THE SCOPE OF INTERNET OF THINGS (IOT) WITH RESPECT TO INFORMATION AND COMMUNICATION TECHNOLOGIES (ICT)

Technical Experts Committee

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FOREWORD

The technical experts committee on measuring the environmental impact of digital technologies was set jointly by Arcep and ADEME on December 2020. It aims at fostering a mutual understanding between telecom/ICT players and environmental players. Made up of technical experts working on a long-term horizon, the Committee may provide an independent technical recommendation/insight enabling to share views and to build up consensus on any technical topic/issue relating to the measurement of the environmental impact of ICT.

Chaired by Catherine Mancini (Leader Project Management at Nokia) also chairing the Fiber Optics Expert Committee and the Mobile Expert Committee set up by Arcep, the Committee includes experts from the following entities: Altice (SFR), Akamai, Amazon Web Service (AWS), Apple, APL, Bouygues Telecom, Cisco, DDemain, Eco-info (CNRS), Ericsson, GreenIT, Google, Huawei, Institut Mines Telecom, Institut Numérique Responsable (INR), Intel, Iliad (Free), LCIE Bureau Veritas, Microsoft, Meta, Netflix, Nokia, OVH Cloud, Orange, Qualcomm, Samsung, Schneider Electric and The Shift Project.

Committee program management: Arcep, ADEME.
Arcep/ADEME Report editors: Ahmed Haddad (Arcep), Charles Joudon-Watteau (Arcep) and Erwann Fangeat (ADEME).

NOTE

This report reflects the outcome of the Committee's validation. The Committee is thankful to the following invited experts for their review and contributions: Gillo Malpart (Mavana), David Bol (UCL Belgium) and Thibault Pirson (UCL Belgium).

This report is categorized within the following focus areas of the Technical Experts Committee:

- METHODOLOGIES FOR MEASUREMENT AND IMPACT ASSESSMENT
- KEY PERFORMANCE INDICATORS
- DATA

THE SCOPE OF INTERNET OF THINGS (IOT) WITH RESPECT TO INFORMATION AND COMMUNICATION TECHNOLOGIES (ICT)

SUMMARY

An increasing number of devices and appliances are now capable of network communication with their peers or with the Internet. Embedded connectivity becomes ubiquitous among a broad range of electronic devices, including Internet of Things (IoT), contributing to blurring the boundaries of the Information and Communication Technologies (ICT) and Entertainment and Media (E&M) sectors with the rest of connected products.

Clarifying the boundaries regarding connected devices is crucial to ensure a consistent accounting of the carbon footprint of the ICT and E&M sectors and how the effort towards net-zero target is balanced between sectors. Having a clear view on such blurred boundaries is also necessary from a resilience point of view. That is, to understand to which degree our digitalized society is dependent on connectivity.

The need to come up with recommendations for methodology development or guidance on this issue has been already identified in ARCEP/ADEME Committee Report published in 2023[1].

Consequently, this Report supports environmental studies' practitioners with guidance on how to gauge the role of connectivity within IoT devices and tentatively the broader set of connected products while leveraging on ITU-T Recommendations and other relevant standards. Gauging such role enables to categorize connected devices with respect to ICT and then to approach carbon allocation rules (to ICT) based, inter alia, on the connectivity's degree of influence on a product.

A consistent heuristic is developed on connected devices to draw boundaries and provide with respect to ICT a product clustering within IoT and more extensively connected devices.

The approach was carried out in several steps:

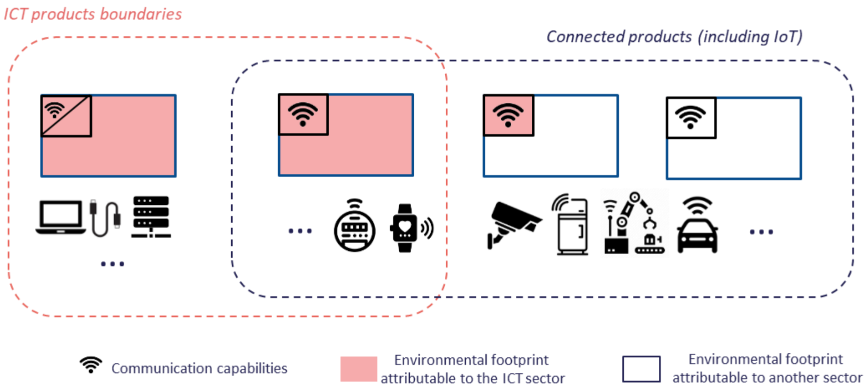
- Bringing a specific focus on what is an IoT device within connected devices;
- Identifying the potential factors that may impact the categorization of a connected/IoT device, justifying their relevance and proposing supporting technical approaches to characterize the role of connectivity on these devices;
- Combining the identified factors into a decision tree able to support a practitioner in the categorization task of a connected/IoT device and further on in the carbon footprint allocation task.

To support a definition of IoT devices' boundaries with respect to ICT and E&M and to capitalize on the proposed heuristic; several recommendations are proposed and deal with:

- Environmental performance labelling
- Economic or environmental statistics supporting public policies on IoT and connected devices

[1] Arcep ADEME Technical Experts Committee, ASSESSMENT OF THE ENVIRONMENTAL IMPACT OF THE ICT SECTOR: METHODOLOGICAL GAP ANALYSIS, April 2023 [https://en.arcep.fr/uploads/tx_gspublication/environment-impact-ICT-sector-methdological-gap-analysis_april2023.pdf]

- Public policies on carbon trajectory (supporting national low-carbon strategies for the digital economy)
- Assessing carbon footprint of IoT-based ICT solutions and connected products-based solutions
- Supporting a more detailed characterization of environmentally sustainable connected products



Another incidental aim of this Report is to address a wider audience, in order to take part in the technical acculturation of non-experts and foster a better understanding. For that purpose, some additional highlights are provided in annexes and appendices. The latter, supplement the implementation of the heuristic with technical guidance and examples. They also support the effort on clarification of how the ICT sector lies within the wider umbrella of what is popularized as the "Digital sector".

The outcome of the work item at its different steps is reflected in this report.

Any comment or suggestion for improvement are welcome and should be addressed to: ComiteExpertsMesure@arcep.fr

History

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1.0	2024-05-24	The Scope of Internet of Things (IoT) with respect to Information and Communication Technologies (ICT)

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THE SCOPE OF INTERNET OF THINGS (IOT) WITH RESPECT TO INFORMATION AND COMMUNICATION TECHNOLOGIES (ICT)

1. Introduction and problem statement

1.1. Introduction and justification of the workflow

An increasing number of devices and appliances designed for different markets are now capable of network communication with their peers in the surrounding area, or with gateways routing their traffic to a broader network or to the Internet. Embedded connectivity becomes, at varying degree, ubiquitous among all electronic devices both for consumer electronics or industrial applications.

Devices connected to the network include a wide range of technologies and equipment, such as TVs, mobile phones, sensors, lighting, thermostats, voice assistants, audio speakers, video cameras, etc. Some of these are new technologies, while many are existing types of appliances and equipment gaining a network connection. In the digital age of information and communication technology, the number of devices that interact with networks and with each other is increasing rapidly. Such a trend leads to an overlap between different areas (Communication, Control, Appliances, Media) which used to be disjoined as illustrated in Figure 1from an IEA Report[2].

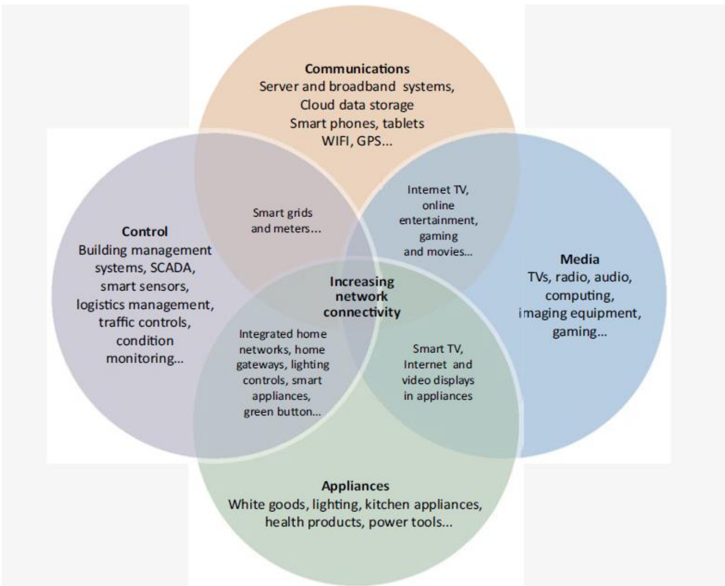

Figure 1 - Connected devices as the outcome of the overlap between Control, Communications, Media and Appliances (source: IEA[2])

The Total Energy Model developed by IEA [TEM IEA-2019] projects the stock of all network connected devices to increase from an estimated 15 billion in 2018 to 46 billion in 2030 and that in the volume of connected objects, those categorized within the IoT umbrella, are expected to capture the highest

[2] IEA 4E Report "More Data Less Energy: Making Network Standby More Energy Efficient in Billions of Connected devices" (2014): https://iea.blob.core.windows.net/assets/3fadb2cb-c2c7-4775-947f-0b8f38be0a19/MoreData_LessEnergy.pdf

share. Such a dynamic is propelled by an ever-increasing digitalization of the economy with proven environmental impact but difficult to assess with confidence as the main hurdles being the lack of data and a difficulty to draw clear boundaries for assessment [France Stratégie - 2022].

The choice of devices to include within the IoT subcategory may seem arbitrary as pointed out in [Malmodin/Lunden – 2018]. A modern car may be a good example for illustration (cf. Figure 2). More and more embedded systems are comprised within a car structure, although they may serve different purposes (comfort & convenience, driver assistance) or support the execution of different functionalities. These embedded systems may be equipped with communication capabilities to enable the car interacting with its close environment or distant platforms, either in a peer to peer mode (e.g. Adaptive cruise control and collision warning, park/reverse assist etc.) or to the Internet (e.g. telematics, Internet access, voice recognition, GPS, eCall emergency system etc.). For this case, the question is thus if all, some or none of these devices should be considered as part of the Information and Communication Technologies (ICT) and Media and Content sectors. Clarifying the boundaries regarding connected devices is crucial to ensure a consistent accounting of the footprint of the ICT and Content and Media[3] sectors and how the effort towards net-zero target is balanced between sectors.

Figure 2 - An illustration of the various functionalities/features of a connected car

1.2. Problem statement

In its report [ARCEP/ADEME Committee – 2023], the Committee has identified the categorization of IoT devices within the ICT sector (and extensively the E&M sector) as well as the approach for assessment (boundary and allocation) as a potentially major issue particularly with the expected growing number of connections linked to IoT devices out of the total number of connections.

Approaching IoT "*needs additional considerations to define the boundary, to avoid double counting of devices with other sectors (e.g. the appliance sector) and to take into consideration the impact of hardware profile of an IoT device (e.g. main-powered vs battery-powered IoT may exhibit a significant difference in terms of their impact assessment, what allocation principles when determining the relevant share of the footprint of an IoT device etc.)*" (cf. [ARCEP/ADEME Committee – 2023])

[3] Called also in some papers (e.g. [Malmodin/Lunden – 2018]) Entertainment & Media (E&M) sector. In the Report, Content & Media and Entertainment & Media (E&M), they refer to equivalent terminologies.

Thus, there is a need to come up with guidance on methodology development regarding the scope of IoT in relation to ICT and E&M sectors and other sectors (e.g. the commercial trading sector); moreover, the complexity of the subscription concept with regards to IoT may deserve specific highlight.

The workflow is scoped considering the following assumptions:

- Focusing first on the ICT sector before extending to Entertainment & Media (E&M) sector.
- Primary focus of the workflow: IoT and extensively connected devices (refer to the definitions and Chapter 2)

One aim of this workflow is to provide environmental studies' practitioners within ICT and E&M fields suggestions and insights to enrich their thinking in order to help them take account of the IoT and tentatively the broader set of connected products while leveraging on ITU-T Recommendations and other relevant standards.

Another incidental aim of this Report is to address a wider audience than environmental studies' practitioners, in order to take part in the technical acculturation of non-experts and foster a better understanding. For that purpose, some additional elements are provided in appendices and annexes.

1.3. Supporting references

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1.4. Terms and definitions

1.1.1. Terms defined in this Report

- **Hosting good (or Hosting device)**: An application specific good embedding the IoT Device e.g. vehicle hosting an e-Call emergency assistance system, a connected washing machine, a utility meter, a security alarm etc.

