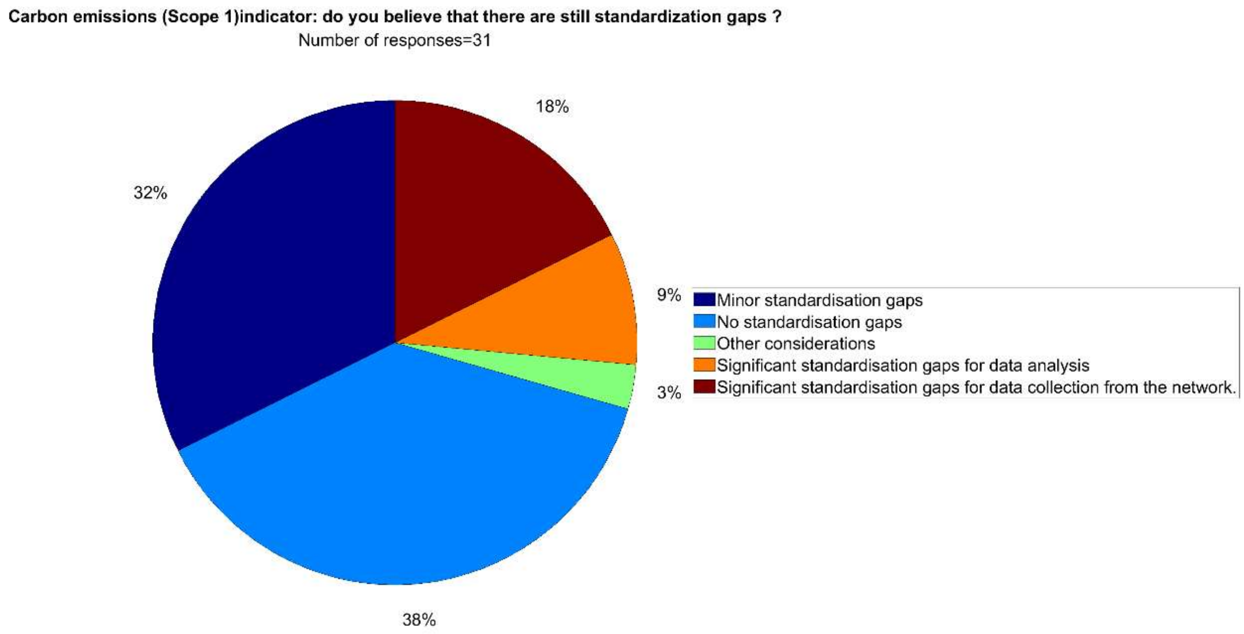

Figure 27 Standardisation gaps in the Carbon emissions - Direct emissions indicator.

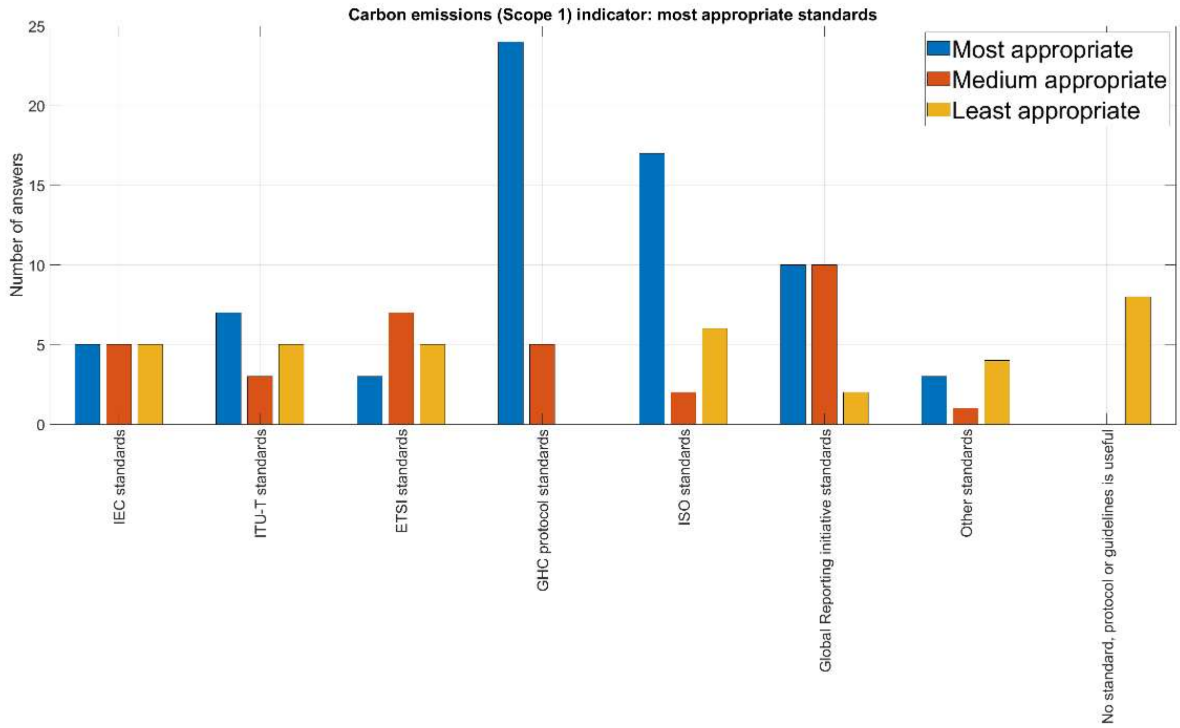

Figure 28 Standards relevant for the Carbon emissions - Direct emissions indicator.

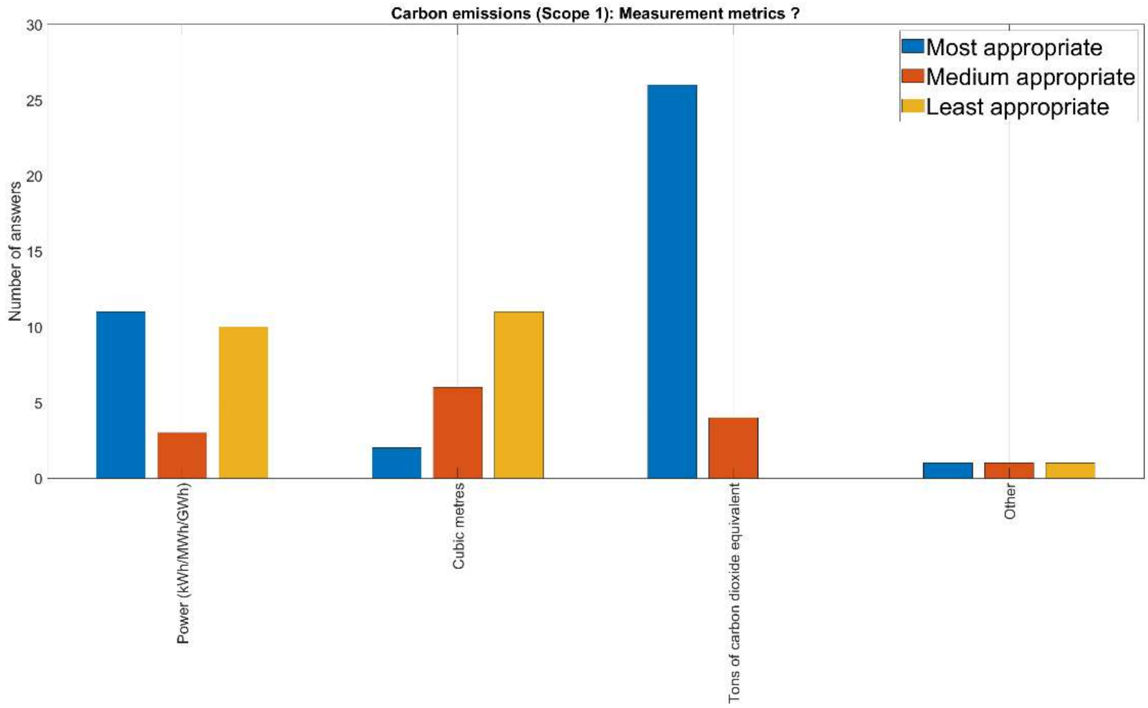

Figure 29 Measurement metrics used in the Carbon emissions - Direct emissions indicator

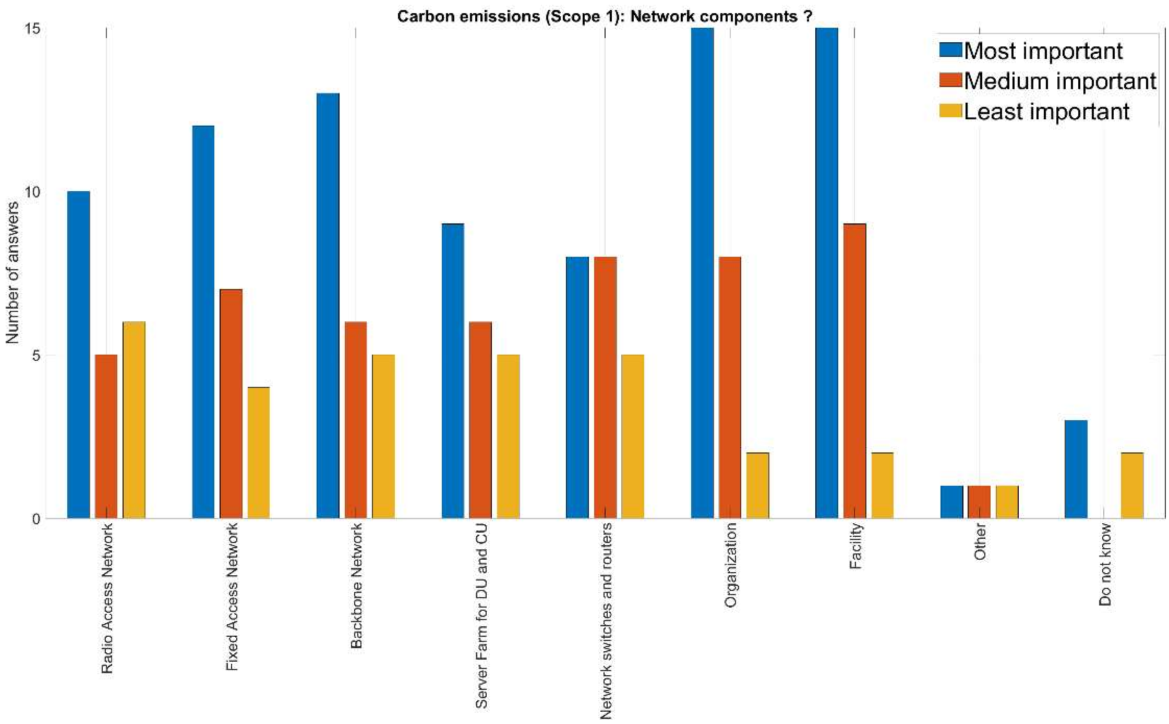

Figure 30 Relevance of the network components for the Carbon emissions - Direct emissions indicator.

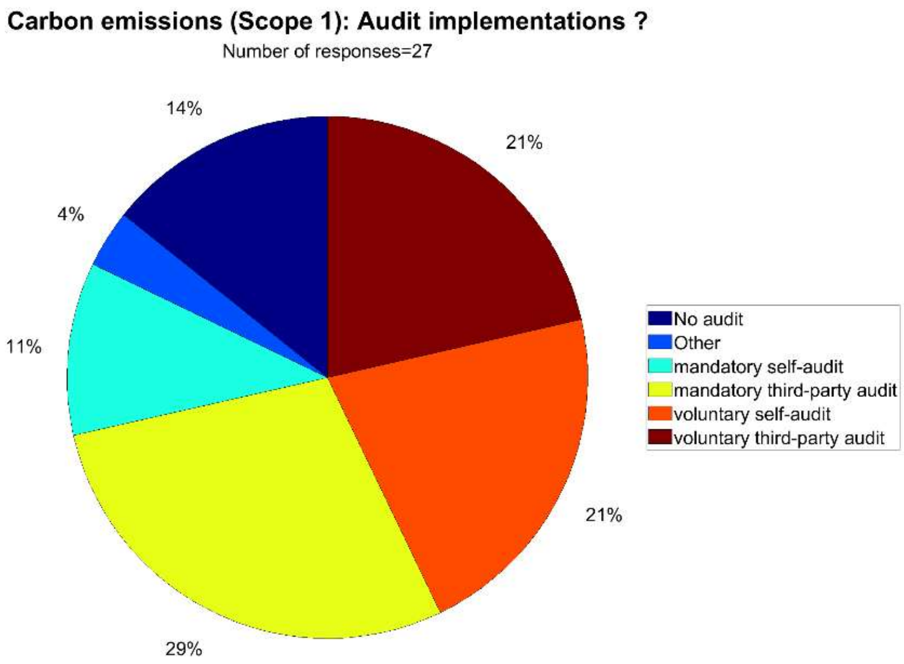

Figure 31 Audit implementations for the Carbon emissions - Direct emissions indicator.

B.7 Energy indirect emissions (e.g., scope 2 emissions) indicator

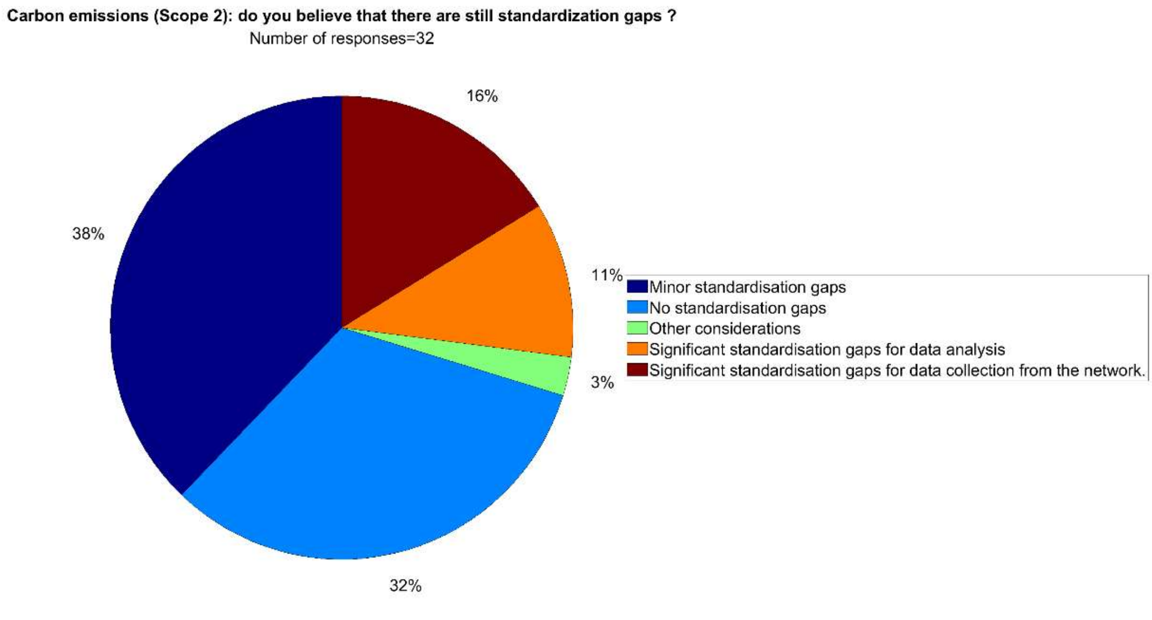

Figure 32 Standardisation gaps in the Energy indirect emissions indicator.

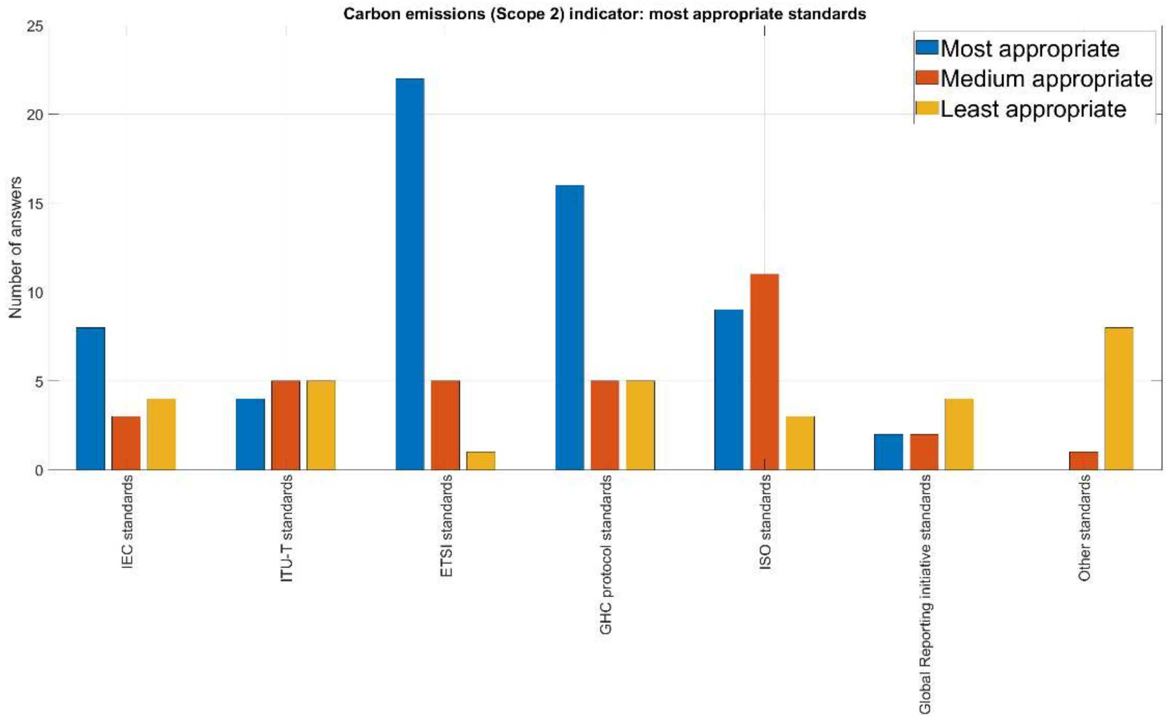

Figure 33 Standards relevant for the Energy indirect emissions indicator.