  NOTE – Refer to the broader concept of “Physical Thing” in **Section 1.4.2**

- **Connectivity**: Exchange of data through physical interfaces between humans, devices and machines.
- **Functionality (of a product):** A function or the minimum set of functions (of a product) deployed in a given context to achieve a particular end.

  NOTE – Functionality and function of a connected product are similar concepts but not identical. For the purpose of this document (i.e., the case of "Connected products"), the concept of "functionality" should be privileged by the practitioner whenever possible. The relevance of the concept of "functionality" is outlined in **Appendix I** which also provides further guidance on how to approach the functionality of a connected product through its functions.
- **Primary functionality (of a product)**: A function or the minimum set of functions (of a product) deployed in a given context to achieve its main purpose (i.e. for which it was mainly designed to do).

  NOTE 1 – The same product may have more than one primary functionality, as the same product may have more than one primary function (e.g. A washer-dryer combo machine have two primary functions: "To wash clothes" and "To dry clothes").

  NOTE 2 – For instance, the primary functionality of a toothbrush is derived from its primary function which is Cleaning teeth.

  NOTE 3 – Product manufacturer specifications together with instruction of use/usage scenario support the identification of the primary functionalities of the product.

  NOTE 4 – This definition is valid when looking at a product as such, but needs further elaboration if we look at a product as part of a service for instance.

  NOTE 5 – Associated services [ETSI EN 303.645] of an IoT product are typically part of its primary functionality.
- **Other functionality (of a product)**: It refers to a functionality of the device other than primary.
- **Connected product:** A product interacting with other products through one or several physical interfaces.

  NOTE – Networked equipment are part of connected products
- **Connected products system:** A set of connected products inter-connected to form a comprehensive system.
- **IoT product**: an IoT device and its associated services (definition inspired from [ETSI EN 303.645])
- **ICT-enabled [device]:** an IoT device where connectivity is essential to fulfill the primary functionality of the device.

  NOTE 1 – This definition considers the implementation of the heuristic according to a conservative approach. Refer to Section 4 for further details.

  NOTE 2 – The concept of "ICT-enabled device" is inspired from the concept of "ICT-enabled service" introduced by UNCTAD and defined as "services products delivered remotely over ICT networks" [UNCTAD – 2015].
- **Digital solution**: a system encompassing digital technologies, Information economy equipment and installations that contributes to meeting a technical, societal or business challenge.

  NOTE – An ICT solution [ITU L.1480] is a Digital solution.

1.1.2. Terms defined elsewhere

- **Gateway**: A unit in the Internet of things which interconnects the devices with the communication networks. It performs the necessary translation between the protocols used in the communication networks and those used by devices (definition from [ITU-T Y.4101/Y. 2067]).

NOTE – According to [ITU-T Y.2060], Gateway is a specific type of IoT device, it is part of the device layer. According to [ITU-T Y.4101], the gateway may stand at the interface between two local area networks or between a local area network and a Wide-area communication network (WAN).

- **Internet of things (IoT)** [ITU-T Y.2060]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies

  NOTE 1 – Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, whilst ensuring that security and privacy requirements are fulfilled.

  NOTE 2 – From a broader perspective, the IoT can be perceived as a vision with technological and societal.

- **Thing** [ITU-T Y.2060]: With regard to the Internet of things, this is an object of the physical world (physical things) or the information world (virtual things), which is capable of being identified and integrated into communication networks.

  NOTE – According to [ITU-T Y.2060], a thing may be physical things (objects of the physical world) or virtual things (objects of the information world).

- **IoT Device application** [GSMA – 2022]: The application software component of the IoT Device that controls the Communications module and interacts with an IoT Service Platform via the Communications module.
- **IoT service platform** [GSMA – 2022]: The service platform, hosted by the IoT Service Provider which communicates to an IoT Device to provide an IoT Service. The IoT Service Platform can exchange data with the IoT Device Application over the Network and through the Communication module, using (among others) IP-based protocols over a packet-switched data channel. Also, the IoT Service Platform typically offers Device Management capabilities, acting as a so-called Device Management Server. Finally, the IoT Service Platform typically offers APIs for IoT Server Applications to exchange data and interact with the IoT Device Applications.
- **Network layer** [ITU-T Y.2060]: As part of the IoT reference model, this consists of the following two types of capabilities:
  - Networking capabilities: provide relevant control functions of network connectivity, such as access and transport resource control functions, mobility management or authentication, authorization and accounting (AAA).
  - Transport capabilities: focus on providing connectivity for the transport of IoT service and application specific data information, as well as the transport of IoT-related control and management information.
- **Connectivity module** [GSMA-2022]: (aka Communication module) The IoT Communications component which provides connectivity. Comprising of Communications Module Firmware, Wireless or wireline technology chipsets and UICC.
- **Network active** [TEM-IEA – 2019]): Network Active is a condition in which a device is communicating with another device on a network.
- **Network standby** [EC Eco-design - 2023]: means a condition in which the equipment is able to resume a function by way of a remotely initiated trigger from a network connection.

  NOTE – This definition, used in this document, does not prejudge of the way the product under study is powered (i.e. mains-powered or battery-powered).

- **Networked equipment** [EC Eco-design – 2013]: Equipment that can connect to a network and has one or more network ports.
- **ICT goods** [ITU L.1410]: Tangible goods deriving from or making use of technologies devoted to or concerned with:
  - the acquisition, storage, manipulation (including transformation), management, movement, control, display, switching, interchange, transmission or reception of a diversity of data;

    - the development and use of the hardware, software, and procedures associated with this delivery; and
    - the representation, transfer, interpretation, and processing of data among persons, places, and machines, noting that the meaning assigned to the data is preserved during these operations.

  NOTE – "ICT-native goods" and "ICT goods" are used interchangeably.

- **Function (of a product)** [NF EN 16271 -2013]: an action of a product or one of its constituents expressed exclusively in terms of purpose.

  NOTE 1 – Refer to **Appendix I** for an alternative definition from an energy perspective [IEC 62301-2011].
  NOTE 2 – Product's functions can be classified into different categories (such as "primary functions", "secondary functions" …), refer to **Appendix I** for further details on functions' categories.

- **Product part** [ETSI TR 103 679]: Sub-unit of a product.
- **Physical thing** [ITU-T Y.2060]**:** Physical things exist in the physical world and are capable of being sensed, actuated and connected. Examples of physical things include the surrounding environment, industrial robots, goods and electrical equipment.

  NOTE 1 – According to [ITU-T Y.2066], Physical things can be instantiated into "artificial things" and "natural things", where an artificial thing is a physical thing that is produced by mankind and can be identified by a product serial number.
  NOTE 2 – The hosting good (or hosting device) is an example of physical (artificial) thing.

- **Reuse** [b-EN 45554]: Process by which a product or its parts, having reached the end of their first use, are used for the same purpose for which they were conceived.
- **Refurbish** [ITU L.1024]: Return a used product [or component] to at least its original performance with a warranty that is equivalent or better than that of the newly manufactured product.
- **Upgrade** [b-EN 45554]: Process of enhancing the functionality, performance, capacity or aesthetics of a product.
- **Circular economy** [ITU L.1023]: An economy closing the loop between different life cycles through design and corporate actions/practices that enable recycling and reuse in order to use raw materials, goods and waste in a more efficient way. The circular economy concept distinguishes between technical and biological cycles, the circular economy is a continuous, positive development cycle. It preserves and enhances natural capital, optimizes resource yields, and minimizes system risks by managing finite stocks and renewable flows, while reducing waste streams
- **Component** [ETSI TR 103 679]: Part of a product that cannot be taken apart without destruction or impairment of its intended use.
- **Physical Interface** [ETSI EN 303 645]: physical port or air interface (such as radio, audio or optical) used to communicate with the device at the physical layer.
- **LPWAN** [IEA – 2017]: LPWA networks provide low power draw and wide area coverage, and are designed for IoT and M2M applications that provide low data rates, long battery lives, and at low cost.
- **Machine-to-Machine (M2M)** [GSMA – 2022]: Machine-to-Machine (M2M) is an integral part of the Internet of Things (IoT) and describes the use of applications that are enabled by the communication between two or more machines. M2M technology connects machines, devices and appliances together wirelessly via a variety of communications channels, including IP and SMS, to deliver services with limited direct human intervention turning these devices into intelligent assets that open up a range of possibilities for improving how businesses are run.

- **UICC** [ITU-T Y.2061]**:** A physically secure device, an IC card (or 'smart card'), that can be inserted and removed from the terminal. It may contain one or more applications. One of the applications may be a USIM.
- **Carbon footprint (of a product)** [ISO 14067 - 2018]**:** sum of GHG emissions and GHG removals in a product system, expressed as CO_2equivalents and based on a life cycle assessment using the single impact category of climate change.
- **Economic input-output (EIO) approach** [ITU L.1410]**:** Method using tables, called input-output (IO) tables, that describe financial transactions between economic sectors in a national economy, to approximate environmental impacts.
- **Associated services** [ETSI EN 303 645]**:** Digital services that, together with the device, are part of the overall consumer IoT product and that are typically required to provide the product's intended functionality

  EXAMPLE 1 – Associated services can include mobile applications, cloud computing/storage and third-party Application Programming Interfaces (APIs).

  EXAMPLE 2 – A device transmits telemetry data to a third-party service chosen by the device manufacturer. This service is an associated service.
- **Consumer IoT device** [ETSI EN 303 645]: A Network-connected (and network-connectable) IoT device that has relationships to associated services and are used by the consumer typically in the home or as electronic wearables.

  NOTE 1 – Consumer IoT devices are commonly also used in business contexts. These devices remain classified as consumer IoT devices.

  NOTE 2 – Consumer IoT devices are often available for the consumer to purchase in retail environments. Consumer IoT devices can also be commissioned and/or installed professionally.
- **Isolable [ETSI EN 303 645]:** able to be removed from the network it is connected to, where any functionality loss caused is related only to that connectivity and not to its main function; alternatively, able to be placed in a self-contained environment with other devices if and only if the integrity of devices within that environment can be ensured.

  EXAMPLE – A Smart Fridge has a touchscreen-based interface that is network-connected. This interface can be removed without stopping the fridge from keeping the contents chilled.
- **ICT solution [ITU L.1480]:** A system encompassing ICT goods, ICT networks and/or ICT services that contributes to meeting a technical, societal or business challenge.

1.5. Abbreviations and acronyms

- **3RU**: Recycle, Reuse, Refurbish and Upgrade
- **EoL**: End of Life
- **LPWAN**: Low Power Wide Area Networks
- **UICC:** Universal Integrated Circuit Card
- **ICT:** Information and Communication Technologies
- **E&M:** Entertainment and Media

Shall, **should** and **may**: This report uses precise terminology and distinguishes between requirements and recommendations, (i.e., between the words ‘shall’, ‘should’ and ‘may’). Terminology is based on ISO/TS 14072 and ISO 14044/ISO 14040, in that order. ‘Shall’ is only used when this strength of obligation is also required in the aforementioned document, while ‘should’ is used to identify recommended elements that can be disregarded with proper justification. Finally, ‘may’ is used for other allowed elements or alternatives.

2. Scoping and methodological approach description

2.1. Scoping

2.1.1. ICT sector and ICT goods

According to ITU-T L.1450 Recommendation, the ICT sector definition follows the sectoral definition given by OECD which is based on Rev 4.0 classes of ISIC nomenclature in force since 2007[4]. The definitions were developed by the Classifications Expert Group of the Working Party on Indicators for the Information Society (WPIIS), they consider *ICT products*[5] and *Content and media products (or E&M)*. Currently, the ICT products definition consists of 10 broad categories and 99 products.

According to OECD [OECD -2011], the following guiding principle is used to identify ICT products (adapted from the agreed guiding principle for the ICT sector):

"*ICT products must primarily be intended to fulfil or enable the function of information processing and communication by electronic means, including transmission and display".*

The guiding principle of ICT products (and ICT sector) highlights the connectivity *("communication by electronic means, including transmission")* as among of its key pillars.

Annex A provides a historical evolution of the ICT and E&M sectors as well as ICT and E&M products.

2.1.2. Connected devices and IoT devices

a) Connected devices

Connected devices – also referred to as networked, edge or end devices – are consumer electronics, appliances and other devices including those for industrial purposes, that can interact with their distant or surrounding environment. While, until recently, only a few devices were typically connected to communications networks, an increasing variety of consumer/industrial devices, appliances and infrastructure across all sectors are being connected to the Internet and to each other, this is enabled by the widespread diffusion of broadband internet, as well as wireless and mobile access.