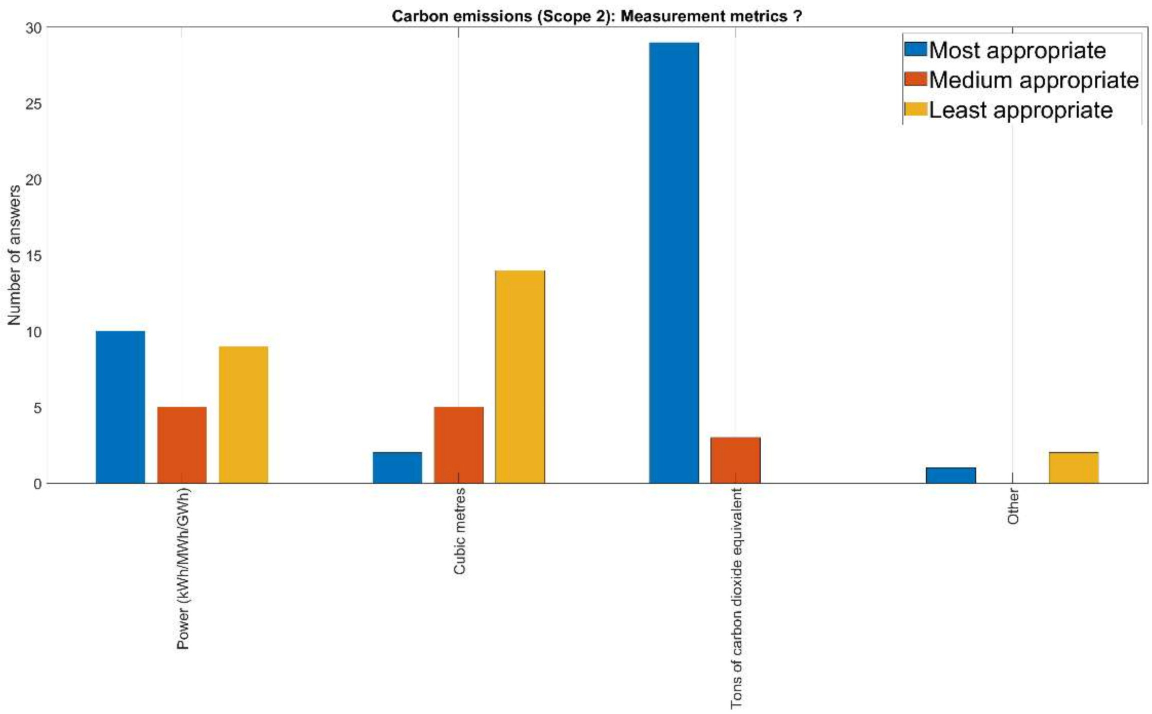

Figure 34 Measurement metrics used in the Energy indirect emissions indicator.

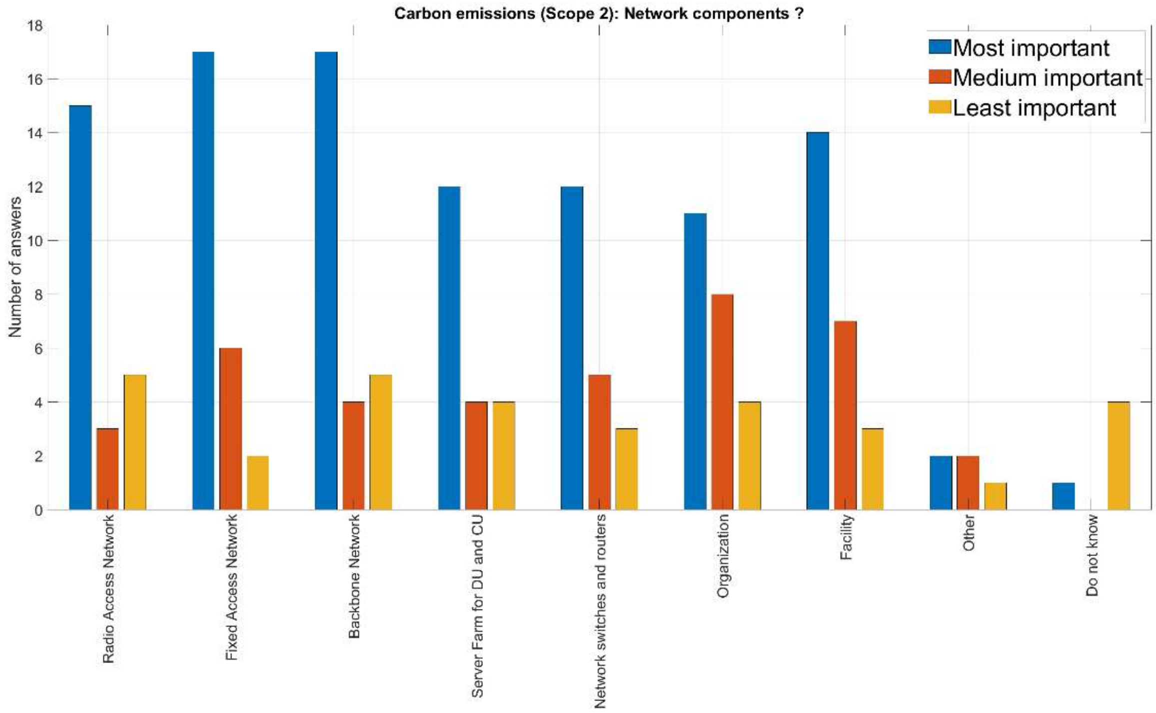

Figure 35 Relevance of the network components for the Energy indirect emissions indicator.

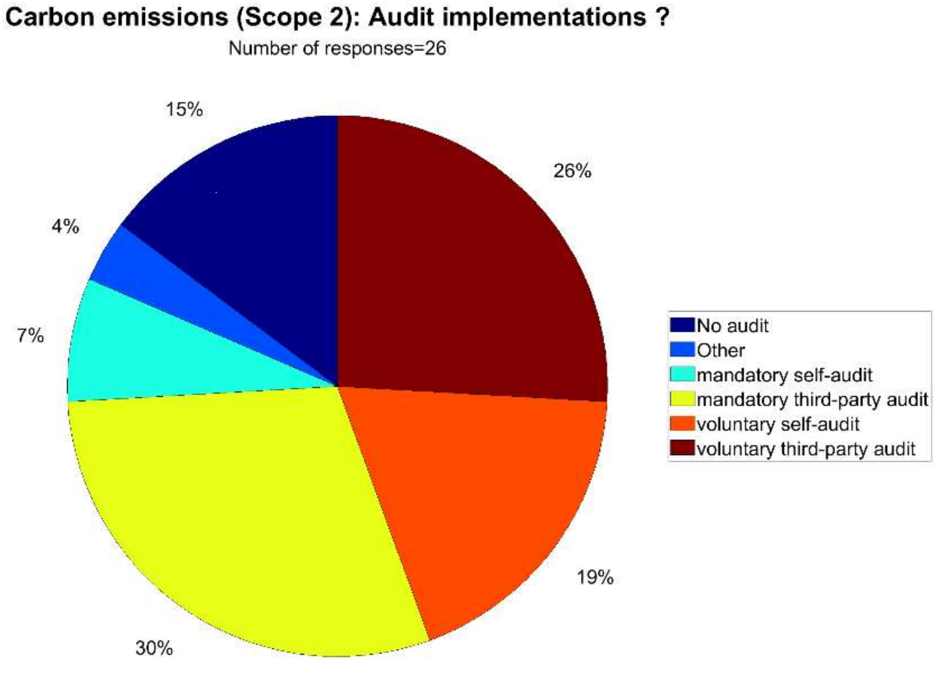

Figure 36 Audit implementations for the Energy indirect emissions indicator.

B.8 Carbon emissions - Other indirect emissions (e.g., scope 3 emissions) indicator

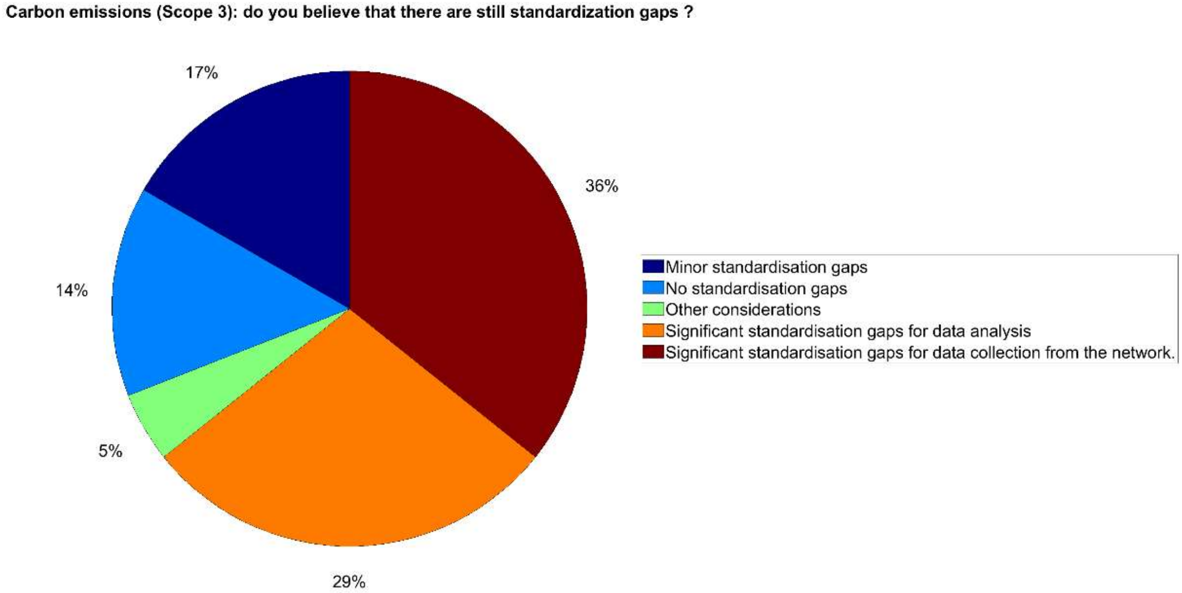

Figure 37 Standardisation gaps in the Carbon emissions - Other indirect emissions indicator.

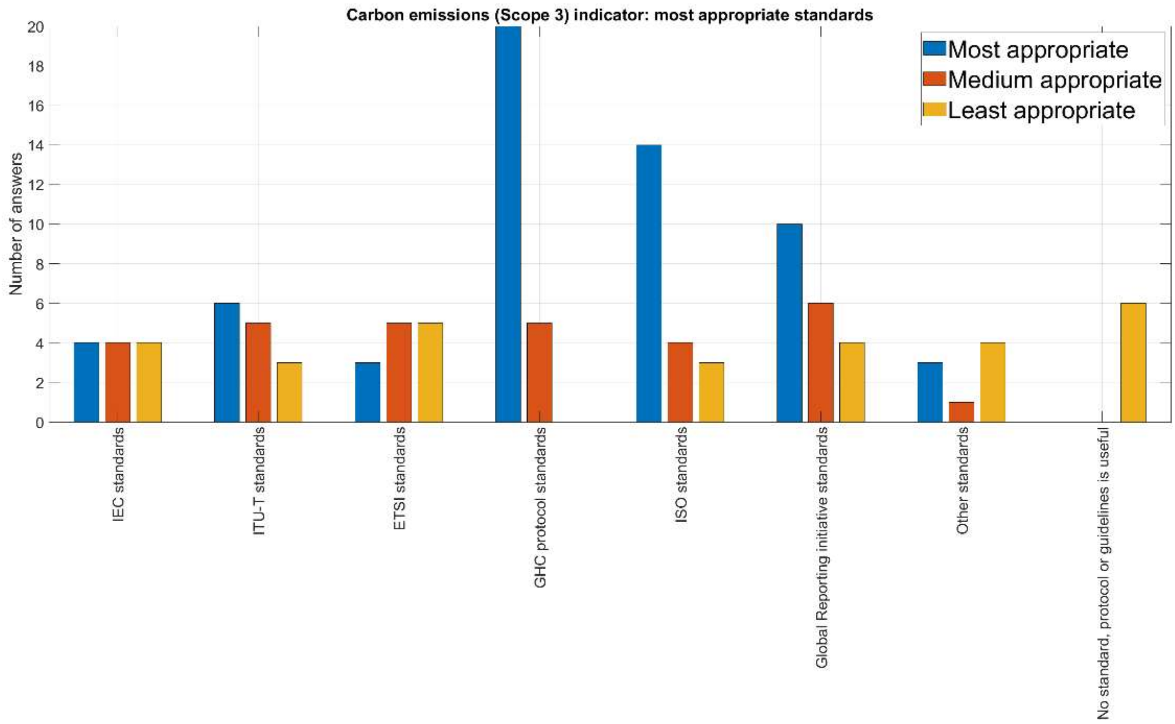

Figure 38 Standards relevant for the Carbon emissions - Other indirect emissions indicator.

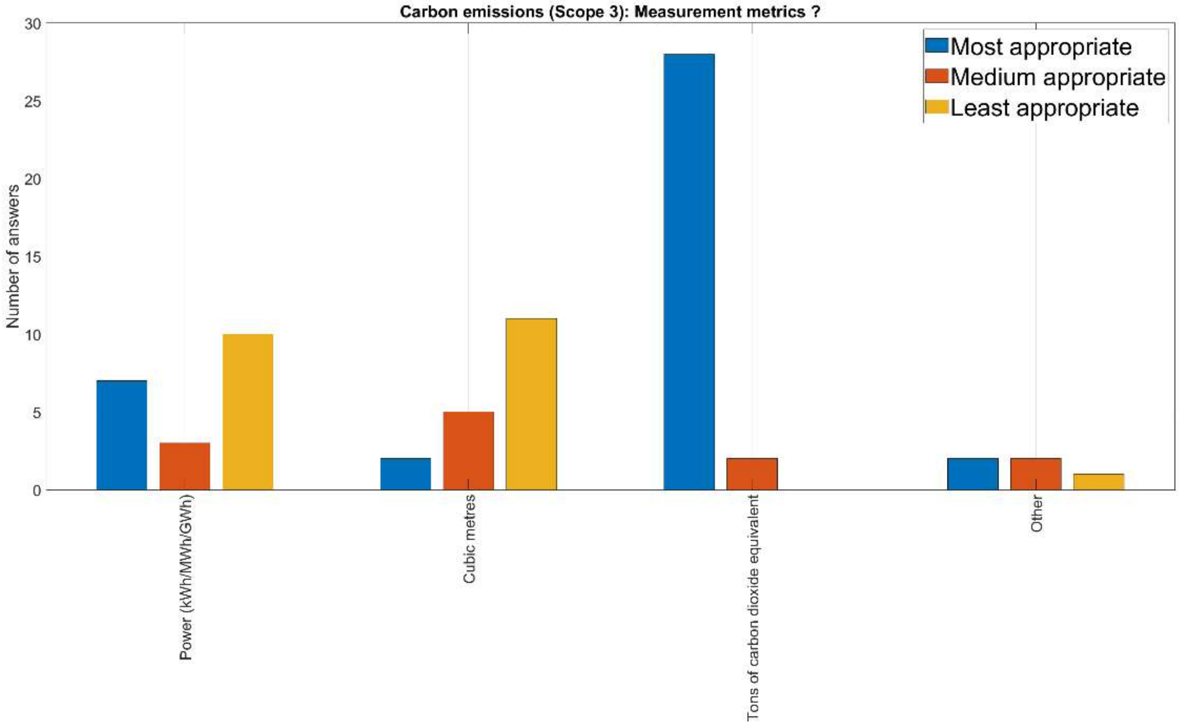

Figure 39 Measurement metrics used in the Carbon emissions - Other indirect emissions indicator.

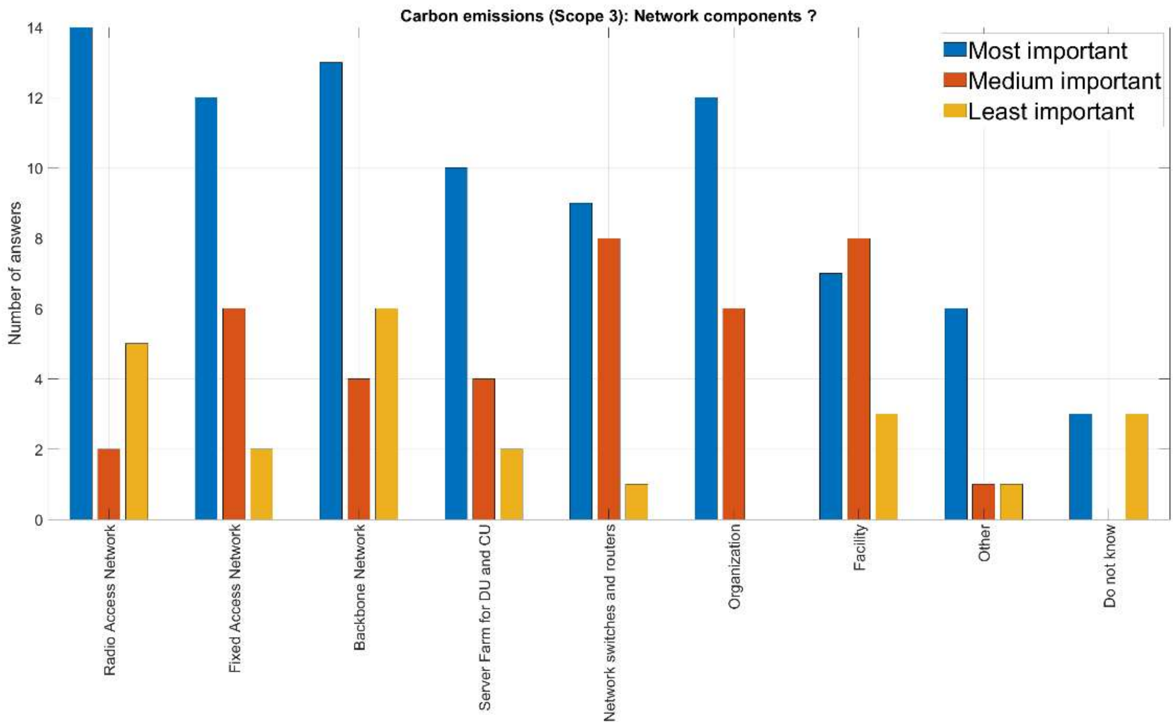

Figure 40 Relevance of the network components for the Carbon emissions - Other indirect emissions indicator.