In its report Digitalization & Energy [IEA – 2017], the IEA has used the following categorization for connected devices: "*In discussing the energy use of connected devices (as a segment of ICT), it is helpful to distinguish between two types of connected devices: "electronic edge devices", whose primary function is data storage/use, such as laptops and smartphones, and "other edge devices", whose primary functions are not data-related, such as networked kitchen appliances and cars".*

b) IoT devices

According to [ITU-T Y.2060], with regard to the Internet of things, an IoT device is a piece of equipment with the mandatory capabilities of communication and the optional capabilities of sensing, actuation, data capture, data storage and data processing.

The defining factor of an IoT device is that it can carry out some form of digital processing and being equipped with communication capabilities which is capable of being identified and integrated into communication networks. This is what distinguishes it from plain hardware (electronic) devices that

[4] Up to the date of publication of this report, ISIC nomenclature in force since 2007 is undergoing a revision.

[5] The term "Product" refers to goods or services.

contain only some circuitry and possibly a battery. Examples of IoT devices include a pacemaker, a Point-of-Sale (PoS) terminal, smart refrigerators, smart bicycles, fitness trackers, smart utility meters, smart parking terminals etc.

NOTE 1 – While IoT systems/IoT devices terms are sometimes used interchangeably, IoT devices are parts of a larger system for a given use case. By letting a peacemaker device communicate to the outside world through a gateway, such as transmitting heart-rate data to a central database, all these goods (including the network) turn out into an IoT system.

NOTE 2 – The communication capabilities of an IoT device may be used by the device to connect to the Internet or not. Communication capabilities may include communication through wireless or wired networks (such as Ethernet, Profibus, Profinet).

The general operation stages of an IoT device, regarding data, include data acquisition, data processing, data storage, and data transmission. The first and last stages exist on every IoT, while the processing and storage may or may not exist in some applications.

[ITU-T Y.4460] derives an architectural reference models for the three types of IoT devices mentioned as depicted in Figure 3. The architectural reference models define the main functional entities of the IoT device and may serve as reference design for IoT device implementation.

NOTE – The architectural reference models define the main functional "logical" entities of the IoT device and may serve as reference design for the IoT device implementation. However, from a hardware perspective, these functional "logical" entities should be mapped onto functional "material" entities (as different functional "logical" entities may be performed by the same "material" entity or a given functional "logical" entity might be performed by more than one "material" entity). **Annex B** provides a possible approach for modelling an IoT device according to its material entities.

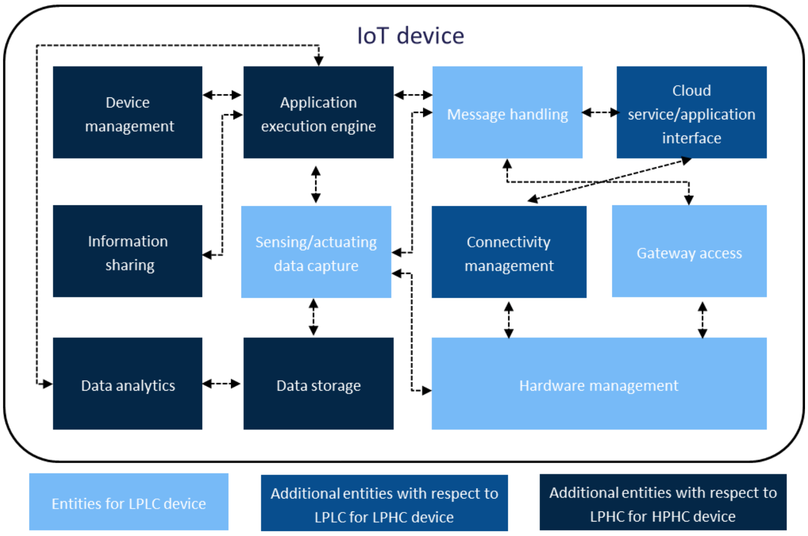

Figure 3 - Architectural reference model showing the functional logical entities of the three types of IoT devices through the perspective of their processing and communication capabilities according to [ITU-T Y.4460].

Requirements for IoT qualification

Figure 4 illustrates a high-level generic architecture of a connected device within the IoT interacting with the ICT infrastructure (networks and datacenters). A connected device consists of a hosting device (e.g. the appliance) embedding one or several IoT devices, which can be represented in a modular way (IoT device firmware/embedded software, micro-controller module, sensing module, power supply, …).

The connectivity module is comprised of several communication chips and connectivity firmware. In Figure 4, the communication networks provide capabilities for reliable and efficient data transfer. The IoT network infrastructure may be realized via existing networks, such as conventional TCP/IP-based networks, and/or evolving networks, such as next generation networks (NGN).

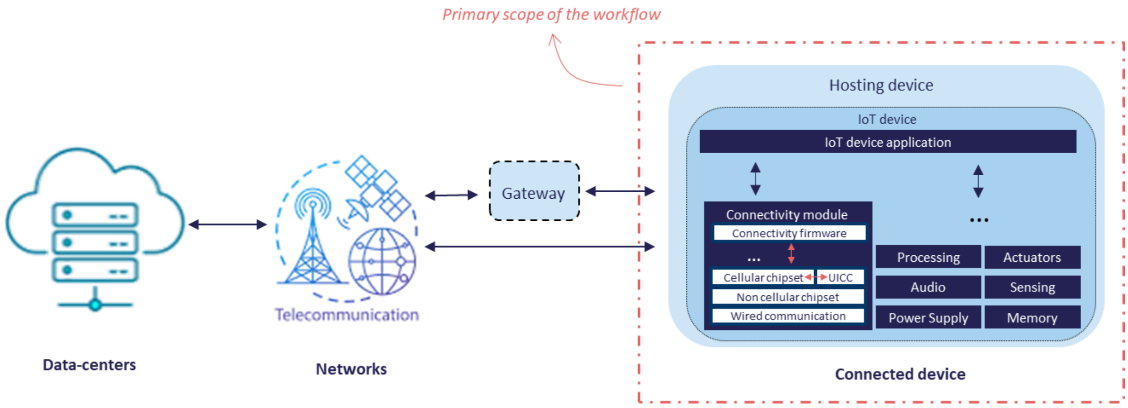

Figure 4 – Illustration of a connected device within IoT

IoT reference model [ITU-T Y.2060]: Figure 5 shows the IoT reference model. It is composed of four layers as well as management capabilities and security capabilities which are associated with the four layers. The four layers are as follows:

- application layer
- service support and application support layer
- network layer
- device layer.

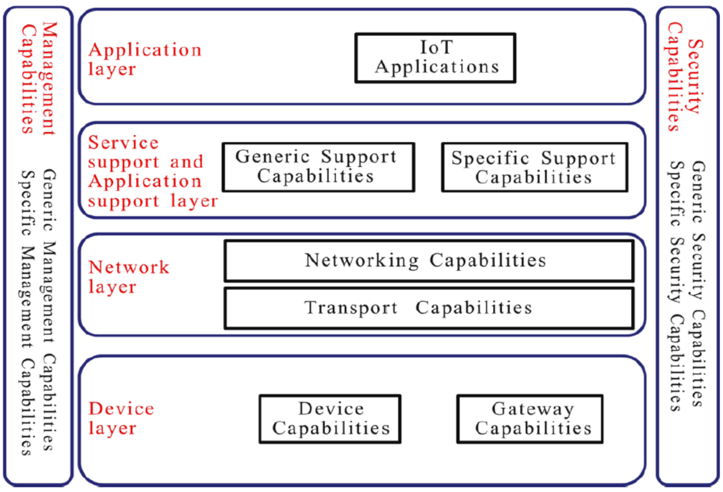

Figure 5 - IoT reference model according to [ITU-T Y.2060]

Based on [ITU-T Y.2060], an IoT infrastructure comprises the following essential elements, which makes possible an initial characterization of an IoT solution:

(1) The IoT Device application and IoT application hosted in an IoT service platform (e.g. server located in a data center) or within a Device Capabilities Exposure (DCE) device interact together as part of the application layer of the IoT solution.

(2) A communication network connecting the IoT service platform either directly to the IoT connected device or to a gateway, which performs the necessary translation between the protocols used in the communication network and those used by the IoT device. This communication network is part of the network layer of the IoT solution, and should comply or be similar to the layer 3 of the OSI model[6] (e.g. packet forwarding and routing usually using IP with possibly radio access technologies like 4G,5G).

(3) Identification-based connectivity: The connectivity between a thing (i.e. IoT device) and the IoT is established based on the thing's (unique) identifier.

NOTE – Identification is an important feature to qualify as an IoT device. As part of Release 19, 3GPP is working on the integration of ambient power-enabled IoT devices into 5G/6G cellular networks (called "Ambient IoT") with capabilities and use cases equivalent to RFID/NFC devices.

(4) Different networking topologies and structures can be envisaged under the umbrella of IoT including: ad-hoc networking, device networks featuring direct communications, isolated or connected constrained devices networks etc. For the case of constrained device networking as specified in [ITU-T Y.4451], an "adaptation layer" in the protocol stack is required to emulate functions generally related to network architectures and networking features (such as packet header compression, packet fragmentation, network addressing …).

(5) According to ITU Y.2060, "IoT devices can communicate with other IoT devices using direct communication through a local area network (i.e. a network providing local connectivity between the devices and between devices and a gateway, such as an ad-hoc network)". In that case, the solution has to be compliant with the reference architecture of IoT DCE as specified in ITU-T Y.4115 Recommendation [ITU-T Y.4115].

The complete set of IoT common requirements are detailed in ITU-T Y.2066[7]. In addition to the aforementioned ITU-T Recommendations, the practitioner may refer to more specific requirements for use cases related to:

- IoT wearable devices (consumer IoT): Refer to ITU-T Y.4117 Recommendation[8].
- Industrial IoT devices: Refer to ITU-T Y.4003 Recommendation[9].
- Automotive and ITS-based IoT devices: Refer to ITU-T Y.2281 Recommendation[10].
- Visible Line Communication-based IoT devices: Refer to ITU-T Y.4465 Recommendation[11] and ITU-T Y. 4474 Recommendation[12].

Appendix III illustrates the implementation of this initial characterization through examples of connected devices.

[6] Open Systems Interconnection model

[7] https://www.itu.int/rec/T-REC-Y.2066-201406-I/en

[8] https://www.itu.int/rec/T-REC-Y.4117-201710-I/en

[9] https://www.itu.int/rec/dologin_pub.asp?lang=s&id=T-REC-Y.4003-201806-I!!PDF-E&type=items

[10] https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-Y.2281-201101-I!!PDF-E&type=items

[11] https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-Y.4465-202001-I!!PDF-E&type=items

[12] https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-Y.4474-202008-I!!PDF-E&type=items

Categories of IoT devices

IoT devices can be categorized according to different perspectives:

- IoT devices can be categorized regarding **the way in which a device interacts with the physical things** (hosting devices). According to [ITU-T Y.2060], 4 canonical types are identified: Data-carrying devices, Data-capturing devices (examples: infrared readers, card readers, barcode scanners …), Sensing and actuating devices (examples: sensors and actuators) and General devices (where communication and processing capabilities are embedded into the device) including equipment and appliances for different IoT application domains, such as industrial machines, home electrical appliances and smart phones.

  Figure 6 depicts the 4 mentioned types and their relationship with the physical thing.

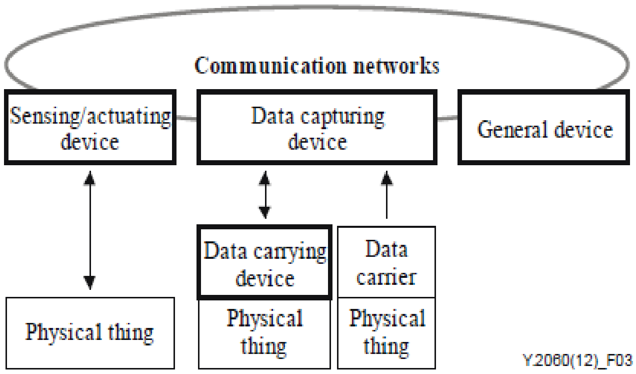

Figure 6 - Types of "IoT devices" through the perspective of their interaction with the physical thing according to [ITU-T Y.2060]

- IoT devices can be categorized, **from an architectural point of view, according to processing power and communication**, two capabilities that are among the most essentials. By correlating these two capabilities, [ITU-T Y.4460] identifies 3 types of devices: Low processing and low connectivity (LPLC) devices (e.g. constrained sensor devices), Low processing and high connectivity (LPHC) devices (e.g. devices in smart home applications) and High processing and high connectivity (HPHC) devices (e.g. an IA-embedded monitoring camera).