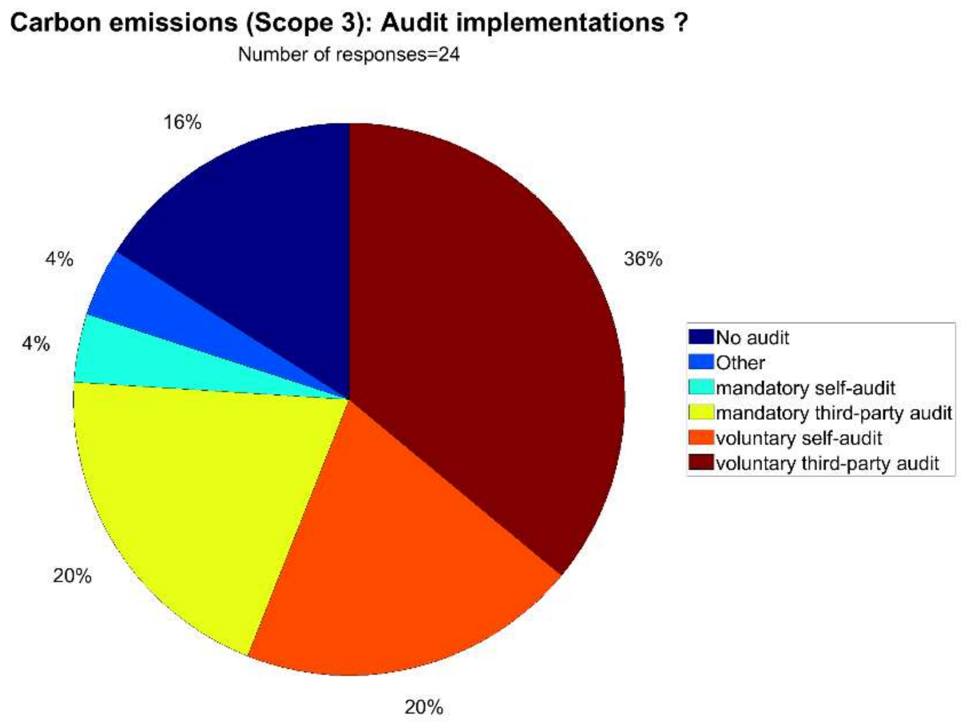

Figure 41 Audit implementations for the Carbon emissions - Other indirect emissions indicator.

B.9 E-waste production indicator

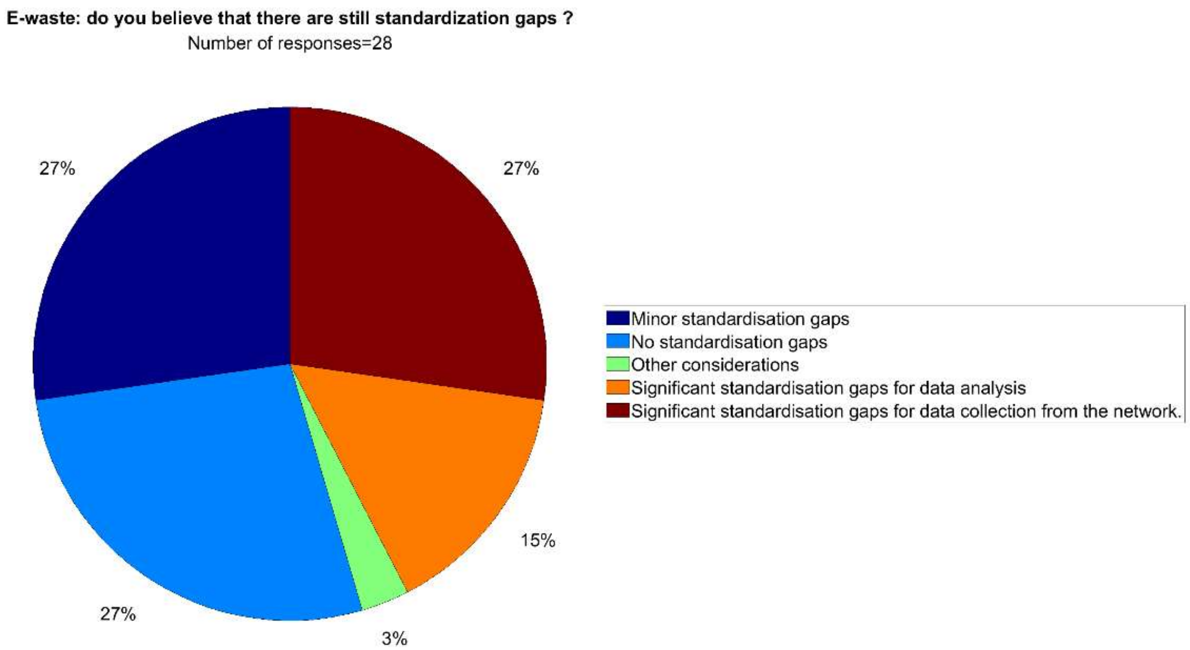

Figure 42 Standardisation gaps in the E-waste production indicator.

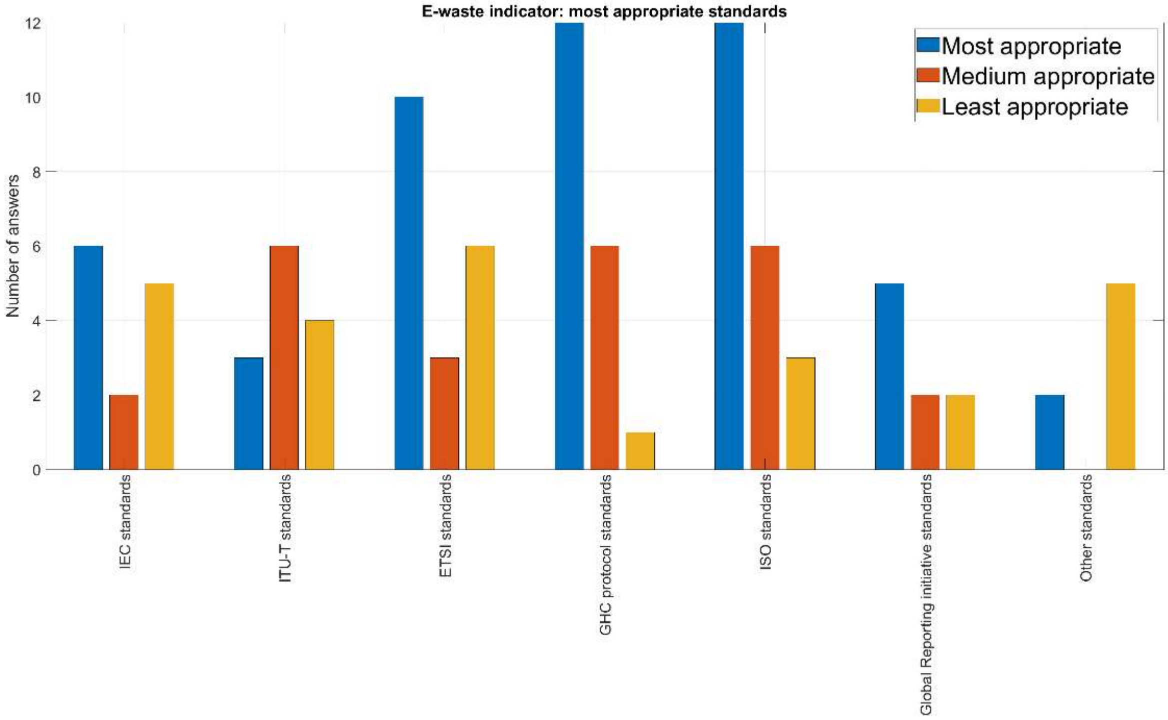

Figure 43 Standards relevant for the E-waste production indicator.

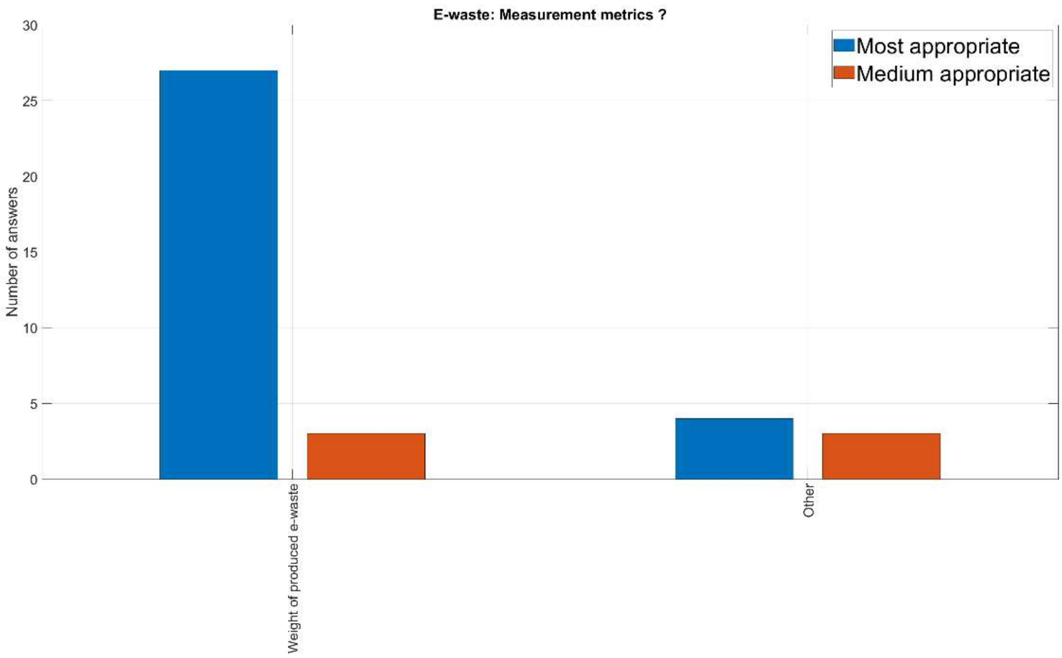

Figure 44 Measurement metrics used in the E-waste production indicator.

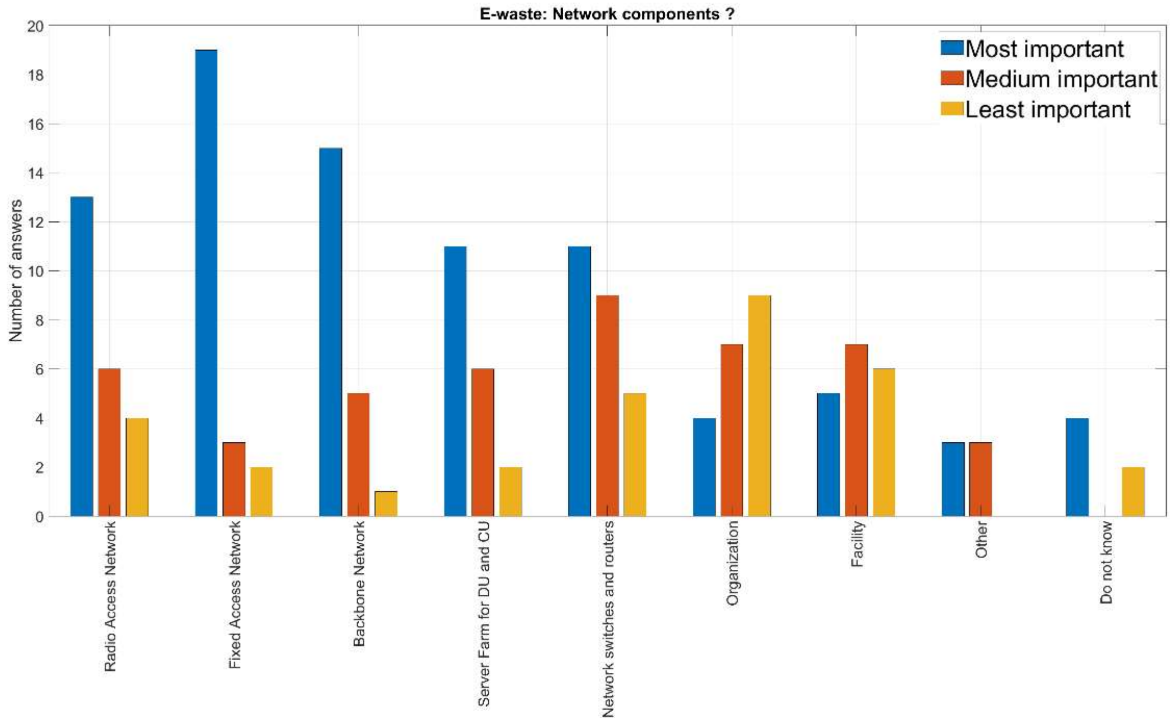

Figure 45 Relevance of the network components for the E-waste production indicator.

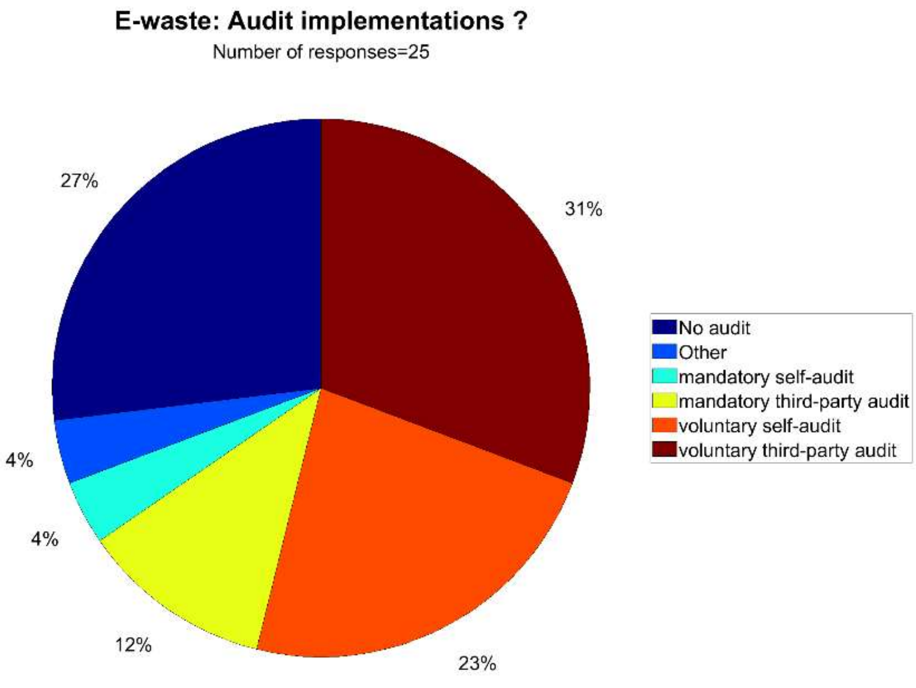

Figure 46 Audit implementations for the E-waste production indicator.

B.10 Distribution or utilisation of recycled/refurbished/reused products indicator

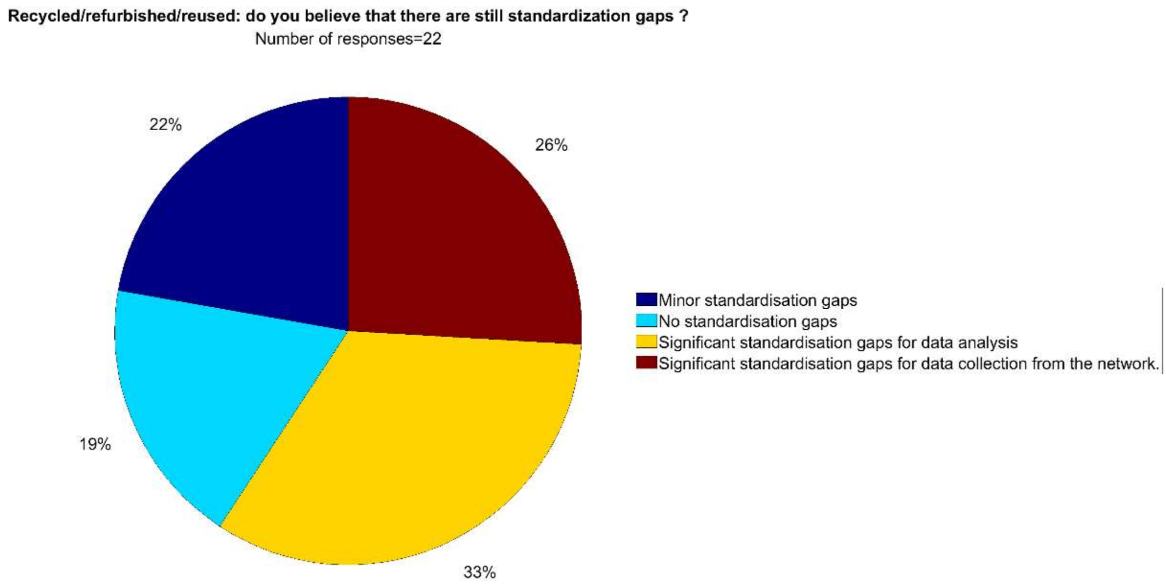

Figure 47 Standardisation gaps in the Distribution or utilisation of recycled/refurbished/ reused products indicator.