  NOTE 1– As the connectivity capability also depends on processing capability, the combination of high processing and low connectivity is not usual (because a device that already has high processing power will also have high connectivity capabilities) according to [ITU-T Y.4460].

  NOTE 2– With regard to the Internet of Things, devices with no processing capabilities are passive IoT devices (low-cost devices with no micro-controllers) such as ID Tags based on NFC/RFID.

IoT within the broader set of connected devices

It is worth noting that not all connected products are IoT products. ICT products, E&M products, IoT products and connected products may overlap but still refer to distinct product types as illustrated in Figure 7.

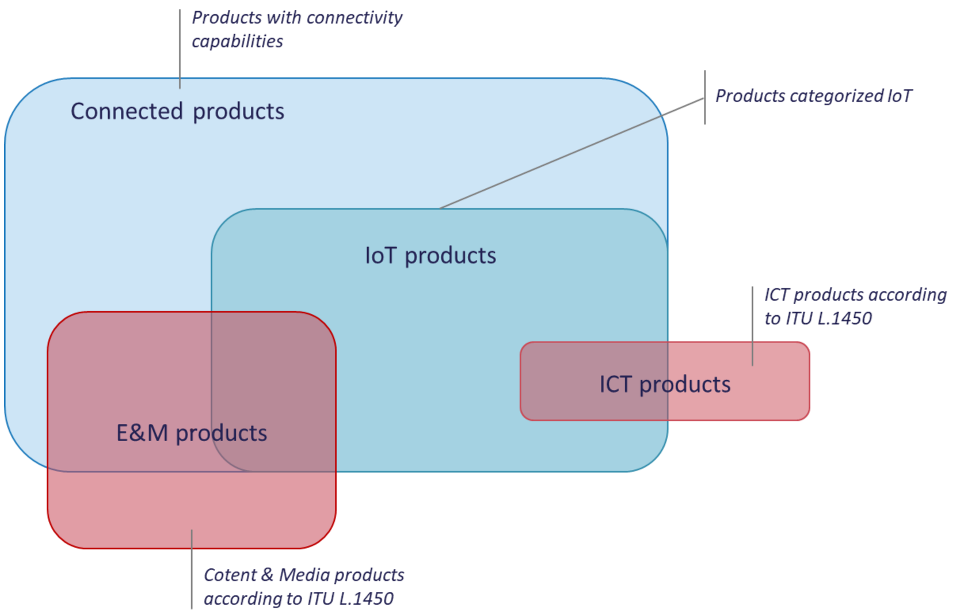

Figure 7 - Cartography of the different types of products: Connected products, IoT products, ICT products and E&M products (the size of each item does not reflect the size of the related market)

Appendix III provides examples of different types of connected devices.

NOTE – Setting the exact boundaries of ICT and E&M sectors with respect to IoT products and connected products is a challenging task. At the time of publication of ITU-T L.1450 Recommendation (2014), it was considered as "optional" to include the embedded connectivity within the boundaries of ICT, however as the ICT sector develops over time this may undergo further discussion.

2.1.3. Connected products and systems of connected products: importance of boundaries setting

As depicted by the cartography shown in Figure 7, there are a lot of different possible sub-categories for a connected product (E&M and IoT, only IoT but not E&M nor ICT, etc.). Furthermore, as expressed in the introduction of the present report, the increasing digitalization can lead to complex systems made of several connected products. Thus, when approaching a system of connected products, the practitioner needs to take care of the boundaries used as it may impact the categorization outcome.

Further guidance on this topic are developed in **Annex C**, illustrated with examples provided in **Appendix III**.

2.2. Methodological approach

The workflow is carried out in a step-wise procedure as follows:

(1) Describing the approaches followed by five selected studies for connected devices categorization (with respect to ICT or ICT and E&M) and allocation choices for footprint accounting;

(2) Identifying the potential factors that may impact the categorization of a connected/IoT device, justifying their relevance and proposing supporting technical approaches for characterization;
(3) Combining the identified factors and deriving a decision tree able to support a practitioner in the categorization task;
(4) Highlighting the main lessons and formulating relevant recommendations to support a definition of IoT-based devices boundaries with respect to ICT and E&M.

3. Review of approaches for connected devices categorization in five selected studies

To the best of the knowledge of the Committee, few studies have addressed explicitly the subject of connected devices categorization and related implications in terms of carbon footprint accounting and allocation to the ICT and E&M sectors. Five studies were found as the most relevant to reflect this matter although connected devices /IoT footprint accounting and share attribution to the ICT and E&M sector were not considered as their main focus.

Table 1 summarizes the key findings regarding the rationale followed by the five studies with regards to connected devices categorization and their footprint allocation to the ICT sector.

NOTE – The reader may refer to [ARCEP/ADEME Committee – 2023] for an extensive comparative analysis between [Malmodin & Lundén – 2018], [The Shift Project – 2021] and [ADEME/ARCEP – 2022] studies regarding the scope of IoT and the methodological approach for ICT footprint assessment.

Table 1 - Rationale of IoT categorization according to five selected studies

Study	Rationale of categorization
[Malmodin & Lundén – 2018]	For ICT: Smart meters, wearables, payment terminals, surveillance cameras, public displays and projectors. For E&M: Headphones and other audio devices and vehicle infotainment displays. According to the authors, these devices are labeled as existing integrated ICT. The study acknowledges the challenge of setting boundaries between ICT sector and other sectors with the increasing pace of digitalization. For vending machines and smart meters, the communication devices connecting these products with the Internet are accounted within the footprint of the ICT sector. Specific electronic equipment for buildings, vehicles, production, medical care, military industry and security are not seen as part of the ICT and E&M sectors unless belonging to the general product categories. The study investigated a future IoT scenario accounting for ICT communications modules built into non-ICT equipment and devices representing the connectivity of the electronic equipment and devices of other sectors (including sensors and tags); the assessed carbon footprint was allocated to the ICT sector.
[The Shift Project - 2021]	The study points out the rise of IoT communicating objects (embedded connectivity in machines, sensors, actuators, RFID tags …) they form the foundation of industry 4.0 and robotics in a manufacturing environment. The list of devices is similar to [ADEME/ARCEP – 2022]. The study accounted for the connection modules embedded onto an object (e.g. smart bulb, stove etc.) or a device (e.g. refrigerator, oven etc.).

[ADEME/ARCEP – 2022]	The study includes all items already listed in IEA/ENDA's report [IEA-TEM – 2019] under the category of automation and security edge devices(1). For carbon footprint assessment, the study accounts for the electronic hardware of the IoT device, i.e. all the modules constituting the IoT device and not only the connectivity module (actuators, PCB, power supply, security, memory, sensing module, processing module, casing, user interface etc.) based on a bottom-up approach developed by Pirson & Bol[13]. RFID tags were not included due to lack of data. Through discussions with Pirson & Bol, Authors faced the lack of precise definitions for the wide range of equipment considered, as within a category of equipment some of them may just have basic functionalities or present high communications abilities (e.g. connected refrigerator with enhanced abilities such as display to communicate about inventory management). Thus, it may cause some uncertainty.
[ITU L.1470]	[ITU L.1470] Recommendation provides detailed trajectories of GHG emissions for the global ICT sector compatible with the UNFCCC Paris Agreement. Appendix III of the [ITU L.1470] details the calculation of the baseline footprint of the ICT sector and sub-sectors, derived in accordance with the methodology outlined in [ITU L.1450]. In Appendix IV, this baseline footprint trajectory is extrapolated up to 2030 considering *inter-alia* ICT's own development. Referring to [Malmodin & Lundén – 2018], the baseline scenario and its extrapolation consider the following IoT devices: smart meters, surveillance cameras, payment terminals, projectors, public displays and wearables. However, the inventory goes beyond these specific devices by including ICT communication modules within non-ICT products. Appendix IV indicates that "in the next iteration of this work all IoT should be included" [ITU L.1470]
[IEA-TEM – 2019] & [IEA-TEM-2021]	In these reports, the problem is approached from an energy consumption perspective. While, the issue of connected devices' categorization with respect to ICT is not tackled as such, the question of energy implications of being connected is addressed (cf. Refer to Section 4). The report calculates (through modelling) the total additional energy use of network connected devices (i.e. the component of energy use that is additional due to being connected to a network either being in network active or network standby condition). For "Electronic Edge Devices" (referring to ICT end-user devices(2) and LAN devices(3)), all modes/conditions of energy use of connected edge devices are considered. For "Other Edge Devices" (encompassing a broad set of connected devices including Entertainment devices(4), Security devices(5) and Automation(6)), all modes/conditions of connected devices that exist to support the device functions while being connected to the network, where this is additional to the normal functioning of the device that is being performed. The reports point out that the additional energy use of products that results from devices becoming connected to a communications network may be difficult in practice to measure and estimate. For instance, an IP Camera will have energy use associated with the camera and the network communications. To isolate the energy use of the network communications component would require estimates of the network communication power use, as this is not typically reported or measured. In practice, the entire energy usage of the device would need to be considered additional, as it would not be present without a network connection (for instance, an IP camera connected to the network as compared to a security camera wired to a recording device). This simplification assumes that all devices that can only perform their main function with a network connection would be considered "additional" in themselves, and hence all the energy use is additional. As observations, [IEA-TEM – 2019] points out that multi-functional connected devices require further investigations as connectivity is likely to include other functions within the device (these multi-function network-connected devices may be increasingly available in the market). Example: for the case of a connected fridge integrating a display device included in the door of the appliance, the report suggests that the energy used by the display device is additional (as Display would not rather be present if the refrigerator hadn't been connected).

[13] « Assessing the embodied carbon footprint of IoT edge devices with a bottom-up life-cycle approach », 2021, Thibault Pirson et David Bol. https://doi.org/10.1016/j.jclepro.2021.128966

(1) Security video IP cameras for home, Security video IP cameras for Public/Business, Security control smart locks, Automation water heaters, Automation street lights, Automation space conditioning smart thermostats, Automation space conditioning air conditioners, Automation lightings – smart light Wifi, Automation lightings – smart light LPWAN, Automation cooking (oven + Cooktop) and Range Hood, Automation audio (VA speakers), Automation appliances (refrigerators, freezers, washing machines, clothes dryers, dishwashers, small appliances), Smart Meters, Sensors for residential LPWAN, Sensors for residential Wifi, Sensors industry LPWAN, Sensors health LPWAN, Gateways for business, Gateways LPWAN to Wifi, Communication Building Control, Blinds + Windows.
(2) Including tablets, storage, PC and mobile phones.
(3) Including access devices (Integrated access, wired and wireless modems) and other LAN devices (wireless access points, routers, switches, repeaters).
(4) Including displays (e.g. smart TV and digital signage), audio (e.g. smart speaker) and Media devices (e.g. Game consoles, STB and OTT media players, Casting sticks).
(5) Including Control security devices (e.g. smart locks) and security related video devices (e.g. IP Camera)
(6) Including Appliances, Cooking, IoT devices (e.g. gateways, blinds+Windows, sensors, smart meters etc.), smart lights, HAVC (space conditioning), Water heaters.

The variability observed in this review highlights the need for developing a more explicit and systematic methodology to support an LCA practitioner for the categorization of connected devices with respect to the ICT and E&M sectors and unveils the following questions:

- Considering or not specific electronic equipment (non-consumer electronics or non-General-Purpose Technology devices);
- What part to include: the communication part, all modules constituting the IoT device or the whole connected device? Understanding how the connectivity is additional or not to the intended working of the device and the feasibility to isolate the contribution of the connectivity part.

4. Designing a heuristic for connected devices categorization within the ICT sector

4.1. Influencing criteria

Building on the review of the previous Section and going beyond, several criteria may influence the categorization of connected devices within the ICT sector as part of an IoT system. In the following, the Committee identifies the preeminent factors, points out their relevance and proposes possible technical approaches to support their assessment.

These factors include:

(1) Identification as part of an IoT system and check if classified as ICT product or E&M product
(2) The significance of connectivity in fulfilling the purpose of the device;
(3) The share of the connectivity in the carbon footprint of the device;
(4) The incremental share of the connectivity in the carbon footprint of the service delivered by the device;
(5) Hardware obsolescence;
(6) Software obsolescence.

4.1.1. Identification as part of an IoT system and classification as ICT or E&M product

This preliminary criterion serves a first purpose of isolating connected products that are part of an IoT system or not. Another incidental purpose is then to divide, within IoT classified devices, those that can be classified as either ICT or E&M to further work on cases whose characterization requires more food for thought.