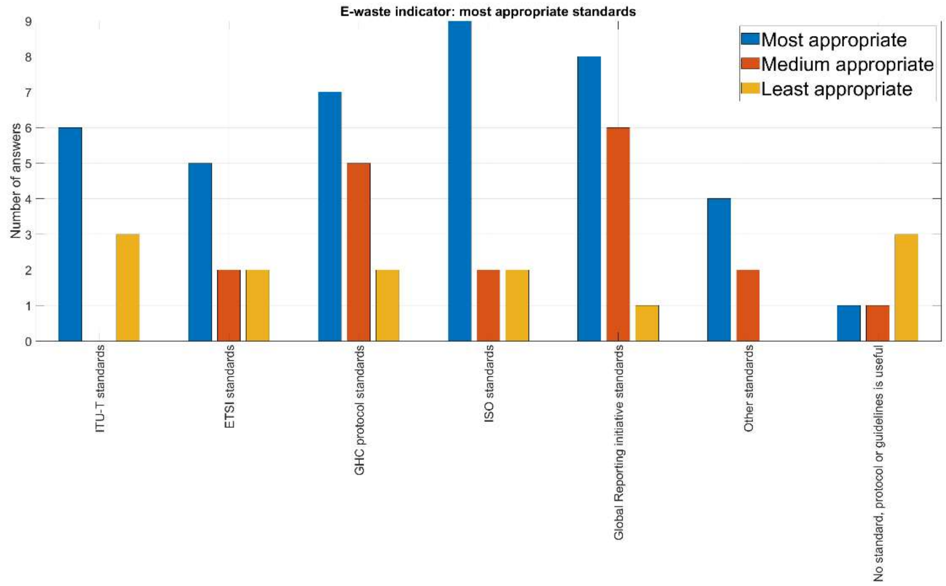

Figure 48 Standards relevant for the Distribution or utilisation of recycled/refurbished/ reused products indicator.

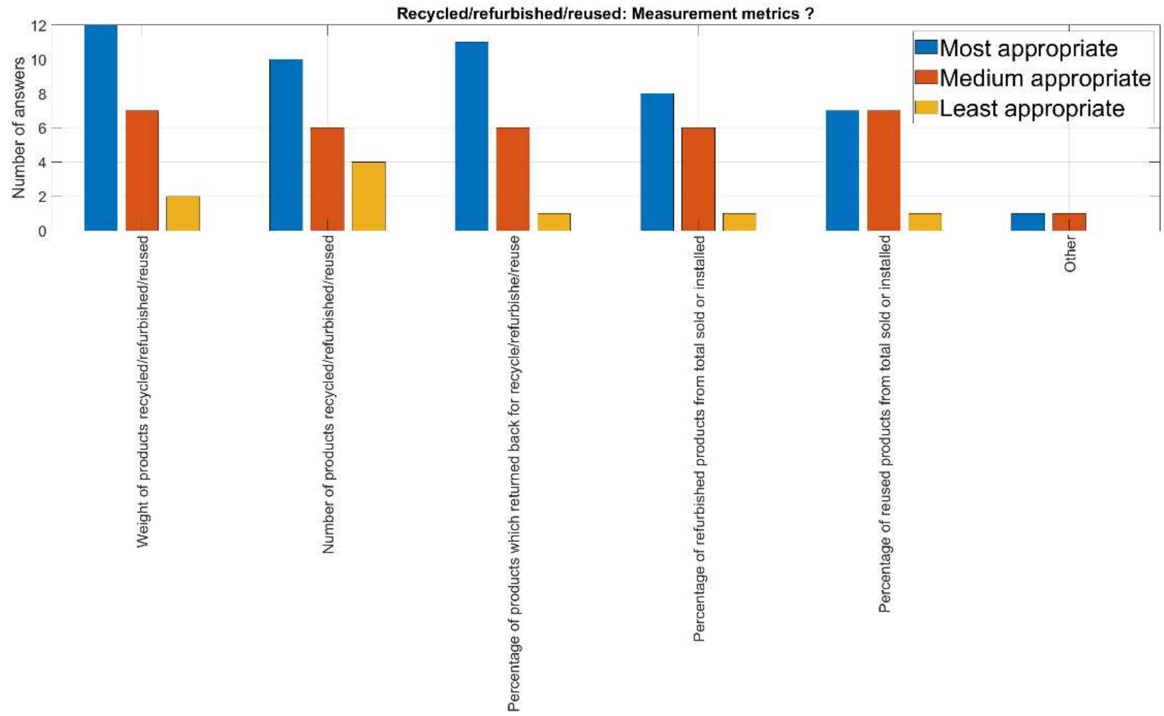

Figure 49 Measurement metrics used in the Distribution or utilisation of recycled/refurbished/ reused products indicator.

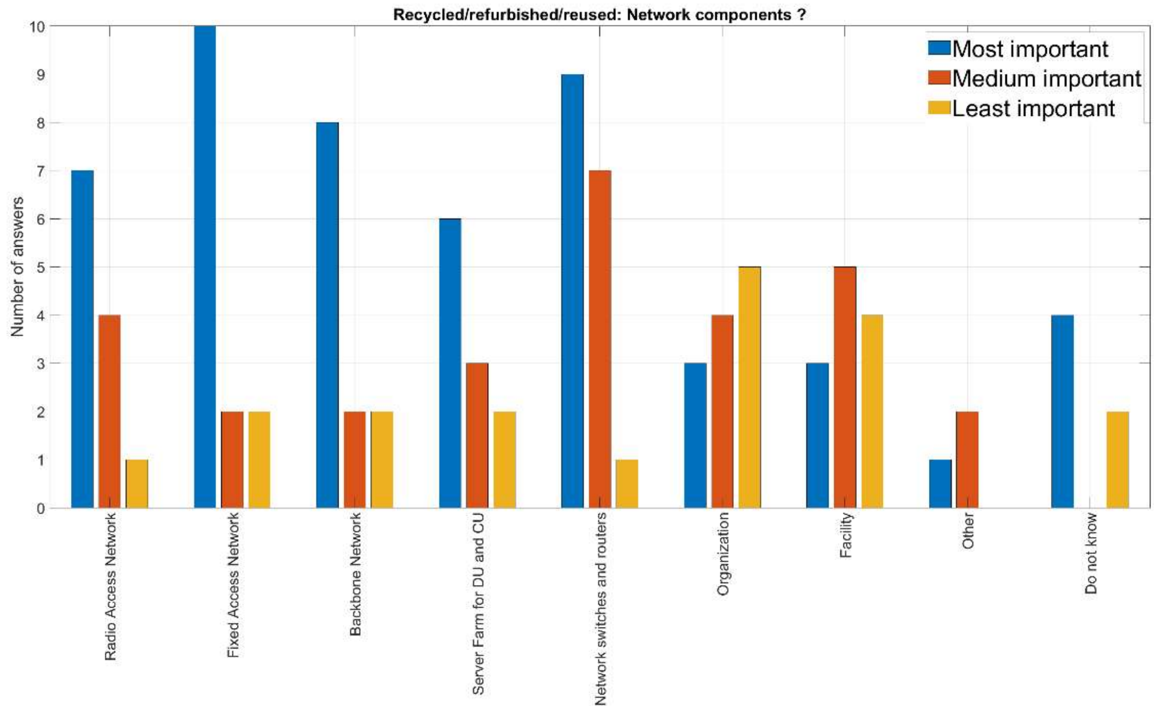

Figure 50 Relevance of the network components for the Distribution or utilisation of recycled/refurbished/ reused products indicator.

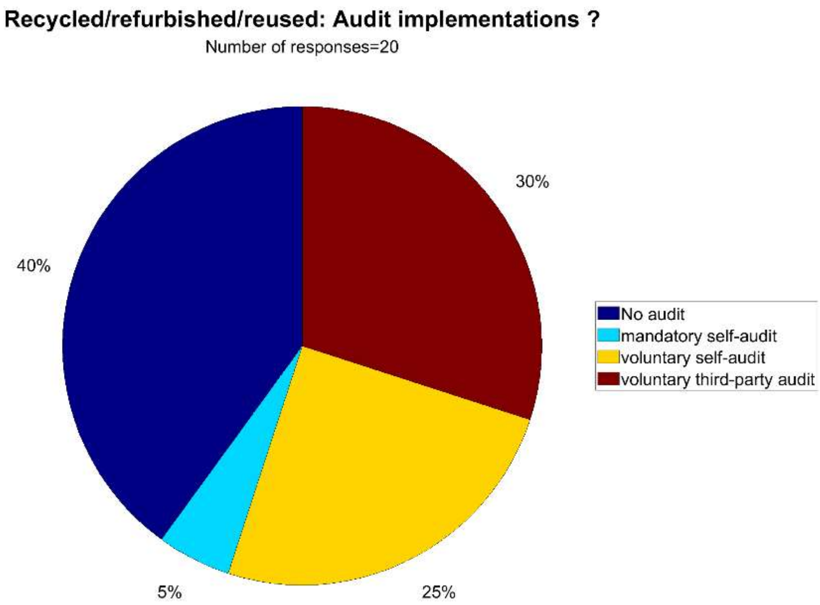

Figure 51 Audit implementations for the Distribution or utilisation of recycled/refurbished/ reused products indicator.

B.11 Specific questions for network operators

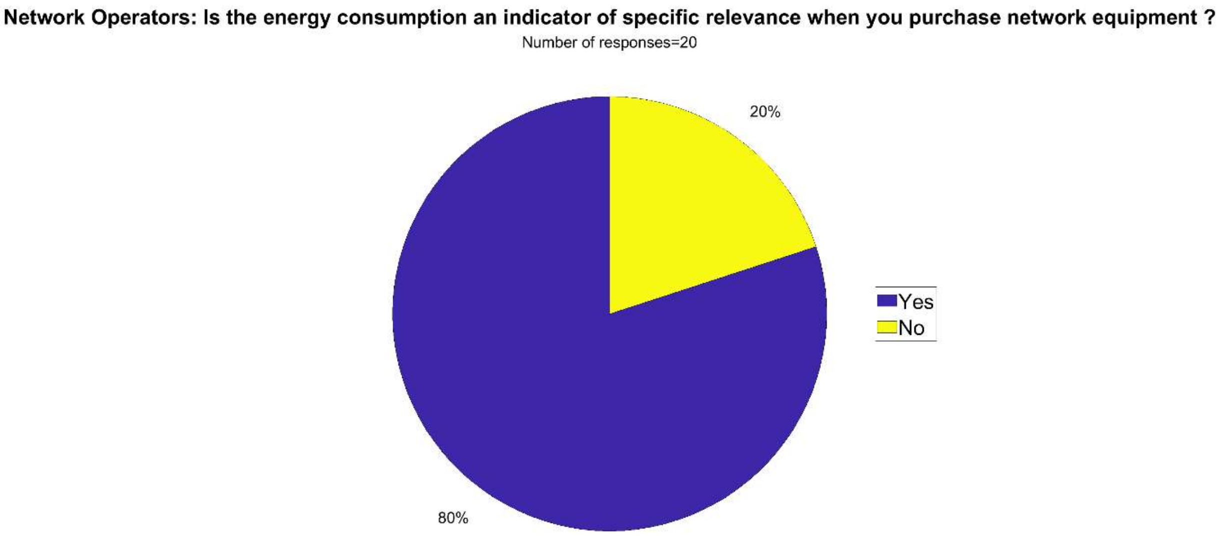

Figure 52 Specific question to network operators for procurement of network equipment.

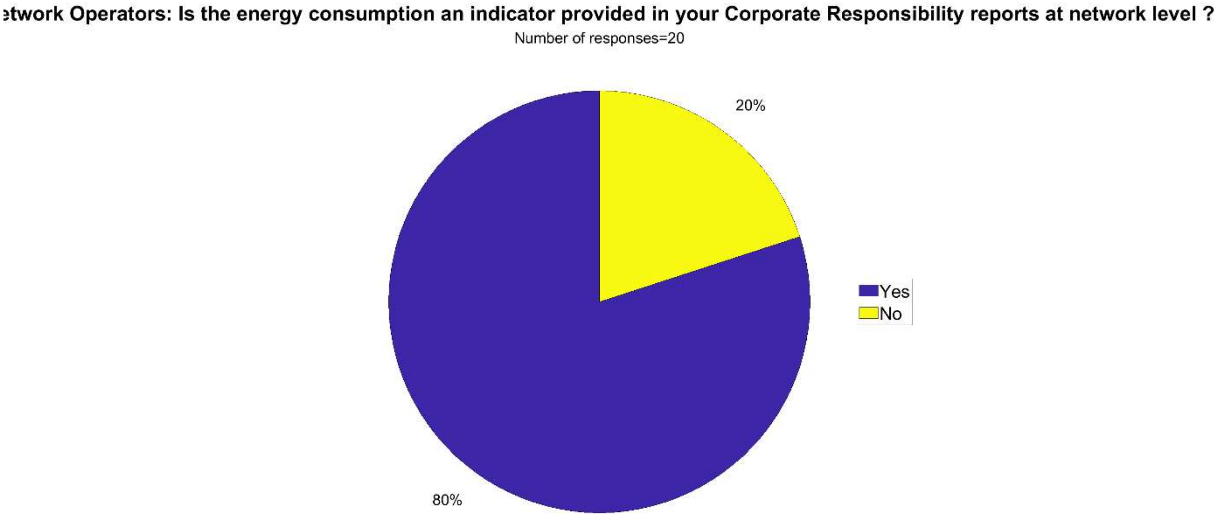

Figure 53 Specific question to network operators for reporting in Corporate Responsibility report

Annex C: Lists of standards on environmental sustainability relevant to the telecommunications sector

Annex A lists the standards relevant to environmental sustainability in telecommunications networks developed by the various standardisation organisations.

C.1 ETSI TC EE standards

Table 36 List of ETSI TC EE standards relevant to environmental sustainability

ETSI Number and Date	Title
ETSI EN 303 808 V1.1.1 (2023-01)	Environmental Engineering (EE); Applicability of EN 45552 to EN 45559 methods for assessment of material efficiency aspects of ICT network infrastructure goods in the context of circular economy
ETSI TS 103 786 V1.1.1 (2020-12)	Environmental Engineering (EE); Measurement method for energy efficiency of wireless access network equipment; Dynamic energy performance measurement method of 5G Base Station (BS)
ETSI ES 203 700 V1.1.1 (2021-02)	Environmental Engineering (EE); Sustainable power feeding solutions for 5G network
ETSI ES 203 682 V1.1.1 (2020-02)	Environmental Engineering (EE); Green Abstraction Layer (GAL); Power management capabilities of the future energy telecommunication fixed network nodes; Enhanced Interface for power management in Network Function Virtualisation (NFV) environments
ETSI TR 103 679 V1.1.1 (2019-05)	Environmental Engineering (EE); Explore the challenges of developing product group-specific Product Environmental Footprint Category Rules (PEFCRs) for smartphones
ETSI TS 103 586 V1.3.1 (2022-10)	Environmental Engineering (EE); Liquid cooling solutions for Information and Communication Technology (ICT) infrastructure equipment
ETSI TS 103 553-1 V1.1.1 (2019-08)	Environmental Engineering (EE); Innovative energy storage technology for stationary use; Part 1: Overview
ETSI TS 103 553-2 V1.1.1 (2021-11)	Environmental Engineering (EE); Innovative energy storage technology for stationary use; Part 2: Battery
ETSI TS 103 553-3 V1.1.1 (2020-01)	Environmental Engineering (EE); Innovative energy storage technology for stationary use; Part 3: Supercapacitor
ETSI TR 103 542 V1.1.1 (2018-06)	Environmental Engineering (EE); Study on methods and metrics to evaluate energy efficiency for future 5G systems
ETSI TR 103 541 V1.1.1 (2018-05)	Environmental Engineering (EE); Best practice to assess energy performance of future Radio Access Network (RAN) deployment
ETSI TR 103 540 V1.1.1 (2018-04)	Environmental Engineering (EE); Mobile Network (MN) Energy Consumption (EC) estimation method; Energy estimation method based on statistical approach