To test whether the connected device is categorized within IoT, the practitioner should refer to the requirements specified in Section 2.

To qualify whether the product is categorized within the ICT sector, the practitioner shall use the guiding principle for identifying an ICT product[14] from OECD, by asking whether the connected device is primarily intended to be used for communication purposes (*"to fulfil or enable the function of information processing and communication by electronic means, including transmission and display"* [OECD -2011]).

NOTE – Annex A of [ITU L.1450] provides examples of IoT devices included within the ICT sector.

To qualify whether the product is categorized within the E&M sector, the practitioner should refer to existing international product classifications.

Further guidance is provided in **Annex A** supplemented with **Appendix V** for the complete list of ICT and E&M products according to relevant International classification systems.

4.1.2. The significance of the connectivity in fulfilling the purpose of the device

The role of the connectivity in fulfilling the primary functionalities of the device is an important criterion to consider in the appreciation. For some connected devices, connectivity is essential to provision their intended functionality, while for some others connectivity may be a feature or an add-on. Distinguishing between a connectivity which plays an essential role *vs* a subordinate role in fulfilling the primary functionalities of the product, may not be straightforward as it would often require a detailed understanding of how the device works (i.e. how it uses its communication capabilities) to provision its functionalities.

This criterion could be implemented following these 2 steps:

i. Identify all functionalities of the connected device; distinguish between primary functionalities vs other functionalities.
ii. Challenge how connectivity is necessary to fulfill a functionality considered as "primary" by applying a negation test. A negation test investigates whether a given primary functionality could still be fulfilled assuming the device goes <u>permanently offline</u> (disconnected).

    NOTE – It is crucial to have a detailed understanding of the connected device being tested especially with regards to its various intended usage scenarios in order to be able to categorize its functionalities (primary vs other). Supporting information sources include for instance manufacturer/service provider product specification.

One may consider that the functionality is to be considered as "fulfilled" as long as a specific associated quality of service is respected. Thus, when implementing this criterion, it is important to describe as well as possible the functionality being tested especially with regards to its targeted quality or other related constraints. **Appendix I** provides guidance supporting the characterization of functionalities of a product.

While "primary functionality" is the main focus of this criterion, other functionalities involving critical considerations may deserve attention by the practitioner. Further elaboration is provided in **Annex D**.

An isolable IoT product is an IoT product where the connectivity is not necessary to fulfill its primary functionalities.

[14] The definition is adapted from the agreed principle for the ICT sector (refer to **Annex A**)

When implementing the negation test, the practitioner shall consider all other "fallback" means as specified by the manufacturer of the device which are able to make the product continue fulfilling its primary functionalities although going permanently offline.

EXAMPLE – The case of a window sensor that can detect the opening or closing of a window and submits its state via ZigBee® to a ZigBee® hub [ETSI TS 103.701]:

"The window sensor can be disconnected from the ZigBee® network in the Smart Hub it is connected to. Afterwards the signals from the window sensor cannot affect the network anymore. In this case the window sensor remains its core functionality to notify a user about the opening or closing of a window by a short acoustical peep sound emitted in case of such an event".

The approach described above is illustrated in Table 2 in a form of a matrix [functionality x connectivity]. In this illustrative example, the device features 4 functionalities in total and is equipped with 3 types of connectivity (cellular, short range wireless and a wired communication). The negation test is applied to functionality 1 and 3 (identified as primary). It is worth considering that some combinations (functionality x connectivity solution) may not be applicable in case of a given connectivity type would not be relevant to consider when testing the fulfillment of a given primary functionality (for instance a wired connectivity may not be relevant for a functionality intended to be provided in a mobility mode).

Appendix III provides examples illustrating the implementation of the negation test for a set of connected devices.

Table 2 - Illustration of the application of the approach through a matrix [functionality x connectivity]

<table>
<tr><th>Connectivity solution</th><th>Cellular technology</th><th>Short range wireless</th><th>Wired connectivity</th></tr>
<tr><td>Functionality #1 - primary</td><td colspan="2">Is the functionality still being fulfilled when the device goes permanently offline? [Yes/No]</td><td>Not applicable</td></tr>
<tr><td>Functionality #2 - other</td><td colspan="3">Out of scope of the negation test</td></tr>
<tr><td>Functionality #3 - primary</td><td colspan="3">Is the functionality still being fulfilled when the device goes permanently offline? [Yes/No]</td></tr>
<tr><td>Functionality #4 - other</td><td colspan="3">Out of scope of the negation test</td></tr>
</table>

4.1.3. The connectivity share in the carbon footprint of the device

a) Embodied emissions

Assessing the share of the connectivity in the carbon footprint of the device could be an alternative way to figure out the significance of the connectivity in the product profile. This can be done through a simplified LCA approach considering the device as a product system. When assessing the impact of the connectivity module, it is important to go beyond the modem integrated circuit itself and consider, through relevant allocations, all attributable processes/components.

Annex B provides a check list of relevant attributable processes and components to consider for assessment. It shows key parameters and example of metrics that may be considered when applying hardware component characterization method as an example of a simplified approach for embodied emissions assessment [GHGP- ICT Guidance – 2017].

Other possible simplified assessment approaches include: approximation of the carbon ratio through other physical (e.g. the mass) or monetary (e.g. the cost) ratios, the use of the Quality Function Deployment approach and the use of economic approaches. Further guidance on these alternative approaches is provided in **Appendix I**.

b) Operational emissions

The energy use stage assessment is the total additional energy use attributable to the connected device, where this results from devices becoming connected to networks. This approach is in line with [TEM-IEA – 2019]. The energy use stage assessment shall include both the network active and the network standby energy of the device (including dormant/sleep modes when relevant). This can be done by considering a typical duty cycle of a representative model of the device (For example, a game console model features the following typical duty cycle: 80% of the time is associated with low-power modes with network connectivity (i.e. in Idle mode), 5% in Standby mode (where the device is expected to resume at any time ex. Gaming pause), 15% of the time in active mode (ex. gaming, going through menu, media display etc.)

Actual energy consumption measurements during usage for a wide range of users is preferred, however such an approach may be difficult in practice to implement due to partitioning issues[15]; in that case, energy consumption can be modeled considering realistic usage scenario.

When assessing the share of the connectivity, the whole device (i.e. including components necessary for the realization primary or non-primary functionalities) shall be considered.

Table 3 provides an example of the scope of energy use stage assessment for the case of a connected smart fridge. This simple illustrated case consists of fridge (the appliance with an embedded system), equipped with occupancy sensors (for items detection) and a display component (displays information on items stored and customized Ads pushed by the service provider) included in the door; the smart fridge is connected to the Cloud through Wi-Fi:

Table 3 - Example of the scope of the energy use stage assessment for a connected smart fridge

Device	Modes	Function	Attributable?	Rationale
Connected Fridge	On-mode	Circulating the refrigerant inside the fridge to keep the food cold	No	The energy use of the appliance is not additional as the cooling mechanism is fulfilled without need for connection.
Connected Fridge (integrated display)	On-mode	Displaying information on items stored and infotainment	Yes	Additional energy as the functionality would not be possible in the absence of network connection.
Connected Fridge (occupancy sensor)	Network standby and active mode	To enable detection	Yes	Additional network energy
Gateway (WiFi router)	Network active	To connect the appliance to the Internet	Yes (recommended)	All the energy use is additional, so that the connected fridge can communicate

NOTE – In Example of Table 3, if the cooling mechanism is regulated by a distant server, the energy use of the appliance itself (On-mode) is attributable to the connectivity module.

[15] Between the energy use of the device in itself and the "incremental" energy use due to the connectivity. For instance, an IP Camera will have energy use associated with the camera and the network communications. To isolate the energy use of the network communications component would require estimates of the network communication power use, as this is not typically reported or measured. In practice, one may assume that the entire energy usage of the device would need to be considered additional, as it would not be present without a network connection.

4.1.4. The incremental share of connectivity in the carbon footprint of the service delivered by the device

This criterion considers the incremental share of the connectivity in the carbon footprint of the service delivered by the connected device. The impact of the connectivity should not be restricted to the device itself, but should also include the impacts of the network usage and datacenter platforms (as most IoT/connected devices are operated on the Cloud). This criterion considers a wider product system boundary, i.e. a system wide-view encompassing: the device, any companion devices or gateway (if relevant), the network and the datacenter.

This criterion is tested by calculating the incremental share of the connectivity within the whole product system. The incremental share refers to the ratio of additional carbon footprint attributable to the connectivity with respect to the carbon footprint of an (hypothetical) non-connected model of the device.

Additional GHG emissions are the amount of emissions in the product system (i.e. the product itself and supporting infrastructure for provisioning the service including networks, DC and Gateways if applicable) attributable to the connectivity, i.e. emissions that might not be incurred if the device was not equipped with connection capabilities.

To calculate the additional GHG emissions of the connectivity, a comparative assessment between a baseline situation featuring the connected product and an alternative situation featuring a hypothetical non-connected version of the product, is conducted. The practitioner may refer to **Appendix I** for further methodological guidance on the comparative assessment considering a single product scale.

The heuristic approaches the incremental share of the connectivity in the carbon footprint of the service only through first-order effects (i.e. the additional GHG emissions attributable to the connectivity) and does not account for potential enablement effects (GHG emissions that would be saved thanks to the fact that the product being connected). The theoretical framework developed here assumes a counterfactual situation where the functionally equivalent product is not connected as the aim of the heuristic is to assert first-order incremental externalities of the connectivity.

NOTE 1 – The practitioner applies relevant allocations to derive the additional GHG emissions stemming from networks, DC and other support goods (such as gateways, smartphones etc.). In particular for shared equipment/infrastructure such as the IoT service platform, the practitioner shall include all the required infrastructure involved in delivering the IoT service considering appropriate allocations

NOTE 2 – This criterion is intended to look at the impact of connectivity at such without targeting specific types of connectivity (wired, cellular, non-cellular etc.).

To assess the carbon footprint beyond the boundaries of the connected products, the practitioner shall follow a consequential thinking even if an attributional method is applied for the comparative assessment. A consequence tree could be used as a possible approach by a practitioner to identify relevant consequences. Further guidance is provided in **Appendix I**.

4.1.5. Hardware obsolescence-related considerations

It may be relevant to assess at what extent the integration of connectivity in the device may impact its circularity. In particular, when embedding connectivity capabilities into the device, several considerations related to product durability, ability to 3RU at equipment level[16] and at a manufacturer level[17], may deserve attention such as:

(1) Product durability:
   - the resistance of housing parts of the connectivity module, subject to be scratched,
   - availability of consumables, wear-out parts, expected to be replaced periodically,
   - Robustness,
   - Battery longevity,
   - …
(2) 3RU at equipment (connectivity module) level:
   - Fasteners and connectors are reusable/removable,
   - …
(3) 3RU at manufacturer level:
   - Repair, reuse, upgrade services availability
   - …

NOTE – These considerations are related to all hardware components involved in the connectivity.

Other criteria similar to those proposed in the reparability index (e.g. parts availability, ease of disassembly and access tools etc.) for electric and electronic products, established by virtue of article 16 of law n° 2020-105 of 10 February 2020[18] against waste and for the circular economy, could be also proposed.

Further guidance on assessing hardware-related obsolescence is provided in **Appendix I**.

NOTE – While a modular design (including the connectivity part) can be welcomed favorably to limit the risk of hardware-related obsolescence, it is important to keep in mind that modularity will also have an effect on product assessment under the other circularity indicators: Modularity is likely to have an effect on durability which includes aging fatigue and wear-out due to environmental and operating conditions. Additional interfaces for modularity and a good ingress protection being in conflict with easy access to parts and components are indicators that durability of modular products might be worse than for conventional designs. Recyclability may rather be improved by modular design[19].

4.1.6. Software obsolescence-related considerations

This criterion investigates at what extent the software/firmware supporting the connectivity may impact the circularity of the connected device. It specifically assesses the availability timespan of the connectivity module software and firmware updates and upgrades.

Further guidance on assessing software-related obsolescence considerations is provided in **Appendix I**.

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[16] This is related to the product's structure and access to its priority parts for repair, connecting systems to facilitate disassembly and reassembly, spare parts, diagnostic and information availability (source: [ITU L.1023])

[17] This is related to the manufacturer ability (on a company level) to facilitate recycling, repair, reuse and upgrade. These requirements are not directly connected to the equipment, but the infrastructure and support to be developed or supported by the manufacturer. (source: [ITU L.1023])

[18] https://www.ecologie.gouv.fr/indice-reparabilite#scroll-nav__6

[19] For further reading, refer to: Schischke, K., Proske, M., Nissen, N., & Schneider-Ramelow, M. (2019). Impact of modularity as a circular design strategy on materials use for smart mobile devices. MRS Energy & Sustainability, 6, E16. doi:10.1557/mre.2019.17

Table 4 provides a summary of the aforementioned criteria for categorization, their relevance and the supporting approaches for their assessment.

Table 4 - Summary of the criteria, their relevance and supporting approaches for their assessment

Criteria	Relevance	Supporting approaches for assessment
Identification as part of an IoT system and classification of the product as part of ICT or E&M	ICT and E&M Product definition according to OECD.	Requirements to qualify as IoT device developed in Section 2 Current international classification systems to identify ICT and E&M products
The significance of the connectivity in fulfilling the purpose of the device	"How being connected is necessary in fulfilling any primary functionality of the device?"	Qualitative assessment of the significance of the connectivity using for instance a negation test supported by explicit information on the role of the connectivity (e.g. manufacturer/service provider product specification)
The share of the connectivity in the carbon footprint of the device	Connectivity as a hotspot in the device's carbon footprint	Screening or simplified LCA considering the device as the product system and applying a relevant allocation rule.
The share of the connectivity in the carbon footprint of the service delivered by the device	Connectivity as hotspot in the carbon footprint of the functionalities delivered by the device	Calculating the incremental share of the connectivity within a wider product system scope (device, network, DC).
Risk of Hardware obsolescence	How connectivity module hardware implementation impedes the device's circularity. Waste management becomes critical as Connectivity module and the hosting device are highly integrated (their EoL are intertwined)	Goods' circularity scoring criteria related to Product durability and Ability to 3RU at an equipment level and manufacturer level
Risk of Software obsolescence	How the Lifecycle of the software/firmware powering/supporting the connectivity impedes the device's circularity	Goods' circularity scoring criteria related to software/firmware product durability.

4.2. Decision tree

4.2.1. General layout of the decision tree

The different factors are grouped, combined and arranged in the form of a decision tree. The grouping is carried out with respect to the area of relevance; three areas of relevance are identified.

The decision tree is then structured around 3 stages referring the 3 areas of relevance:

- **The first stage** deals with the role of the connectivity in fulfilling the function(s)/intended usage(s) of the connected device.
- **The second stage** deals with the share, in terms of environment load (e.g. GHG), of the connectivity in the connected device.

- **The third stage** deals with EoL considerations of the connected device, including aspects related to device's circularity and hardware/software obsolescence.

However, while the first stage investigates the categorization of a connected device from a functional/purpose perspective, the second and third stages approaches the problem from an environmental perspective, which is generally not usual for product categorization. Considering an environmental perspective might be justified in the categorization task as long as the "Connectivity" constitutes the decisive criterion to acquire or sell the connected product from a market (either a consumer or provider) point of view. Hence, an intermediate test is included to help guide the practitioner whether to end-up the heuristic with the outcome of Stage 1 or to pursue the analysis with subsequent stages. **Appendix I** provides further guidance on possible approaches for implementing this intermediate test.

The general layout of the decision tree is illustrated in Figure 8.

Based on the above-mentioned criteria, the decision tree leads to five possible outcomes:

- "*Non IoT good*"
- IoT good, subdivided into:
    - "*ICT native good*" or
    - "*E&M good*" or
    - "*ICT-enabled good*"
    - "*Non ICT-enabled good*"

Further elements of analysis are developed in **Appendix II** to understand how the criteria characterize a product and lead to one or another outcome of the decision tree in order to provide food for thought for a categorization of IoT (and more extensively connected) devices.

Considering the 4 types of IoT devices mentioned in Section 2.1.2, it could be inferred that, IoT sensing/actuating devices, Data capturing devices would be considered as ICT-enabled devices; while no systematic conclusion could be derived with Data carrying device and General IoT devices, the latter type of IoT devices refers to a large variety of devices.

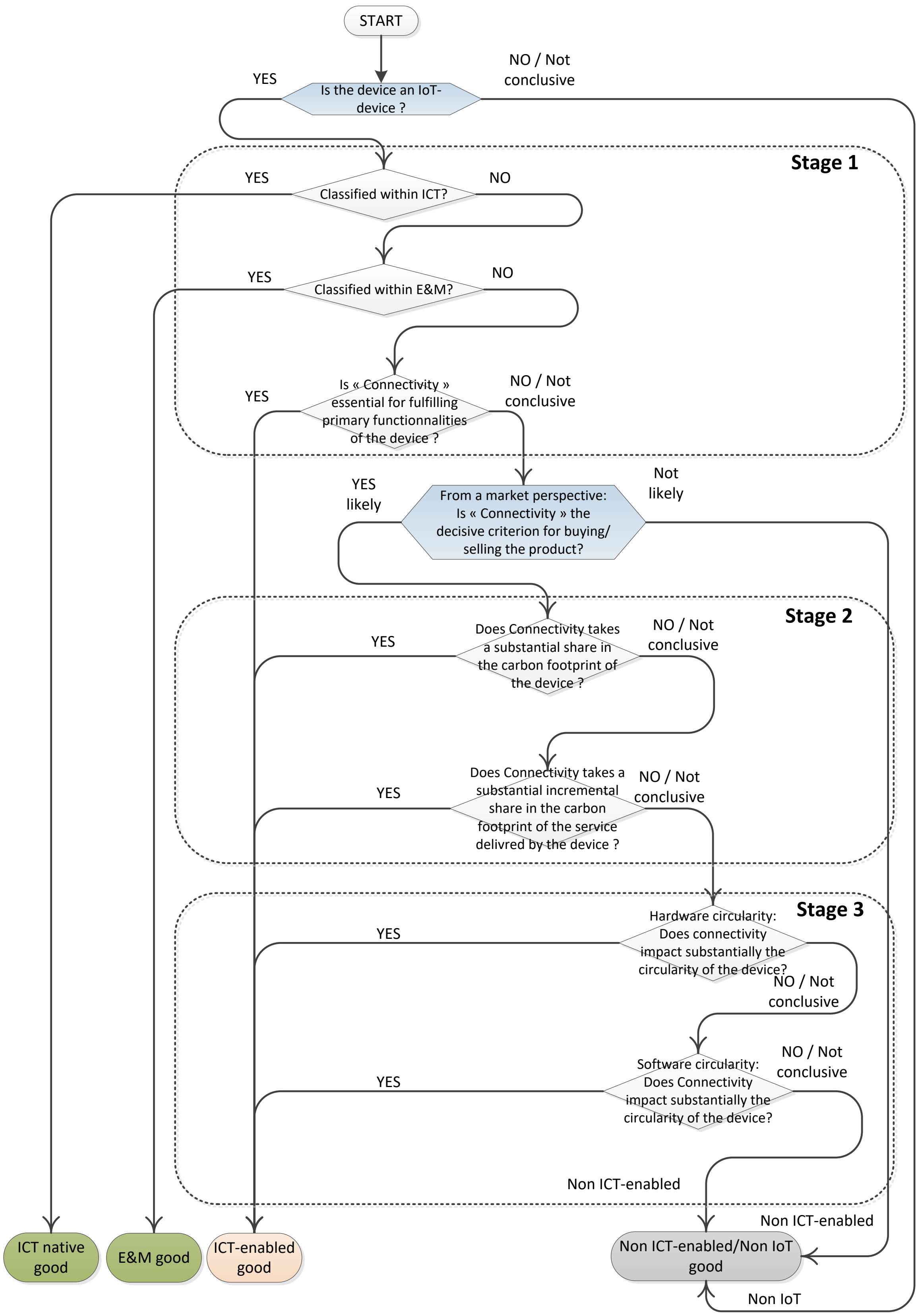

Figure 8 - General layout of the decision tree

4.2.2. Implementing the decision tree

A practitioner may use the decision tree according to 3 possible approaches as highlighted in Table 5:

- **a conservative approach**, which aims at supporting the analysis by going through the most prominent steps considering mainly steps of stage 1 (dealing with the functionality/purpose of the device); going beyond is either recommended or optional.
- **an extended approach**, which aims at undertaking a more extensive analysis by going at least through the two first stages of the decision tree. Steps of the last stage are optional as they revolve around eco-design-related considerations (more likely to be implementation specific).
- **a full approach,** which aims at recommending going through all the stages of the heuristic to provide the most comprehensive analysis. In this approach, steps of the last stage are recommended.

The selection of the most suitable approach depends on the objective and the type of the study/assessment, without prejudice to other considerations such as data availability. Refer to Section 6 for further guidance. In any case, the practitioner should be transparent on the rationale of the approach being selected.

Table 5 -The three approaches for using the heuristic

Decision tree stages		Conservative approach	Extended approach	Full approach
Stage 1	Identification as part of an IoT system and classification as ICT product or E&M product	Included	Included	Included
	Significance of the connectivity in fulfilling the purpose of the device	Included	Included	Included
Stage 2	Share of connectivity in the CF of the device	Recommended	Included	Included
	Incremental share of the connectivity in the CF of the service	Optional	Recommended	Included
Stage 3	Hardware obsolescence	Optional	Optional	Recommended
	Software obsolescence	Optional	Optional	Recommended

Methodological guidance is provided in **Annex B** regarding the modelling of the embodied carbon emissions of the connected device and for modelling the attributable share to ICT of the footprint of the connected device.

4.3. Refinement

As IoT is following interesting growth dynamics, a further topic of interest could be thinking of **carbon allocation rules** based on the categorization work and the heuristic developed in the core of the document. Preliminary elements on these topics are available in **Appendix II** which starts such exploratory topic of research and think of allocation-based rules while seeking consistency with the OECD Digital Economy framework described in **Annex A**.

Figure 9 shows for illustrative purpose the outcome of the implementation of the heuristic in terms of devices categorization and the share of the ICT sector footprint.

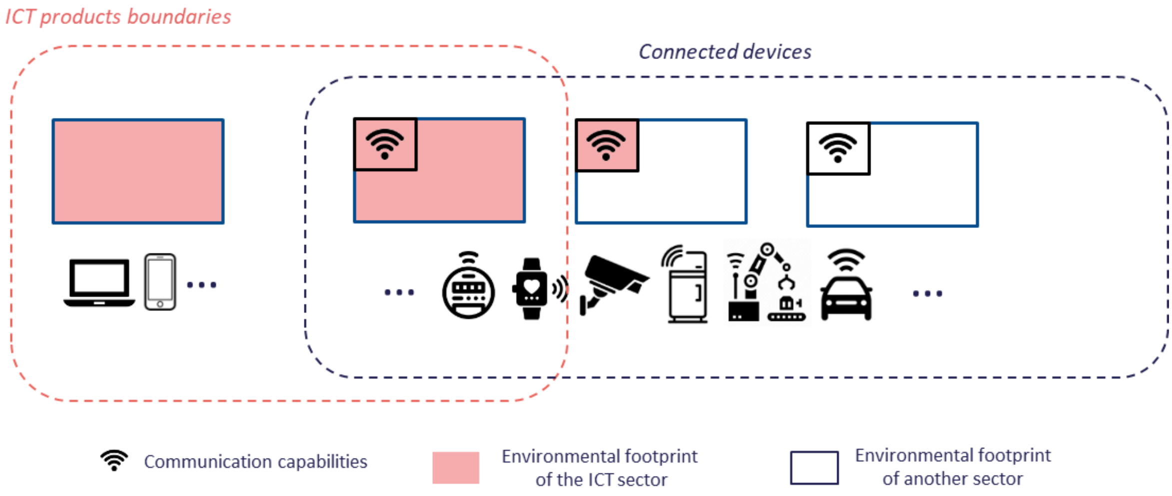

Figure 9 - Illustration of the outcome of the heuristic (ICT products boundaries and connected devices)

As **artificial intelligence's applications within IoT** solutions are expanding, this innovative technology may have implications on the categorization of such "hybrid" system (Artificial Intelligence of Things or AIoT). Preliminary elements of analysis on this topic are available in **Appendix VI**.

The operational mode: autonomous mode vs human-assisted mode: Connected products may perform their primary functionality following an autonomous mode (fully automated) or a human-assisted mode (with human intervention). When the primary functionality is executed in an autonomous model, the connectivity would be considered as necessary to fulfill the primary functionality at least because of the need to update the software/firmware embedded with the product and being involved in the execution of the primary functionality[20].