ETSI ES 203 539 V1.1.1 (2019-06)	Environmental Engineering (EE); Measurement method for energy efficiency of Network Functions Virtualisation (NFV) in laboratory environment
ETSI TR 103 476 V1.1.2 (2018-02)	Environmental Engineering (EE); Circular Economy (CE) in Information and Communication Technology (ICT); Definition of approaches, concepts and metrics
ETSI ES 203 475 V1.1.1 (2017-11)	Environmental Engineering (EE); Standardisation terms and trends in energy efficiency
ETSI ES 203 474 V1.1.1 (2018-03)	Environmental Engineering (EE); Interfacing of renewable energy or distributed power sources to 400 VDC distribution systems powering Information and Communication Technology (ICT) equipment
ETSI EN 303 472 V1.1.1 (2018-10)	Environmental Engineering (EE); Energy Efficiency measurement methodology and metrics for RAN equipment
ETSI EN 303 471 V1.1.1 (2019-01)	Environmental Engineering (EE); Energy Efficiency measurement methodology and metrics for Network Function Virtualisation (NFV)
ETSI EN 303 470 V1.1.1 (2019-03) ETSI ES 203 237 V1.1.1 (2014-03)	Environmental Engineering (EE); Energy Efficiency measurement methodology and metrics for servers Environmental Engineering (EE); Green Abstraction Layer (GAL); Power management capabilities of the future energy telecommunication fixed network nodes
ETSI TR 103 229 V1.1.1 (2014-07)	Environmental Engineering (EE); Safety Extra Low Voltage (SELV) DC power supply network for ICT devices with energy storage and grid or renewable energy sources options
ETSI ES 203 228 V1.4.1 (2022-04)	Environmental Engineering (EE); Assessment of mobile network energy efficiency
ETSI EN 303 215 V1.3.1 (2015-04)	Environmental Engineering (EE); Measurement methods and limits for power consumption in broadband telecommunication networks equipment
ETSI ES 203 199 V1.3.1 (2015-02)	Environmental Engineering (EE); Methodology for environmental Life Cycle Assessment (LCA) of Information and Communication Technology (ICT) goods, networks and services
ETSI TS 103 199 V1.1.1 (2011-11)	Environmental Engineering [EE]; Life Cycle Assessment (LCA) of ICT equipment, networks and services; General methodology and common requirements
ETSI ES 203 184 V1.1.1 (2013-03)	Environmental Engineering (EE); Measurement Methods for Power Consumption in Transport Telecommunication Networks Equipment
ETSI ES 203 136 V1.2.1 (2017-10)	Environmental Engineering (EE); Measurement methods for energy efficiency of router and switch equipment
ETSI TR 103 117 V1.1.1 (2012-11)	Environmental Engineering (EE); Principles for Mobile Network level energy efficiency
ETSI TS 102 706-2 V1.5.1 (2018-11)	Environmental Engineering (EE); Metrics and Measurement Method for Energy Efficiency of Wireless Access Network Equipment; Part 2: Energy Efficiency - dynamic measurement method

ETSI ES 202 706-1 V1.7.1 (2022-08)	Environmental Engineering (EE); Metrics and measurement method for energy efficiency of wireless access network equipment; Part 1: Power consumption - static measurement method
ETSI ES 202 706 V1.4.1 (2014-12)	Environmental Engineering (EE); Measurement method for power consumption and energy efficiency of wireless access network equipment
ETSI TS 102 706 V1.3.1 (2013-07)	Environmental Engineering (EE); Measurement method for energy efficiency of wireless access network equipment
ETSI TS 102 533 V1.1.1 (2008-06)	Environmental Engineering (EE) Measurement Methods and limits for Energy Consumption in Broadband Telecommunication Networks Equipment
ETSI TR 102 532 V1.2.1 (2012-11)	Environmental Engineering (EE); The use of alternative energy solutions in telecommunication installations
ETSI TR 102 530 V1.2.1 (2011-07)	Environmental Engineering (EE); The reduction of energy consumption in telecommunications equipment and related infrastructure
ETSI ES 202 336-Parts 1-12	Environmental Engineering (EE); Monitoring and control interface for infrastructure equipment (power, cooling and building environment systems used in telecommunication networks)
ETSI EN 301 575 V1.1.1 (2012-05)	Environmental Engineering (EE); Measurement method for energy consumption of Customer Premises Equipment (CPE)
ETSI ES 201 554 V1.2.1 (2014-07)	Environmental Engineering (EE); Measurement method for Energy efficiency of Mobile Core network and Radio Access Control equipment
ETSI EN 300 019-2-8 V2.2.1 (2020-03)	Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 2-8: Specification of environmental tests; Stationary use at underground locations
ETSI EN 300 019-2-7 V3.0.1 (2003-04)	Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 2-7: Specification of environmental tests; Portable and non-stationary use
ETSI EN 300 019-2-6 V3.0.7 (2023-07)	Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 2: Specification of environmental tests; Sub-part 6: Ship environments
ETSI EN 300 019-2-5 V3.1.1 (2021-09)	Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 2: Specification of environmental tests; Sub-part 5: Ground vehicle installations
ETSI EN 300 019-2-4 V2.5.1 (2018-07)	Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 2-4: Specification of environmental tests; Stationary use at non-weather protected locations
ETSI EN 300 019-2-0 V2.2.1 (2022-08)	Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 2: Specification of environmental tests; Sub-part 0: Introduction

ETSI EN 300 019-2-1 V2.3.1 (2017-11)	Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 2-1: Specification of environmental tests; Storage
ETSI EN 300 019-2-2 V2.4.1 (2017-11)	Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 2-2: Specification of environmental tests; Transportation

C.2 ITU standards

Table 37 ITU-T's recommendations on e-waste and circular economy.

ITU standard ID	Text
ITU-T L.1020	Circular economy: Guide for operators and suppliers on approaches to migrate towards circular ICT goods and networks
ITU-T L.1021	Extended producer responsibility - Guidelines for sustainable e-waste management
ITU-T L.1022	Circular economy: Definitions and concepts for material efficiency for information and communication technology
ITU-T L.1023	Assessment method for circular scoring
ITU-T L.1024	The potential impact of selling services instead of equipment on waste creation and the environment – Effects on global information and communication technology
ITU-T L.1030	E-waste management framework for countries
ITU-T L.1031	Guideline for achieving the e-waste targets of the Connect 2030 Agenda
ITU-T L.1032	Guidelines and certification schemes for e-waste recyclers
ITU-T L.1034	Adequate assessment and sensitization on counterfeit information and communication technology products and their environmental impact
ITU-T L.1035	Sustainable management of batteries
ITU-T L.1036	Scheduled waste management for a base station (inclusive of e-waste)
ITU-T L.1040	Effects of information and communication technology-enabled autonomy on vehicles longevity and waste creation
ITU-T L.1050	Methodology to identify key equipment for environmental impact and e- waste generation assessment of network architectures
ITU-T L.1060	General principles for the green supply chain management of information and communication technology manufacturing industry
ITU-T L.1061	Circular public procurement of information and communication technologies
ITU-T L.1100	Procedure for recycling rare metals in information and communication technology goods

ITU-T L.1101	Measurement methods to characterize rare metals in information and communication technology goods

Table 38 ITU-T's recommendations on power feeding and energy storage.

ITU standard ID	**Text**
ITU-T L.1202	Methodologies for evaluating the performance of an up to 400 VDC power feeding system and its environmental impact
ITU-T L.1205	Interfacing of renewable energy or distributed power sources to up to 400 VDC power feeding systems
ITU-T L.1210	Sustainable power-feeding solutions for 5G networks
ITU-T L.1220	Innovative energy storage technology for stationary use - Part 1: Overview of energy storage
ITU-T L.1221	Innovative energy storage technology for stationary use - Part 2: Battery
ITU-T L.1222	Innovative energy storage technology for stationary use - Part 3: Supercapacitor technology
ITU-T L.1240	Evaluation method of safety operations and energy saving for power supply systems in telecommunication rooms or buildings

Table 39 ITU-T's recommendations on energy efficiency, smart energy and green data centres.

ITU standard ID	**Text**
ITU-T L.1300	Best practices for green data centres
ITU-T L.1301	Minimum data set and communication interface requirements for data centre energy management
ITU-T L.1302	Assessment of energy efficiency on infrastructure in data centres and telecom centres
ITU-T L.1303	Functional requirements and framework of green data centre energy-saving management system
ITU-T L.1304	Procurement criteria for sustainable data centres
ITU-T L.1310	Energy efficiency metrics and measurement methods for telecommunication equipment
ITU-T L.1315	Standardisation terms and trends in energy efficiency
ITU-T L.1316	Energy efficiency framework
ITU-T L.1317	Guidelines on energy efficient blockchain systems

ITU-T L.1318	Q factor: A fundamental metric expressing integrated circuit energy efficiency
ITU-T L.1320	Energy efficiency metrics and measurement for power and cooling equipment for telecommunications and data centres
ITU-T L.1321	Reference operational model and interface for improving energy efficiency of ICT network hosts
ITU-T L.1325	Green ICT solutions for telecom network facilities
ITU-T L.1330	Energy efficiency measurement and metrics for telecommunication networks
ITU-T L.1331	Assessment of mobile network energy efficiency
ITU-T L.1332	Total network infrastructure energy efficiency metrics
ITU-T L.1333	Carbon data intensity for network energy performance monitoring
ITU-T L.1340	Informative values on the energy efficiency of telecommunication equipment
ITU-T L.1350	Energy efficiency metrics of a base station site
ITU-T L.1351	Energy efficiency measurement methodology for base station sites
ITU-T L.1360	Energy control for the software-defined networking architecture
ITU-T L.1361	Measurement method for energy efficiency of network functions virtualization
ITU-T L.1362	Interface for power management in network function virtualization environments – Green abstraction Layer version 2
ITU-T L.1370	Sustainable and intelligent building services
ITU-T L.1371	A methodology for assessing and scoring the sustainability performance of office buildings
ITU-T L.1380	Smart energy solution for telecom sites
ITU-T L.1381	Smart energy solutions for data centres
ITU-T L.1382	Smart energy solution for telecommunication rooms
ITU-T L.1383	Smart energy solutions for city and home applications
ITU-T L.1390	Energy saving technologies and best practices for 5G radio access network (RAN) equipment

Table 40 ITU-T's recommendations on the assessment of methodologies of ICTs and CO2 trajectories.

ITU standard ID	**Text**
ITU-T L.1400	Overview and general principles of methodologies for assessing the environmental impact of information and communication technologies

ITU-T L.1410	Methodology for environmental life cycle assessments of information and communication technology goods, networks and services
ITU-T L.1420	Methodology for energy consumption and greenhouse gas emissions impact assessment of information and communication technologies in organisations
ITU-T L.1430	Methodology for assessment of the environmental impact of information and communication technology greenhouse gas and energy projects
ITU-T L.1440	Methodology for environmental impact assessment of information and communication technologies at city level
ITU-T L.1450	Methodologies for the assessment of the environmental impact of the information and communication technology sector
ITU-T L.1451	Methodology for assessing the aggregated positive sector-level impacts of ICT in other sectors
ITU-T L.1460	Connect 2020 greenhouse gases emissions - Guidelines
ITU-T L.1470	Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement
ITU-T L.1471	Guidance and criteria for information and communication technology organisations on setting Net Zero targets and strategies
ITU-T L.1480	Enabling the Net Zero transition: Assessing how the use of information and communication technology solutions impact greenhouse gas emissions of other sectors
ITU-T L.1481	Guidance on how to address the Connect 2030 targets on net greenhouse gas abatement

Table 41 ITU-T's recommendations on adaptation to climate change.

ITU standard ID	**Text**
ITU-T L.1500	Framework for information and communication technologies and adaptation to the effects of climate change
ITU-T L.1501	Best practices on how countries can utilize ICTs to adapt to the effects of climate change
ITU-T L.1502	Adapting information and communication technology infrastructure to the effects of climate change
ITU-T L.1503	Use of information and communication technology for climate change adaptation in cities
ITU-T L.1504	ICT and adaptation of agriculture to the effects of climate change
ITU-T L.1505	Information and communication technology and adaptation of the fisheries sector to the effects of climate change

ITU-T L.1506	Framework of climate change risk assessment for telecommunication and electrical facilities
ITU-T L.1507	Use of ICT sites to support environmental sensing

Table 42 ITU-T's recommendations on circular and sustainable cities and communities.

ITU standard ID	**Text**
ITU-T L.1600	Overview of key performance indicators in smart sustainable cities
ITU-T L.1601	Key performance indicators related to the use of information and communication technology in smart sustainable cities
ITU-T L.1602	Key performance indicators related to the sustainability impacts of information and communication technology in smart sustainable cities
ITU-T L.1603	Key performance indicators for smart sustainable cities to assess the achievement of sustainable development goals
ITU-T L.1620	Guide to circular cities
ITU-T L.1630	Framework of a building infrastructure management system for sustainable cities

Table 43 ITU-T's recommendations on low cost sustainable infrastructure.

ITU standard ID	**Text**
ITU-T L.1700	Requirements and framework for low-cost sustainable telecommunications infrastructure for rural communications in developing countries

C.3 ISO standards

Table 44 List of ISO standards relevant to climate change indicators and energy management.

ISO Number and Date	**Title**
ISO/IEC 13273:2015	Energy efficiency and renewable energy sources — Common international terminology (Part 1: Energy efficiency, Part 2: Renewable energy sources)
ISO 14001:2015	Environmental management systems Requirements with guidance for use
ISO 14020:2022	Environmental statements and programmes for products — Principles and general requirements
ISO 14021:2016	Environmental labels and declarations — Self-declared environmental claims (Type II environmental labelling)
ISO 14024:2018	Environmental labels and declarations — Type I environmental labelling — Principles and procedures

ISO 14025:2006	Environmental labels and declarations — Type III environmental declarations — Principles and procedures
ISO 14031:2021	Environmental management — Environmental performance evaluation — Guidelines
ISO 14040:2006	Environmental management — Life cycle assessment — Principles and framework
ISO 14044:2006	Environmental management — Life cycle assessment — Requirements and guidelines
ISO 14046:2014	Environmental management — Water footprint — Principles, requirements and guidelines
ISO 14050:2020	Environmental management — vocabulary
ISO 14064-1:2018	Greenhouse gases — Part 1: Specification with guidance at the organisation level for quantification and reporting of greenhouse gas emissions and removals
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
ISO 14065:2020	General principles and requirements for bodies validating and verifying environmental information
ISO 14067:2018	Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification
ISO 14080:2018	Greenhouse gas management and related activities — Framework and principles for methodologies on climate actions
ISO/TS 14071:2014	Environmental management — Life cycle assessment — Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006
ISO 14091:2021	Adaptation to climate change — Guidelines on vulnerability, impacts and risk assessment
ISO/IEC 30134:2016	Information technology — Data centres — Key performance indicators
ISO 50001:2018	Energy management systems

C.4 Global Reporting Initiative (GRI)

The GRI standards relevant to activities for reporting environmental sustainability in the telecommunications field are listed below, followed by a short description[80]:

- GRI 1: Foundation 2021

It explains key concepts for sustainability reporting. It also defines the requirements that the organisations must comply with to report in accordance with the GRI Standards. It is the first standard that organisations should consult to understand how to report using the GRI Standards.

- GRI 204: Procurement Practices 2016

[80] https://www.globalreporting.org/how-to-use-the-gri-standards/gri-standards-english-language/

It addresses the topic of procurement practices and how these practices can cause or contribute to negative impacts in the supply chain, covering the support for local suppliers or those belonging to vulnerable groups.

- GRI 205: Anti-corruption 2016

This standard deals with the topic of anti-corruption, which is strongly linked to negative impacts, i.e., as poverty in transition economies, damage to the environment, abuse of human rights, abuse of democracy, misallocation of investments, and undermining the rule of law. It explains how the organisations should demonstrate integrity and responsible business practices.

- GRI 301: Materials 2016

This standard addresses the issue of materials used for an organisation's product and services, as these can be non-renewable (e.g. minerals, metals, gas, oil) or renewable (e.g. water, wood). The type and amount of materials used by the organisation can show its dependence on natural resources, and the impacts it has on their availability, indicating the organisation's approach to activities like recycling and reusing, which lead to resource conservation.

- GRI 302: Energy 2016

The standard deals with an organisation's energy consumption and how this energy can be used in an efficient way, as it can be self-generated or purchased and can come from renewable sources or not.

- GRI 303: Water and Effluents 2018

The standard deals with the amount of water consumed by an organisation and its discharges which can impact the ecosystem in many ways. Organisations are encouraged to take action in areas with water stress and align their activities with other water users by respecting their needs and complying with public policy.

- GRI 304: Biodiversity 2016

The standard addresses the topic of biodiversity, which is important for ensuring the survival of the ecosystem, leading eventually to poverty reduction and sustainable development.

- GRI 305: Emissions 2016

It deals with emissions into the air, coming from the discharge of substances into the atmosphere. Types of emissions include: GHG, ozone-depleting substances (ODS), nitrogen oxides (NO) and sulfur oxides (SO), among other significant air emissions.

The requirements for GHG emissions in GRI 305 are based on the requirements of the GHG Protocol Corporate Accounting and Reporting Standard and the GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard developed by the GHG Protocol standards.

- GRI 306: Waste 2020

An organisation generates waste by its own activities or by activities in its value chain (suppliers, consumers). This waste can impact negatively the environment and human health when it is managed in a non-efficient way. The standard explains how an organisation can move toward the SDG 12 and in particular how to implement environmentally sound waste management by preventing and reducing waste through reuse and recycling.

- GRI 308: Supplier Environmental Assessment 2016

This standard explains how suppliers of an organisation can be assessed for a range of environmental criteria such as impacts related to energy, water, or emissions. This is important as the organisation can have negative impacts not only by its activity but also by entities in its value chain, i.e., its suppliers.

- GRI 413: Local Communities 2016

An organisation's activities and infrastructure can have significant economic, social, cultural and environmental impacts on local communities, which are defined as individuals or groups of individuals living or working in areas that are affected or that could be affected by the organisation's activities. GRI 413 explains how organisations are expected to anticipate and avoid negative impacts on local communities, e.g. by establishing an effective stakeholder identification and engagement process. Due to the heterogeneous nature of local communities, an organisation is expected to consider the differentiated nature of communities and the distinct and specific vulnerabilities these groups can suffer because of the organisation's activities.

Annex D. Quantitative analysis

The quantitative analysis aims to estimate the impact of some indicators using public data on the deployment of telecommunication networks.