The case of composite devices and multi-primary function devices (e.g. combo primary functions): For the case of Composite multi-primary functionalities devices (e.g. a combo washer & dryer machine), 2 possible situations may occur depending on how the primary functionalities are sequenced:

- Where the functionalities are simultaneous or overlapping, the practitioner shall apply the heuristic on each functionality.
- Where the functionalities are subsequent to each other, if the outcome of test 3 (of stage 1) is positive for the first functionality, the practitioner does not need to pursue the analysis as the device would be considered de facto as ICT-enabled, otherwise, the practitioner needs to carry on and challenge the subsequent functionality

[20] For instance, for the case of automated driving systems including autonomous vehicles, this would correspond to SAE level 4 (called also "High automation") or SAE level 5 (called also "Full automation") according to the Taxonomy related to On-Road Motor Vehicle Automated Driving Systems published by the Society of Automative Engineers [SAE – 2021]

5. Relevant contextual parameters for IoT devices

As illustrated in Figure 10, in general, there is quite a strong correlation between the number of mobile users or subscribers and the number of subscriptions[21]. Similarly, there has been a correlation between the number of households and fixed subscriptions. Thus, subscriptions have been found to be a reasonable proxy for the number of users. With the increasing amount of IoT devices, subscriptions may be less correlated with users and instead other contextual parameters may become more important or relevant for the impact assessment of the share of the IoT subcategory within the ICT sector. In addition, the proliferation of connectivity solutions and protocols (WIFI, LPWAN, LPSAN etc.) while some of them may be proprietary makes the connectivity of IoT devices not subscription-based but founded on Internet Protocol or other narrow band solutions, such connectivity solutions might not be part of the statistics.

Actually, it is easy to track and monitor the evolution of devices such as M2M due to their mobile subscriptions, while IoT devices connected via non-cellular technologies are more challenging to track.

In this Section, the Committee recommends on relevant contextual parameters for IoT devices.

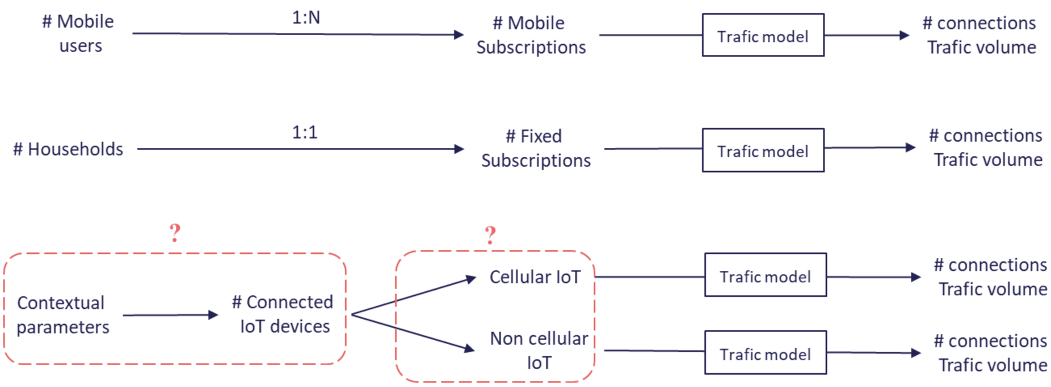

Figure 10 - From contextual parameters to network connections and traffic volume

The number of connected devices operating at a given year (the stock at year '*y*') can be derived using the following general formula:

$$\#\, connected\ IoT\ devices_y = \#\, connectable\ IoT\ devices\ _y \times\ \rho_y$$

Contextual factor ρ_y refers to the share of devices being effectively connected (installed and operating devices) at year '*y*'.

The number of cellular IoT and non-cellular IoT devices is derived by taking the share of each IoT device type:

$$\#\, Cellular\ IoT\ chips_y = \#\, connected\ IoT\ devices_y\ \times \%\, cellular$$

$$\#\, Non\ cellular\ chips_y = \#\, connected\ IoT\ devices_y \times \%\, non\ cellular\ \times \#\, chips/IoT$$

Where the terms "*% cellular*" and "*% non-cellular*" refer respectively to the proportion of connected devices through cellular networks and the proportion of connected devices through non-cellular technologies. "*#chips/IoT*" considers the average number of communication modules equipping an IoT device.

[21] Although some users may have more than one subscription and subscriptions may be used by more than one user.

NOTE 1 – For cellular IoT devices, it is reasonable to assume a single communication module per device although it may use more than a single cellular technology (e.g. for 2G/3G IoT devices), while an IoT device connected through Wi-Fi and Bluetooth technologies would require two communications chips.

NOTE 2 – The proportions of cellular and non-cellular IoT used in the formula may not add-up.

NOTE 3 – Equations above depict a conceptual approach that can be further refined; for instance, ρ_y may vary with the type of connectivity.

Connectable devices refer to shipped devices at a given year, it could be derived using the penetration rate of the device type in its associated market and based on relevant contextual parameters (households, users, dwellings/premises, industrial robots, cars etc.). Using contextual parameters is an effective approach for monitoring the rate of digitalization of society through IoT. Examples of contextual parameters are provided in **Appendix IV**.

Alternatively, the number of connectable devices could be derived using statistics from sales or shipments of devices with a methodology similar to the Bottom-Up Energy Analysis System (BUENAS) model developed by Lawrence Berkeley National Laboratory[22] and used by IEA [EDNA-TEM – 2019].

Refer to **Appendix IV** for further details.

6. Lessons and recommendations

The present Report finds its origin with the increasing digitalization of the economy propelled with massive spread of IoT and other connected devices. OECD has built "A Roadmap toward a Common Framework on Measuring the Digital Economy", including a proposed common agreed definition on the Digital Economy and a set of existing indicators. For that purpose, OECD has defined the "Going Digital Toolkit"[23] structured along 7 policy dimensions (Access, Use, Innovation, Jobs, Society, Trust, Market openness). M2M is part of the policy dimension "Access"[24], which currently includes 7 indicators among a total current number of 42 indicators.

Indeed, IoT is expected to be one driver of the digital ecosystem in terms of value and equipment. Hence, the interest to develop the present report's approach aiming to develop a consistent heuristic on connected devices within IoT to draw boundaries and provide with respect to ICT and E&M a product clustering within IoT and more extensively connected devices.

As it lies in the neighborhood of ICT, IoT is today included to some extent in digital environmental footprint assessment studies while being included in products and solutions from various sectors (e.g. agriculture, transportation, construction, health, manufacturing). Indeed, its direct environmental impact is expected to rise with respect to a growth in volumes. On the other hand, among the potential enablement effects of digital technology towards various sectors that could reduce their environmental impacts, there are a lot of technological solutions based on connected or IoT devices. Thus, it is necessary to be able to draw boundaries between ICT, IoT and connected device but also within connected devices.

For instance, here are some areas of works that could capitalize on the heuristic developed in this report:

(1) Environmental performance labeling:

[22] Bottom-Up Energy Analysis System (BUENAS) | International Energy Analysis (lbl.gov)

[23] OECD Going Digital Toolkit

[24] Access | OECD Going Digital Toolkit

Product Category Rules (PCR) are currently developed in order to provide a robust and transparent framework when it comes to product environmental assessment for marketing positioning. IoT is of course an important area of work as it will grow thus, being able to draw boundaries within the digital world between ICT, IoT and simply connected devices is a necessary preliminary basis before accounting the environmental footprint of an IoT device/service. Furthermore, a PCR approach always faces the problematic of allocation rules (of the impact). Thus, the work developed in the core of this document and its appendix (e.g. including the heuristic's product categorization, guidance for the assessment of the footprint of a connected device) could be an interesting basis for such area of work.

(2) Economic or environmental statistics supporting public policies on IoT and connected devices:

As stated earlier, IoT is a very dynamic industry and it will logically be an area of importance as well for public institutions. Providing an exhaustive approach and concepts to have a clearer view between ICT, IoT and connected devices including an assessment of direct impacts and indirect effects, is important to support future economic and industrial choices. To serve such objective, a clear categorization is necessary to any economic or environmental observatories that would have to monitor the spreading of digital within the economy, whether it's ICT, IoT or other kind of connected devices. For instance, the heuristic's product categorization could support all interested stakeholders or any competent public entity in charge of such monitoring through the establishment of a satellite account[25] for environmental and economic monitoring of Connected devices and IoT products.

The revisited framework of the OECD Digital Economy for IoT and connected products categorization developed in **Appendix II** could be an example for such a "connected products/IoT" satellite account:

- For economic monitoring purposes, the proposed satellite account would help derive insightful activity data such as: the number of connected products/IoT products per tier, the number of connectivity interfaces equipping connected products/IoT products per tier, the volume of data traffic exchanged through by connected products/IoT products per tier etc.
- For environmental monitoring purposes, the proposed satellite account would help derive insightful impact data such as: the total energy consumption of connected/IoT products per tier, the total carbon footprint of connected/IoT products per tier etc.

Similar to the case of connected products/IoT and going beyond to address the issue of the scope of ICT with respect to other emerging digital technologies-based products such as Artificial Intelligence and Blockchain[26], the introduction of a satellite account would be a

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[25] According to System of National Accounts (SNA): "*satellite accounts provide a framework linked to the central accounts and which enables attention to be focused on a certain field or aspect of economic and social life in the context of national accounts; common examples are satellite accounts for the environment, or tourism, or unpaid household work*". https://unstats.un.org/unsd/nationalaccount/glossresults.asp?gID=493

This definition is in line with OECD glossary of statistical terms and other NSO including INSEE (refer to: https://www.insee.fr/en/metadonnees/definition/c1153#:~:text=A%20satellite%20account%20is%20a,the%20environment%20are%20some%20examples)

[26] This is in line with the gap highlighted by the Expert Committee in its Report [ARCEP/ADEME Committee – 2023] : "*With regards to current trends and the growing perspective of the use of crypto-mining and blockchain, this needs additional consideration to define the boundary and to avoid double counting perspective this includes for instance understanding the potential specificities of hardware and infrastructure being used to implement and run blockchain technology and the protocol of consensus used compared with conventional ICT infrastructure/hardware. In addition to cryptocurrencies, Blockchain*

relevant approach. Such a satellite account could be designed in a similar way as the “connected products/IoT” satellite account, i.e. a tiered approach for products categorization aiming at assessing the various degrees at which the other pillars of the ICT sector/products definition (i.e. “information processing” and “display”) are being used by such emerging digital technologies-based products:

- **Core scope:** Emerging digital technologies-based products as part of the Information Economy
- **Narrow scope:** Emerging digital technologies-based products that are reliant on “information processing/display”.
- **Broad scope:** Emerging digital technologies-based products that are significantly enhanced by “information processing/display”.

In addition, the heuristic could be used to implement this categorization after some adaptations at its tests where the practitioner would challenge the significance of the role of the “information processing/display” and its attributable impact instead of the “connectivity”.

Further details are provided in **Appendix VII**.

(3) Public policies on carbon trajectory (supporting national low-carbon strategies for the digital economy):

Planning the decarbonation of a country is always difficult as carbon budgets have to be shared among economic sectors but the digital economy is transversal and spread within traditional economic sectors (see **Annex A**). Thus, the work developed in the current report provides a classification and a scoping that can be used to foresee different carbon emission trajectories depending of the scope that is used (only ICT or IoT or even transversal and larger within the digital economy).

For example, as presented in the report’s identified possible areas of future research, a flexible approach by tiers to encompass the different types of connected devices and possible allocations of their carbon footprint to the tier which they belong to[27] (see **Appendix II**) could be used to derive different trajectories for GHG emissions through an economic sector-specific or transversal digital economy analysis. For instance, one can derive a trajectory per tier (see Figure 11) in order to use levers of actions where they are the most efficient in terms of decarbonation while being able to also keep a view on economic constraints aside of environmental ones.

Based on such trajectories by tier, the practitioner could aggregate them to derive:

- A trajectory for the ICT and E&M sector ([Tier 1] & [Tier 1+])[28]. This may provide complementary insights for current standards developed on this field (such as ITU L.1470 Recommendation and Part II of ITU L.1450 Recommendation).

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applications include NFT. The same challenge in terms of the need to define the boundary is also exposed for the case of AI/ML as AI computing resources (“stacks of hardware and software used to support specialized AI workloads and applications in an efficient manner”) may differ from general purpose compute resources”.

[27] Note for the reader: the concept of “tier” used in the Report refers to what is developed in its **Appendix II** (i.e. to categorize the different parts of the Digital Economy). For the sake of clarity, it should be noted that it is a different concept from what is developed (and called “tier”) in Section 4 “Methodological gap identification and recommendations” of the Committee’s Report “*Assessment of the environmental impact of the ICT sector: methodological gap analysis*”.

[28] The reader may notice that those tiers work by successive inclusions. According to what is developed in **Appendix II**, Tier 1 (encompassing connected products within the Information Economy, i.e. within ICT + E&M sectors) is included in Tier 1+ which would be the extension of the core scope (tier 1) to ICT-enabled products.