In particular, we considered the deployment of cellular networks in:

- France, using the data from ANFR at https://www.cartoradio.fr/#/cartographie/stations
- Italy using the data from https://lteitaly.it/it/

D.1 Data from France

We have downloaded the data of all the cellular networks from France using the web site https://www.cartoradio.fr/#/cartographie/stations.

The data was downloaded in November 2023 and it consisted of more than 689,000 terminals of different mobile communication generation and standards (LTE, GSM, UMTS) and 20 sites (which may include more than one base stations).

The radio terminals are subdivided among the different cellular technology generations as from the following pie chart:

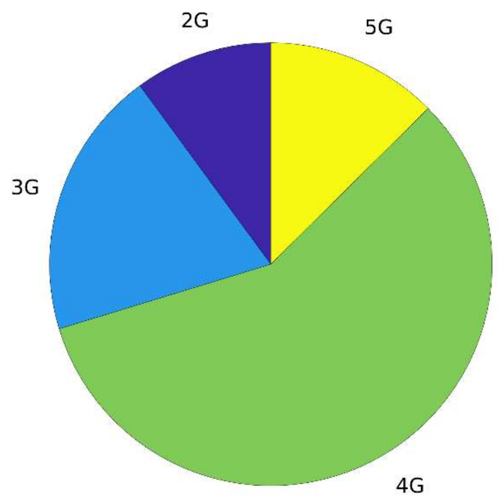

Figure 54 Repartition of the cellular technology generation in the downloaded data from France.

We have considered all the base stations and terminals among the different cellular telecom providers, which are partitioned according to the following figure.

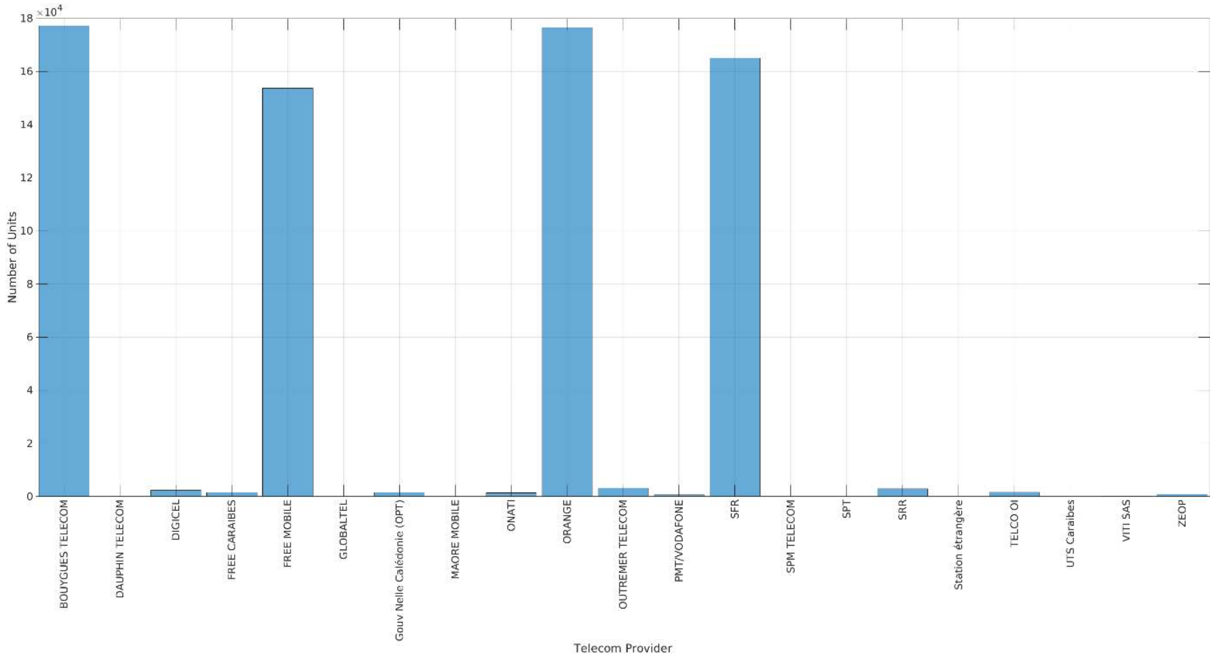

Figure 55 Distribution of the telecom providers for France data.

We have considered the power consumption indicator using data from the resources below in references (Alsharif 2017), (Golard 2021), (Pihkola 2018). One issue is that the power consumption of a typical base station depends on many factors including the traffic load, the cellular generation (3G,4G), if more than one spectrum band is supported and so on.

Then, some simplifications and approximations are needed, which lead to the following table:

Table 45 Power consumption for different categories of Base Station.

Type of terminals	**Power Consumption per hour W/h: High Value**	**Power Consumption per hour W/h: Low Value**
GSM900	1800	600
GSM1800	2300	900
UMTS900	1000	750
UMTS2100	1700	1300
4G-LTE (700)	965	800
4G-LTE (800)	965	800
4G-LTE (900)	965	800
4G-LTE (1800)	1380	1100
4G-LTE (2100)	1237	1000
4G-LTE (2600)	1980	1350

5G (700-1800-2100-3500)	2000	1000
5G sleep mode (70%)	1400	700

We have also estimated the trend on the deployment of base stations and related power consumption according to the year using the indicated year of "Put in Service" for each radio terminals.

The distribution of the radio terminals per year is shown in the following figure.

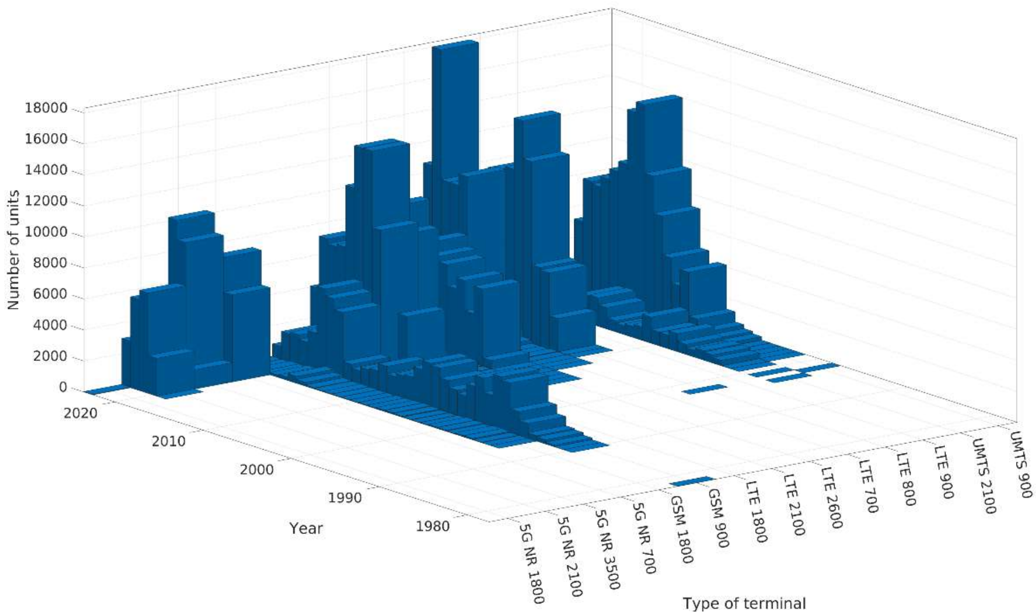

Figure 56 Number of terminal units put in service every years from 1978.

Then, using the year data and the data from Table 45, we estimate the total consumed power for different network configurations as shown in the following Figure.

The 5G sleep mode was calculated using the results from (Huawei 2020),(Golard 2021),(Frenger 2019). Roughly a 5G base station in sleep mode consumes 70% of the same 5G base station without sleep mode.

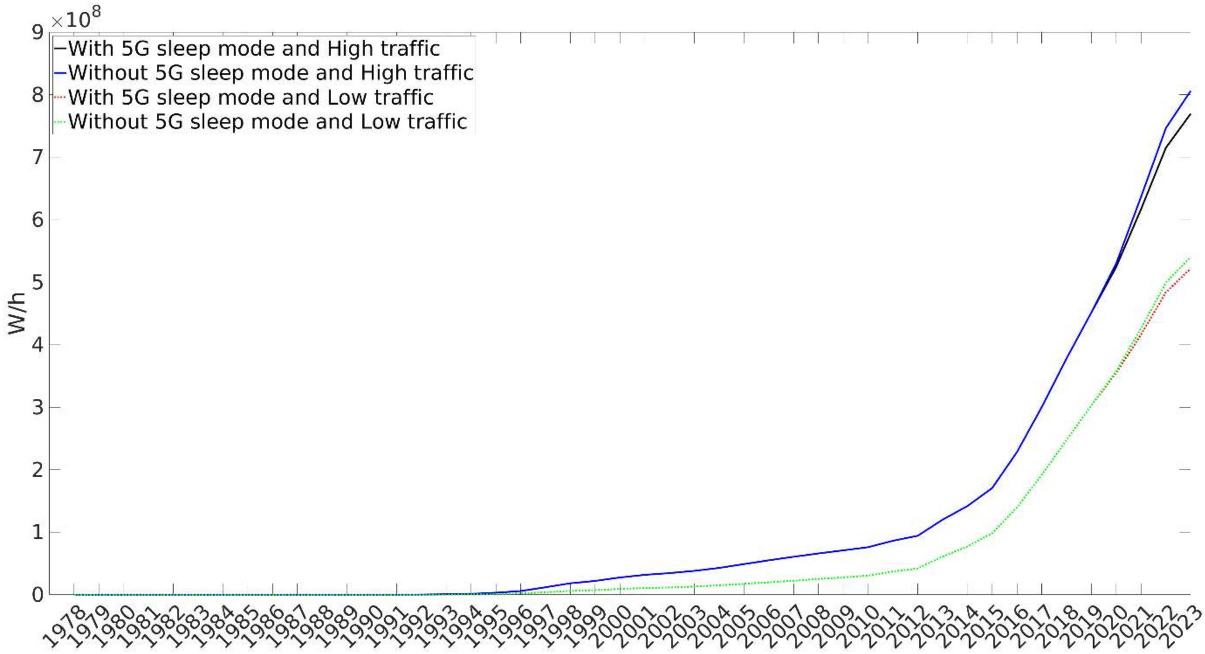

Figure 57 Power Consumption of the French mobile network according to the year for different network configurations.

It can be seen that the power consumption increases dramatically in the last years. The use of the 5G sleep mode can decrease the power consumption but the most significant difference is due to the traffic load. Unfortunately, the traffic load is supposed to increase significantly in the following years.

The total amount for the entire network in one year is approximately 7 TWh, which is in the same order of magnitude of the figures indicated in the references (Golard 2021), (Citizen-consulting 2020).

D.2 Data from Italy.

The data from Italy is collected from the web site https://lteitaly.it/it/. Differently to ANFR data, the data from LTE Italy site is crowdsource and not officially confirmed by any provider. In this case, a web crawler was implemented to download the data from each base station.

The data available for collection is different from the French data from ANFR as it is missing many fields and relevant information like the date that a base station enters in service.

Then, it is possible to derive graphs of energy consumption as it was done in Section D.1.

The data is available for the four main mobile operators: Vodafone, Iliad, WIND and TIM. Contrary to the data for France, the provided data is already defined for each base station, which supports a number of radio terminals for different frequencies. Then, an additional step was executed to obtain a similar structure as in D.1 for the number of radio terminals transmitting in different spectral bands.

The analysis of the data provided the following figures and tables.

Vodafone

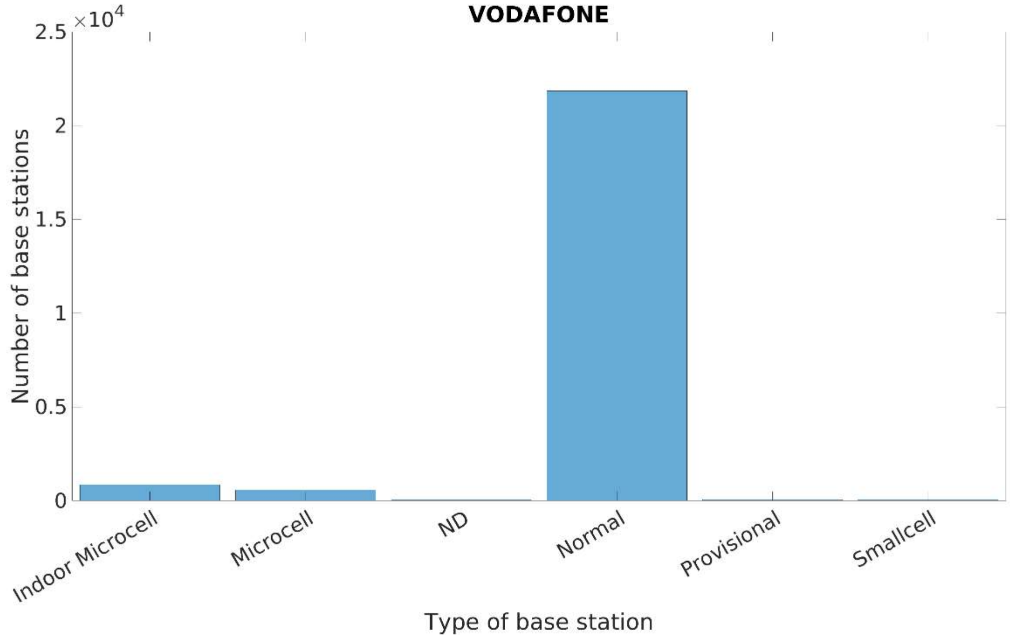

Figure 58 Type of base stations for the Vodafone telecom provider.

The figure above provides the number of base stations for the different categories (ND is Not Defined) for the Vodafone telecom provider. This information is useful to characterize the size of the base station.

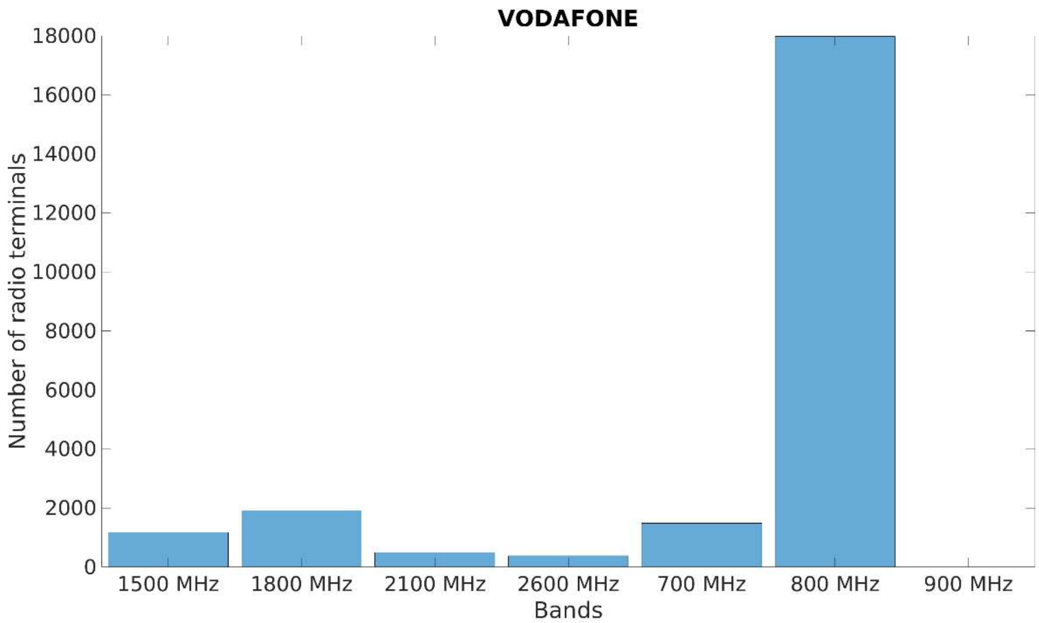

Figure 59 Number of radio terminals for the Vodafone telecom provider.

The figure above provides the number of radio terminals for the Vodafone telecom provider. We can see that the large majority is for the 800 MHz band. This information is used to define the overall power consumption in one year by Vodafone in Italy on the base of the same Table 45 used for ANFR.

Iliad

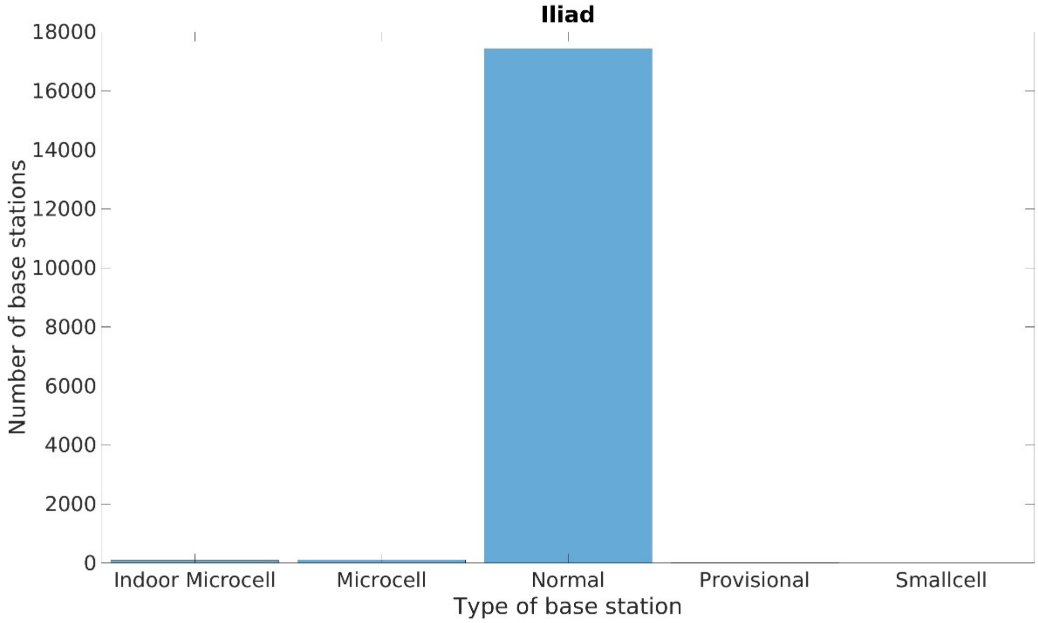

Figure 60 Number of base stations for the Iliad telecom provider.

The figure above provides the number of base stations for the Iliad telecom provider and similar considerations can be applied here as for the Vodafone provider. We note that for Iliad, the Normal base station type is predominant.

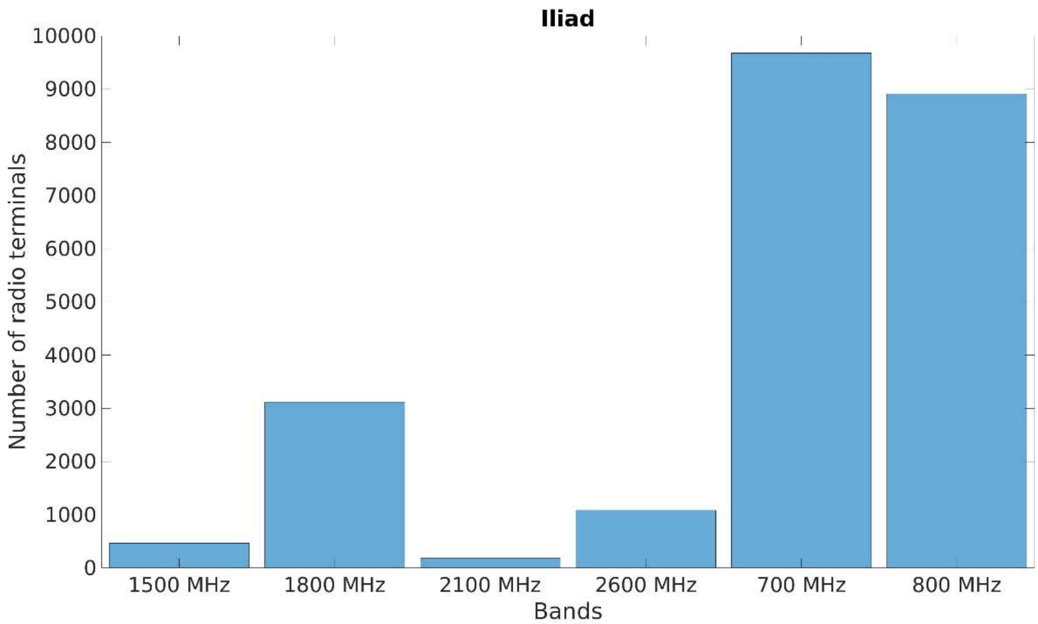

Figure 61 Number of radio terminals for different spectral bands for the Iliad operator.

The figure above provides the number of radio terminals for the Iliad telecom provider. We can see that the distribution is different from the other telecom providers. This information is used to define the overall power consumption in one year by Iliad in Italy on the base of the same Table 45 used for ANFR.

WIND

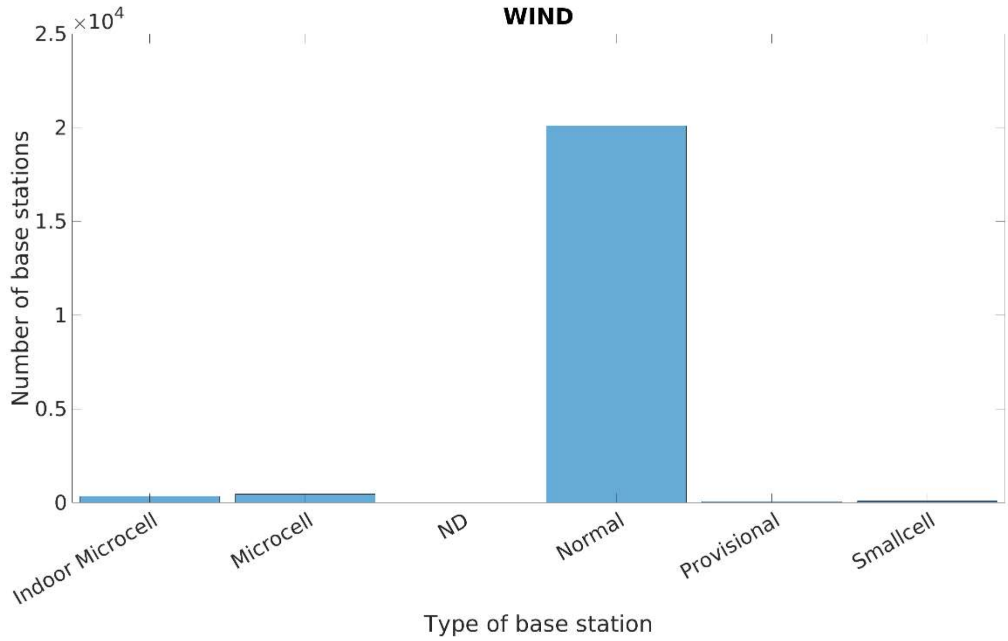

Figure 62 Number of base stations for the WIND telecom provider.

As for the other telecom providers, the number of base stations for Wind is shown in the figure above.

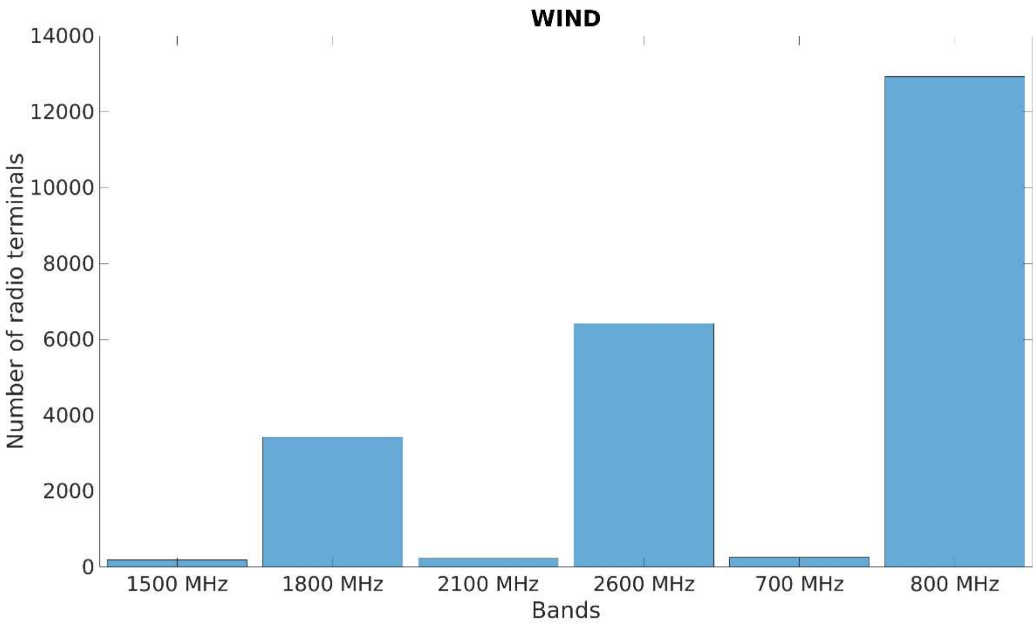

Figure 63 Number of radio terminals in different bands for the WIND operator.

The figure above provides the number of radio terminals using different spectral bands for the WIND operator, which shows a greater diversification than the other operators. Such data is used to estimate the overall power consumption of the mobile network for the WIND operator on the base of Table 45.

TIM

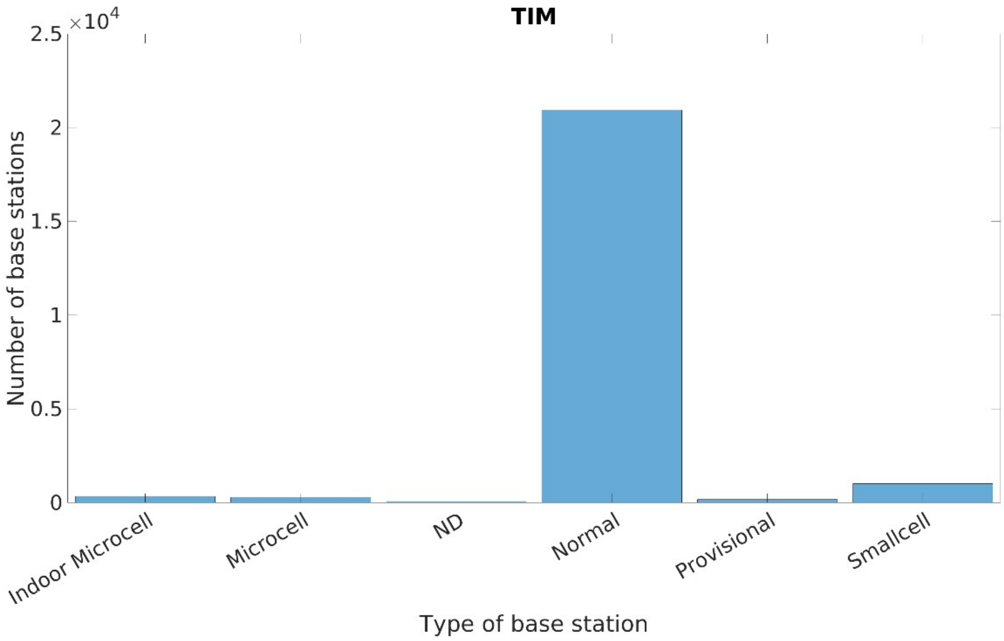

Figure 64 Number of base stations for the TIM telecom provider.

As for the other telecom providers, the figure above shows the number of base stations for the TIM telecom provider.

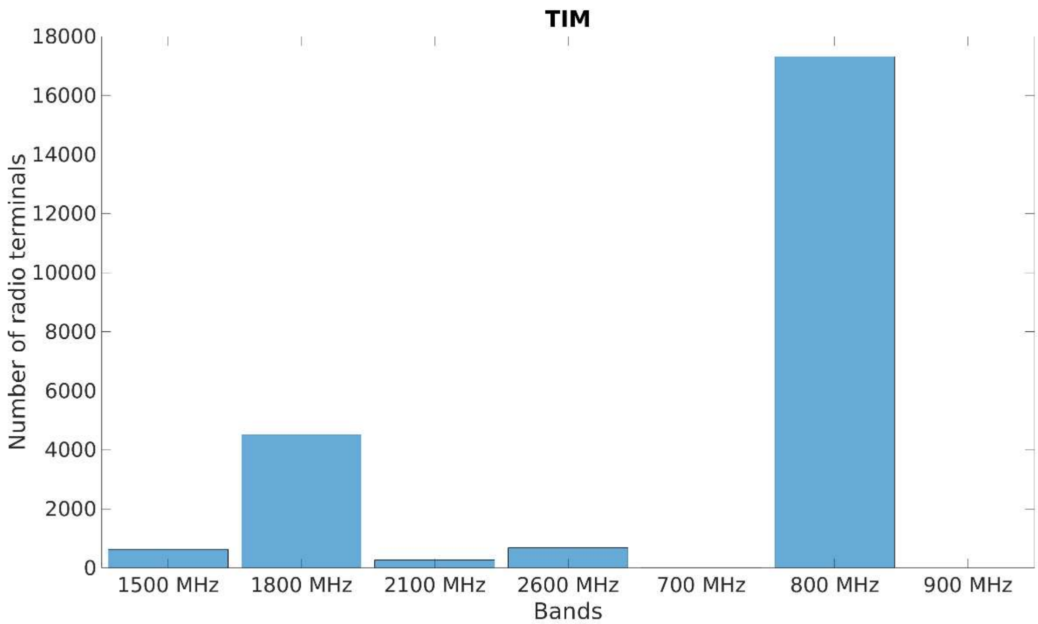

Figure 65 Number of radio terminals for the different spectral bands for the TIM operator.

Finally, the number of radio terminals for the different spectral bands for the TIM operator. As for the other telecom providers, this information is used to estimate the total energy consumption on the basis of Table 45.

D.3 Summary of the yearly power consumption and comparison with the literature.

The following provides the summary of the yearly power consumption provided by this report and from literature.

The yearly figures from France and Italy are based on the data described respectively in sections D.1 and D.2. For Italy, the sum of the four considered providers was used and the detail for each provider is also furnished.

The other figures are provided by the indicated references.

The figures are provided for the highest estimate due to the maximum traffic load.

Table 46 Summary of the yearly power consumption provided by this report and from literature for all the RANs in a country.

Country	Yearly Power Consumption	Normalized to population of France Value multiplied for PC/PF where PC is the population of the country and PC is the population of France.	Normalized to surface area of France Value multiplied for SC/SF where SC is the surface of the country and SC is the surface area of France.
France (this report)	6.981 TWh	6.981 TWh	6.981 TWh
Italy (this report)	4.548 TWh (Vodafone 1.123 TWh, ILIAD 1.295 TWh, WIND 1.297 TWh, TIM 0.833 TWh)	5.33 TWh	8.204 TWh
France (Citizen-Consulting 2020)	3.6 TWh (calculated for 2020 as 70% of the overall mobile networks consumption)	3.6 TWh	3.6 TWh
Finland (Pihkola 2018)	0.6 TWh (calculated for 2016)	7.285 TWh	0.96 TWh
Sweden (Malmodin 2016)	0.7 TWh (calculated for 2015)	3.88 TWh	0.844 TWh

The figures provided in the table above show that the estimates calculated in this report are generally aligned or in the same order of magnitude of what is reported in literature taking in consideration that some estimates from literature are calculated for some years ago.

On the other side, we have also to note the limitations of this high level study because the power consumption of a base station depends on many different factors including the traffic load, the radio coverage, the number of radio terminals and the implementation of energy efficiency measures like the sleep mode.

One final consideration is that the collected data can also be used to support the estimate for other indicators. For example, (Golard 2021) shows how from the energy consumption, it is possible to derive estimates for the energy efficiency and the GHG scope 2. ANFR has also additional details on the position and the size of the base stations (height in meters), which can be used to estimate other indicators like renewable energy. In a similar way, the knowledge of the frequency bands can be used to have estimate on the use of circular economy for the reparability of the electronic components.

Annex E. Research projects

A number of research projects funded by the European Commission have investigated the implementation of sustainability indicators in telecommunications networks. One of the main areas of investigation has been energy consumption and energy efficiency. This sub-section aims to report on the main recent projects, which could be relevant for this study:

- The Horizon 2020 HEXA-X project[81] started in January 2021 and it was completed in June 2023. It was a project aimed to investigate and develop a vision based on upcoming 6G technologies to integrate the digital and physical world with the application of Artificial Intelligence (AI) to improve resource management, network efficiency and in particular sustainability goals. In particular, for sustainability, the goal was to transform networks into an energy-optimised digital infrastructure to reduce the global ICT environmental footprint. The HEXA-X concept is to create a digital fabric, which has the ability to sense and understand the state of the physical world in real-time and as such boost sustainability from the environmental, economic, and social perspectives.
- 6G BRAINS[82] is another project focused on 6G, which has the objective to foster the use of artificial intelligence (in particular deep learning and reinforcement learning) in the optimisation of resources and the performance in terahertz communications, End-to-End (E2E) Slicing, Integrated Access Backhaul (IAB), Industrial Virtual Assistant (IVA), Simultaneous Localisation and Mapping (SLAM), Content Distribution Network (CDN), massive Machine Type Communications (mMTC) and Ultra-Reliable Low Latency Communications (URLLC). One of the objectives of the project is to improve the energy efficiency of 6G networks, by addressing the risk of increased energy consumption due to higher traffic and the use of terahertz communication.
- The 6GREEN project[83] aims to conceive, design and realise an innovative service-based and holistic ecosystem, able to extend "the communication infrastructure into a sustainable, interconnected, greener end-to-end intercompute system" and promote energy efficiency across the whole 5G/6G value-chain. The ultimate objective is to enable and to foster 5G/6G networks and vertical applications, reducing their carbon footprint by a factor of 10 or more. One of the underlying goals of the project is to evaluate the difficulty in collecting metrics and data of sustainability indicators from elements of the telecoms networks to improve their efficiency. This analysis can be useful to enhance the measurability of the indicators.
- Hexa-X-II is a Smart Network and Services Joint Undertaking (SNS JU) 6G Flagship project. Hexa-X-II is a follow-up of Hexa focused on the design of 6G technologies. Hexa-X-II leads the way to the end-to-end (E2E) system design (based on integrated and interacting technology enablers) and the enabling platform delivering novel services for the next generation (6G) of wireless networks with a particular focus on sustainability of the next generation telecom networks. This project started in January 2023.
- ICTFOOTPRINT.eu was a small project completed in 2019 aimed to foster the adoption of methodologies for sustainability indicators in the ICT sector and create a marketplace of opportunities for solution providers in ICT energy & environmental efficiency. The project also aimed to develop a tool, which allows SMEs to make an assessment of their carbon footprint in an efficient way. In this context, ICTFOOTPRINT has identified and evaluated various ICT Life Cycle Impact Assessment (LCIA) methodologies complemented by a map of standards, which can be useful for stakeholders to calculate the environmental footprint of their activities.
- Horizon 2020 ETN SCAVENGE. The objective of the Horizon 2020 ETN SCAVENGE (Sustainable CellulAr networks harVEstiNG ambient Energy) project (started in 2016 and completed in 2021) was to create a training network for early-stage researchers (ESRs) who will contribute to the design and implementation of eco-friendly and sustainable next-generation (5G) networks. The focus of the project was on the improvement of energy efficiency of telecommunications networks and systems and the use of renewable energies. This was implemented using theoretical models, and

[81] https://hexa-x.eu/about/
[82] https://6g-brains.eu/
[83] https://www.6green.eu/

the design, optimisation and proof-of-concept implementation of core networks, BSs and mobile elements and integration with the smart grid to evaluate its relationship with the telecommunication network.

Annex F. Inter-dependencies among indicators

We also analysed the dependency between indicators because the previous analysis has shown that the efforts by a stakeholder in improving the performance of the telecom network for one indicator has also an impact (usually positive) on the performance of the network from the point of view of other indicators.

The presented dependencies are focused only on the indicators with the highest priorities. The analysis can be easily extended to other indicators.

The table below is accessible through the following link shows the dependency among the various indicators:

Table 47 Dependency among the different sustainability indicators (click on the table to instantiate it as an Excel table)

Indicators	Energy consumption	Carbon emissions - Direct emissions (e.g., scope 1 emissions)	Carbon emissions - Energy indirect emissions (e.g., scope 2 emissions)	Carbon emissions - Other indirect emissions (e.g., scope 3 emissions)	Energy efficiency	Use of renewable energy (rate)	Distribution or utilisation of recycled/refurbished/ reused products	Expected lifetime	Water usage/consumption	Raw Materials	E-waste production	Recycled/refurbished/ reused components (also excavated masses) used in products	Recyclability
Energy consumption	N/A	N/A	The efforts to improve the performance of energy consumption in the telecommunication network has a positive impact on the GHG scope 2 because the decrease in energy consumption reduces the GHG as well.	The efforts to reduce the energy consumption in the telecommunication network has a limited impact on the scope 3 mostly related to the procurement of equipment of energy efficient network equipment.	The effort to reduce energy consumption in the telecommunication network can support the research and adoption of solutions for energy efficiency.	The effort to reduce energy consumption could be related to the use of renewable energy when it is more efficient than central provided solutions even if it is more expensive.	The effort to reduce energy consumption may be in opposition on the use of refurbished products or recycle of old products when these are less energy efficient than new ones in the market (which is often the case).	The effort to reduce energy consumption may be in opposition on the extension of the lifetime of the equipment used in the networks if new equipment, which is more efficient when it comes to the market.	The effort to reduce energy consumption may impact positively the usage of water but specifically for the servers and server farms used in the network.	No dependency	No dependency	The effort to reduce energy consumption may be in opposition on the use of refurbished components or recycle of old components when these are less energy efficient than new ones in the market (which is often the case).	The effort to reduce energy consumption may be in opposition on the use of recyclable material, which it is less efficient than new products.
Carbon emissions - Direct emissions (e.g., scope 1 emissions)	The effort to reduce the GHG for scope 1 has a limited impact on the energy consumption of a telecommunication network because it is not in scope 1.	N/A	N/A	N/A	The effort to reduce GHG scope 1 may impact the energy efficiency of the telecommunication network if it impacts the mainteinance efforts (i.e., reduction of GHG scope 1 may impact the use of company vehicles which are used for mainteinance of the telecommunication network)	N/A	N/A	impact the life expectancy of the equipment in telecommunication network if it impacts the mainteinance efforts (i.e., reduction of GHG scope 1 may impact the use of company vehicles which are used for mainteinance of the telecommunication network)	N/A	N/A	The reduction of GH scope 1 may impact negatively the processing of e-waste if there is a reduction in the company transportation means.	N/A	N/A
Carbon emissions - Energy indirect emissions (e.g., scope 2 emissions)	The effort to reduce the GHG for scope 2 has a direct positive impact on the enery consumption because energy consumption in telecommunication networks is a significant contributor to GHG scope 2 (but it is not the only one).	N/A	N/A	N/A	The effort to reduce the GHG for scope 2 has a direct positive impact on the adoption of energy efficient solutions in the telecommunication networks as energy consumption a significant contributor to GHG scope 2 (but it is not the only one).	The effort to reduce GHG scope 2 is often implemented by companies by the adoption of sources of renewable energy.	an impact on the increase of use of refurbished products because the procurement of new equipment, its installation and deployment can increase the GHG scope 2. On the other side, refurbished and old products may not be energy efficient as new ones.	The effort to reduce GHG scope 2 has an impact on the life expectancy of the equipment as it may drive the need to extend the equipment active lifetime.	The effort to reduce GHG scope 2 may impact the use of water consumption used for cooling of the server and the server farms to make them more efficient.	N/A	N/A	an impact on the increase of use of refurbished components because the procurement of new equipment, its installation and deployment can increase the GHG scope 2. On the other side, refurbished and old components may not be energy efficient as new ones.	The effort to reduce GHG scope 2 may be in opposition on the use of recyclable material, which it is less efficient than new products.
Carbon emissions - Other indirect emissions (e.g., scope 3 emissions)	N/A	N/A	N/A	N/A	The effort to reduce GHG scope 3 may impact the energy efficiency of the telecommunication network if it impacts the mainteinance efforts (i.e., reduction of GHG scope 1 may impact the use of company vehicles which are used for mainteinance of the telecommunication network)	N/A	N/A	impact the life expectancy of the equipment in telecommunication network if it impacts the maintenance efforts (i.e., reduction of GHG scope 1 may impact the use of company vehicles which are used for maintenance of the telecommunication network)	N/A	N/A	The reduction of GH scope 1 may impact negatively the processing of e-waste if there is a reduction in the company transportation means.	N/A	N/A
Energy efficiency	The improvement of the performance of energy efficiency has a direct positive impact on the energy consumption of the telecommunication network because it reduces the overall energy consumption.	N/A	The improvement of the performance of energy efficiency has a direct positive impact on the GHG scope 2 because it reduces the overall energy consumption.	N/A	N/A	N/A	The deployment of energy efficiency solutions may be against the use of refurbished products as they may be older models, which do not implement energy efficient solutions or they do not support them.	The improvement of the energy efficient indicator may have a negative impact on the life expectancy of the network equipment because it has to be frequently replaced with new equipment supporting new energy efficient solutions.	The support for energy efficient solutions may reduce the water consumption as it may optimize the energy consumption.	The support for energy efficient solutions may increase the use of raw materials because it supports a faster replacement of network equipment.	The support for energy efficient solutions increase e-waste because it supports a faster replacement of network equipment.	The deployment of energy efficiency solutions may be against the use of refurbished components as they may be older models, which do not implement energy efficient solutions or they do not support them.	The deployment of energy efficiency solutions may be against recyclability because older equipment and components are difficult is not impossible to reuse with new energy efficient equipment and components..
Use of renewable energy (rate)	N/A	N/A	The use of renewable energy has a positive impact on the GHG scope 2. In fact, some stakeholders uses renewable energy with the goal to obtain and report a lower GHG scope 2.	N/A	N/A	N/A	N/A	There could be a limited impact if the use of specific type of renewable energy may require some changes in the equipment.	N/A	N/A	N/A	N/A	N/A
Distribution or utilisation of recycled/refurbished/ reused products	The use of refurbished products may have a negative impact on energy consumption if their energy consumption rate is worst than newer products.	N/A	The use of refurbished products may have a negative impact on energy efficiency because newer products may be more energy efficient because of the implementation of energy efficiency solutions.	N/A	The use of refurbished products may have a negative impact on GHG scope 2 if their energy consumption rate is worst than newer products.	N/A	N/A	The use of refurbished products has usually a positive impact on the expected lifetime of network equipment and systems because through the refurbishing process the lifetime is extended.	Re-used/refurbished products may have a negative impact on water use because they do not replace newer products with lower energy consumption.	The use of refurbished/reused products has a positive impact on the use of raw materials because they decrease the demand for raw material due to the diminshed equipment replacement.	The use of refurbished/reused products has a positive impact on the e-waste because they decrease the demand for equipment replacement.	The use of refurbished/reused products has a positive impact on the refurbishment of components as they often require components from the previous technology cycle.	The use of refurbished/reused products has a positive impact on recyclability.
Expected lifetime	The improvement of expected lifetime may have a negative impact on energy consumption because the existing equipment is not replaced as its lifetime is extended and new (more energy efficient) equipment is not installed.	N/A	indicator may have a positive impact on the GHG scope 2 because there is no need to replace existing equipment which may cause increase of GHG scope 2. On the other side, the extension of the equipment lifetime may also decrease the equipment replacement with new energy efficient	N/A	The improvement of expected lifetime may have a negative impact on energy efficienct because the existing equipment is not replaced as its lifetime is extended and new (more energy efficient) equipment is not installed.	N/A	The expected lifetime indicator is closely related to the distribution or utilisation of recycled/refurbished/ reused products in a positive way because an extended lifetime support the reuse and the refurbishement of products.	N/A	N/A	Improvements in the expected lifetime has a positive impact on the raw materials indicator because an extension in the lifetime of the equipment decreases the need for raw materials.	Improvements in the expected lifetime has a positive impact on the e-waste indicator because an extension in the lifetime of the equipment decreases the production of electronic waste.	The expected lifetime indicator is closely related to the distribution or utilisation of recycled/refurbished/ reused components in a positive way because an extended lifetime support the reuse and the refurbishement of components and the related products where they are used.	N/A
Water usage/consumption	N/A	N/A	N/A	The improvement on water usage/consumption may have a positive impact on GHG scope 3 because the processing of water and the deployment of related processing facilities decreases.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Raw Materials	N/A	N/A	N/A	The improvement of the performance related to the raw materials can have a positive impact on GHG scope 3 because a decrease in the use of raw materials positive impact the supply chain and manufacturing processes thus reducing the GHG scope 3.	N/A	N/A	The dependency was already described in the relationship from Distribution or utilisation of recycled/refurbished/ reused products to raw materials	The dependency was already described in the relationship from Expected lifetime to raw materials	N/A	N/A	The dependency was already described in the relationship from e-waste to raw materials	The dependency was already described in the relationship from Distribution or utilisation of recycled/refurbished/ reused components to raw materials	The dependency was already described in the relationship from recyclability to raw materials
E-waste production	N/A	N/A	N/A	The improvement in e-waste can support an improvement in GHG scope 3 because the related processes may be more efficient.	N/A	N/A	The depedency between these two indicators was already discussed in the relationship from Distribution or utilisation of recycled/refurbished/ reused products to e-waste	The depedency between these two indicators was already discussed in the relationship from expected lifetime to e-waste	N/A	The improvement in e-waste can benefit the collection of raw materials from used network equipment whenever this is possible.	N/A	The depedency between these two indicators was already discussed in the relationship from Distribution or utilisation of recycled/refurbished/ reused components to e-waste	The dependency between the raw materials indicator and recyclability is already discussed
Recycled/refurbished/ reused components (also excavated masses) used in products	The use of refurbished components may have a negative impact on energy consumption because newer components and related products may be more energy efficient because of the implementation of energy efficiency solutions.	N/A	The use of refurbished components may have a negative impact on GHG scope 2 because newer component and related products may be more energy efficient because of the implementation of energy efficiency solutions.	N/A	The use of refurbished components may have a negative impact on energy efficiency because newer component and related products may be more energy efficient because of the implementation of energy efficiency solutions.	N/A	The improvement in the refurbishment of components may have a positive impact on the refurbishment of products as such process will be easier if more refurbished components are available.	The improvement in the refurbishment of components may have a positive impact on the expected lifetime of the network equipment.	N/A	The improvement in the refurbishment of components may have a positive impact on the raw materials because there will be a smaller need to collect raw materials.	The improvement in the refurbishment of components may have a positive impact on the e-waste because there will be less electronic material to be disposed.	N/A	The improvement in the refurbishment of components is closely related to recyclability as some technologies and process can be similar. Then, an improvement in this indicator can also benefit recyclability.
Recyclability	N/A	N/A	N/A	An improvement in the recyclability of the network products and components can improve the supply chain efficiency and consequently GHG scope 3.	N/A	N/A	The improvement in recyclability is closely related to distribution of refurbished products as some technologies and processes can be similar. Then, an improvement in this indicator can also benefit recyclability.	N/A	N/A	An improvement in recyclability can greatly benefit the indicator of raw materials because there will be less need to collecting and using raw materials.	An improvement in recyclability can greatly benefit the indicator of e-waste as they often share similar technologies and processes.	The improvement in recyclability is closely related to distribution of refurbished components as some technologies and processes can be similar. Then, an improvement in this indicator can also benefit recyclability.	N/A

A graphical representation of the dependency among the indicators is also shown with a graph based figure below. This representation also gives a visual perspective on which indicators are more related to other indicators, which can also be used to support a prioritization of the indicators.

In the figure below, each node represents an indicator, while the connecting lines identify the dependency/impact where the arrows indicate how the source indicator impacts the destination indicator. A colour code is used to indicate the negativity or positivity of impact with the green colour indicating a positive impact and a red colour indicating a negative impact or relationship. The figure below shows that some of the high priority sustainability indicators (e.g., energy consumption, Energy efficiency, Carbon emissions scope 2) have a high number of relationships with the other indicator and for this reason, the graph generating tool has positioned them at the centre of the figure.

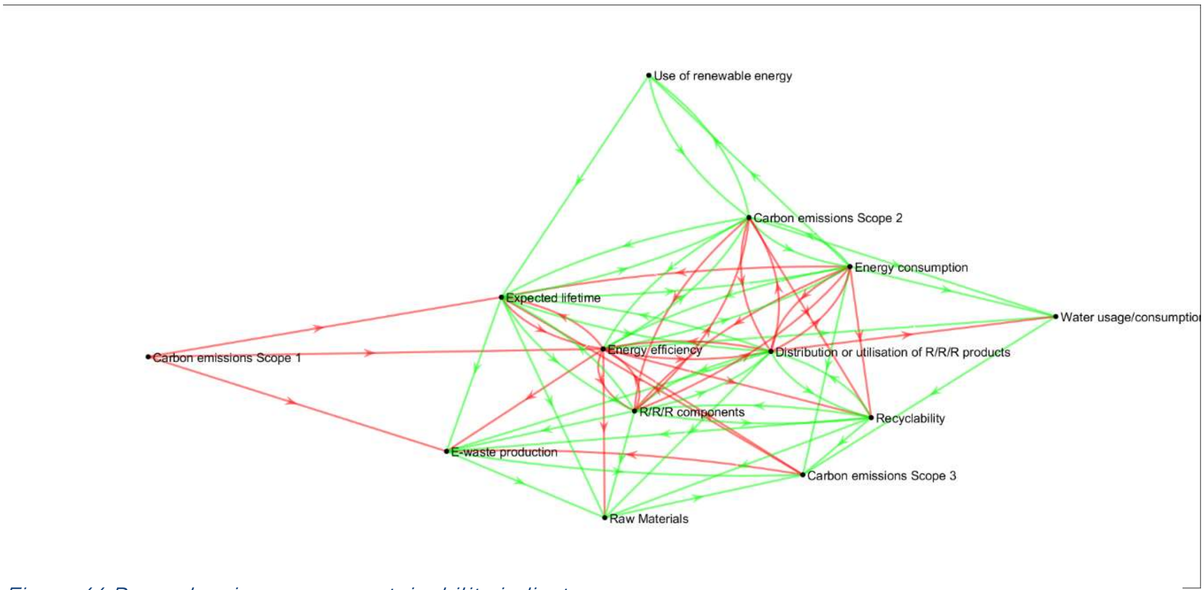

Figure 66 Dependencies among sustainability indicators

Annex G. Requirements traceability

This annex is used to identify and describe the main requirements of the study and how they can be traced to the different sections of the main report. Such requirements are derived from the initial Terms of Reference (ToR) document proposed by DG CNECT or other requests, which were formulated by DG CNECT or JRC during the study.

Table 48: Requirements tracing.

Requirement ID	**Requirement description**	**Section addressing the requirement**
REQ1.1	Overall: Development of common indicators to measure the sustainability of electronic communications networks (ECNs), i.e. fixed and wireless (including both cellular, fixed networks and WLAN) networks, for the provision of electronic communications services (ECSs)	Section 5
REQ1.2	The type of data (e.g. typical network deployments, number of subscribers, traffic demand and patterns) and their related analysis necessary to determine the relevant indicators should be defined.	Sections 2,4.2, Section D of the Annexes
REQ1.3	The analysis should address the whole life cycle of networks and services with a comprehensive multi-criteria analysis including energy efficiency and consumption, Greenhouse Gas (GHG) emissions, and other relevant types of environmental impacts such as use of rare earths, recyclability/circularity.	Section 4
REQ1.4	A survey of existing indicators from literature, previous studies and surveys (e.g. BEREC), and standards (in particular ETSI and ITU, as well as possible emerging standards in other world regions, notably the US) should be performed to assess the state of art in this field, in particular the identification of relevant measurements metrics and methods.	Section 3, Annex A
REQ1.5	The survey on the existing literature should also account for developments related to the EU taxonomy for sustainable activities.	Section 3.1
REQ1.6	Analysis of the footprint of network operations (OPEX) and in particular the possibility to use indicators to compare the ongoing footprints of individual networks taking in consideration the evolution of communication technologies from copper to fibre and from 4G to 5G and beyond and the softwarisation and virtualisation of both fixed and cellular networks.	Section 5, Annexes C, D
REQ1.7	Quantitative analysis based on public data sets, vendors/operators technical specifications and/or ITU databases could be used to support the definition of the indicators.	Section 4, Annex D
REQ1.8	A workshop should be organised with stakeholders to assess the findings of the study and receive feedback.	Section 5

REQ1.9	The study should address the preliminary steps for the development of an "EU Code of Conduct for the sustainability of telecommunications networks" that can help to steer investments towards sustainable infrastructures.	Section 4,5

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