- A trajectory for the digital economy from the perspective of ICT/E&M ([Tier 1] & [Tier 1+] & [Tier 2] & [Tier 3])

It should be emphasized that these two possible types of analysis, including IoT are still research topics and that their implementation through the different ITU-T environmental recommendations would need to be worked out by the different relevant working groups.

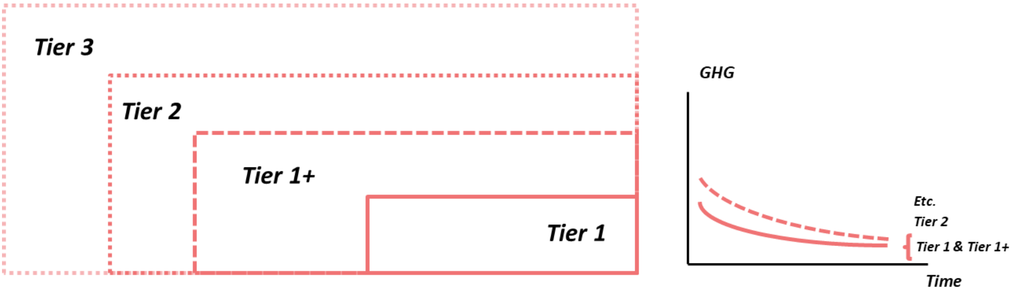

Figure 11- Illustration of the different GHG emissions trajectories stacked by tier

(4) Assessing carbon footprint of IoT-based ICT solutions and connected products-based digital solutions:

Assessing the carbon footprint of an IoT-based ICT solution (such as an ICT service featuring IoT) may be challenging when it comes to define the boundary of the solution with respect to ICT. A similar challenge applies for comparative analysis/LCA between an IoT-based ICT solution and a reference solution (non-ICT) or between two ICT solutions (where one of them at least is an IoT-based ICT solution). While complementing ITU L.1410 guidance, the heuristic may be leveraged by a practitioner to handle the specific case of ICT solutions involving IoT. To assess the carbon footprint of an IoT-based ICT solution, the practitioner may rely on the distinction between ICT native, ICT-enabled and non-ICT products together with the tiered framework approach for product categorizations and carbon accounting developed in **Appendix II**.

The same rationale applies when assessing the carbon footprint of a connected products-based digital solution (i.e. a digital solution featuring connected products) from the perspective of ICT.

(5) Supporting a more detailed characterization of environmentally sustainable connected products:

Products and economic activities categorizations aiming at highlighting their support for enabling environmental sustainability were promoted by several initiatives such as the EU Green Taxonomy[29], the European Green Digital Coalition (EGDC)[30] and Net Zero Initiative (NZI)[31].

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[29] https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en

[30] https://www.greendigitalcoalition.eu/

[31] https://www.carbone4.com/charte-engagements-nzi-it

Connected devices expected to have a net positive enabling impact, i.e. supporting climate change mitigation, for instance by helping other sectors decarbonize their activities, may achieve enablement mainly through substitution or optimization.

- For connected devices achieving substitution-driven enablement: the reference activity is being substituted upon the use of the connected device leading, when compared to the reference scenario, to a net positive GHG impact. When the reference activity corresponds to the primary functionality of the connected device, then the connectivity would be essential to fulfill the primary functionality of the device; in particular when the connected device is an IoT device, it would be considered as an ICT enabled device (when the heuristic is implemented through a conservative approach).
- For connected devices achieving optimization-driven enablement: the reference activity is being optimized upon the use of the connected device leading, when compared to the reference scenario, to a net positive GHG impact. When the reference activity corresponds to the primary functionality or another functionality of the connected device, then the connectivity would not be essential to fulfill the primary functionality of the device; in particular when the connected device is an IoT device, it would not be considered as an ICT enabled device (when the heuristic is implemented through a conservative approach)

Depending on the assessment/study type and its objective, Table 6 highlights the recommended approach for implementing the heuristic:

Table 6 - Recommended approach for using the heuristic depending on the study/assessment objective

Study/assessment objective	**Assessment type**	**Recommended approach**
Establishing PCR for environmental performance labelling for IoT devices	meso	Extended approach
Public policies for IoT	macro/meso	Conservative and tentatively extended approach
Establishing a carbon trajectory for the ICT and the E&M sectors ([Tier 1] & [Tier 1+])	macro	Conservative approach
Establishing a carbon trajectory for the Digital Economy from ICT perspective	macro	Conservative approach
Assessing the carbon footprint of IoT-based ICT solutions	micro	Full approach
Assessing the carbon footprint of IoT-based Digital solutions from ICT Perspective	micro	Full approach

Annex A

Boundaries of the ICT and E&M sectors and materiality of the so-called "Digital Sector"

(This Annex is related to Section 2)

The ICT and E&M[32] sectors are characterized by a rapid development, this has been exacerbated by the ever-increasing digitalization of the Society and the promoted consequences in terms of economic welfare, social and economic inclusion and other externalities.

In this Annex:

- Section 1 provides an overview of the historical evolution of the ICT and the E&M sectors and ICT/E&M products definitions.
- By adopting a forward-looking approach, Section 2 lays down the challenges raised by this definition with emerging technologies such as IoT, Blockchain and AI and questions the relevance and the feasibility of defining the so-called "Digital Sector".

A. 1 ICT/E&M Sectors and ICT/E&M products definitions: Historical evolution in a nutshell

The difficulties in establishing a classification of ICT products had been recognized by the OECD since 1998. Some of these difficulties are inherent to the sector itself as they are related to the rapidly changing characteristic of ICT products, while other difficulties are more related to the statistical task (challenges in relating the definition to available classifications and the dated nature of product classifications such as the United Nations Central Product Classification).

From its first attempt in 1998 to present, the definition of the ICT sector has undergone several changes as depicted in Figure 12.

[32] Entertainment and Media (E&M) and Content & Media (C&M) are used interchangeably as they refer to the same concept. ITU L.1450 Recommendation refers to E&M, while OECD and nomenclature standards (such as ISIC and CPC) refer to C&M.

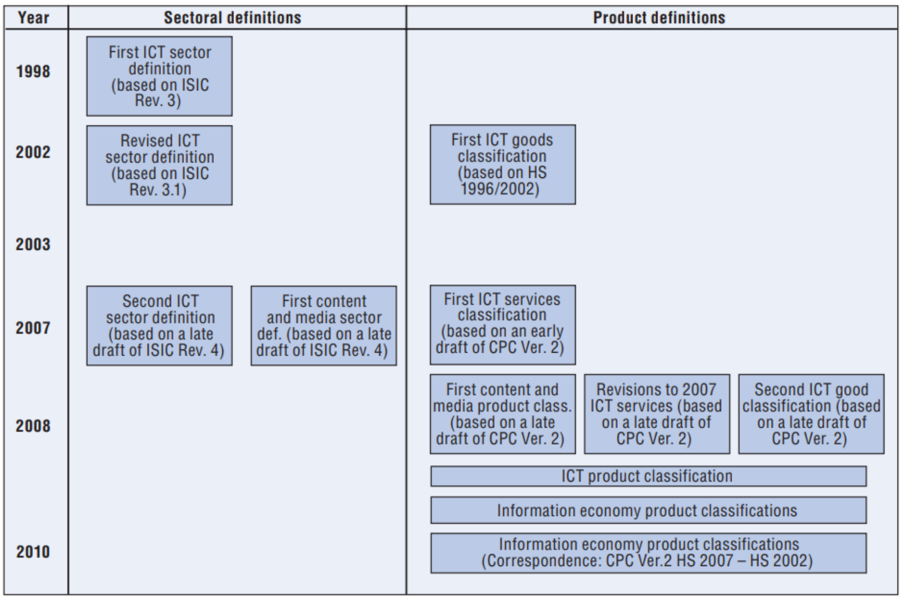

Figure 12 - Illustration of the historical development of sectoral and product definitions (source: [OECD-2011])

Retrospectively and referring to the timeline depicted in Figure 12, the main following developments can be highlighted:

- **1998 – 2002:**
    - Core indicators on the ICT sector and trade in ICT goods: Basic core set around 2 indicators: "the proportion of total business sector workforce involved in the ICT sector" and "The value added in the ICT sector (as a percentage of the total business sector value added)";
    - Original Guiding principle for ICT sector definition considers:
        - For manufacturing industries, the products (goods) of a candidate industry must: "*<u>fulfill the function</u> of information processing and communication including transmission and display, <u>or use electronic processing</u> to detect, measure and/or record physical phenomena or control a physical process*".
        - For service industries, the products (services) of a candidate industry must "*<u>be intended to enable the function</u> of information processing and communication by electronic means*".
    - According to [OECD -2011], "*when the first ICT sector definition was developed in 1998, it was recognized that the preferred procedure would have been to first define ICT goods and services and then to formulate the ISIC classes that had activities involving those goods and services. However, in order to obtain an initial set of indicators for the ICT sector in a limited amount of time, the approach taken was to first define the activities and subsequently work on a list of ICT goods and services that could complement and help to refine the activity-based definition*". Thus, the guiding principles for the ICT and Content and media products are adapted from guiding principles for the sector definitions.
    - Another guiding principle of the definition was to use existing classification systems (ISIC for sectoral definition, HS and then CPC for products classification systems) in

order to take advantage of existing data sets and therefore ensure immediate use of the proposed standard.

  - It is worth noting that the 1998's agreed definition by the OECD was almost done in inclusive rationale [OECD – 2011] (e.g., the definition proposed would not include any "parts" of industries but would rather include the entire of industry even though in some cases the latter might not be strictly an ICT activity[33]. Actually, this was justified by the fear that a complete exclusion of an industry would mean the exclusion of significant businesses which are producing ICT goods and services[34]);

- **2005:** OECD defined "digitized products", including both products which can be delivered over the internet in digitized form and have a physical analogue (e.g., downloaded movie and a DVD of that movie) and other digitized products where the analogy with a physical product is less direct (e.g., web-based products accessed online). Digitized products include also "offline services" which are services that are ordered online but are delivered or substantially delivered offline (e.g. bookings for accommodation or travel).

- **2007:**

  - Regarding ICT products, the discussion was held on the relevance to keep with the broader original guiding principle or to narrow the list of industries, given that more and more products incorporate technologies that use electronic processing. Regarding ICT service, the determination of what constitutes an "enabling" service or technology (mentioned in the original guiding principle) represented the main challenge.
  - In particular, the activity-based approach for categorization brought up some difficulties in maintaining consistency between different industries within the same activity: how to distinguish between industries who use electronic processing in a significant way (thus justifying their inclusion) from those that do that in an incidental way (thus their inclusion is questioned), given that ICT are embedded into a growing number of products produced by a variety of industries. Similar challenges were raised regarding other examples such as Broadcasting activity where the transmission of programs is part of the activity but the majority of the experts' group were of the opinion that the development of channels and programming (which are also part of the Broadcasting activity) is the defining characteristic of industries categorized within Broadcasting activities and thus Broadcasting and programming activities are excluded from the ICT sectoral definition.
  - Revision of the guiding principle for ICT manufacturing: *"The products of a candidate manufacturing industry must <u>be intended to primarily fulfill the function</u> of electronic information processing and communication (including transmission, recording, storage and display)"*. The scope was narrowed by removing the capabilities of detecting, measuring and/or recording physical phenomena or controlling a physical

[33] Example: The inclusion of "Manufacturing of insulated wire and cable" was motived by the perceived growing importance of optical fiber cables which have changed this industry over time despite expressed concerns regarding the inclusion of transmission cable of electric power.

[34] Example: Radio and Television Activities are normally excluded from the sector's definition. However, where transmission of radio and television programs were done as part of the work of the business, the transmission activities, Radio and Television Activities were hence included.

process through the use of electronic processing, while including ‘recording’ and ‘storage’ functions[35].

  - Narrowing the scope of ICT products definition to be consistent with the changes to the definition of the ICT sector. These exclusions do not prejudge from some exceptions, which the expert’s group decided to include. These exceptions include for instance: the inclusion of “burglar”, “fire alarms” and “similar apparatus”, and the inclusion (for consistency with other inclusions) “Digital Cameras” and “Other Recording media including matrices and masters for the production of disks”, two out-of-industry products.
  - The introduction of Content & Media Sector (based on ISIC Rev. 4) followed by a definition of related products. The latter are identified using the following guiding principles:
    - It is an organized message intended for human beings.
    - It results from an organized production activity.
    - It is combined with, or carried by, a medium.
    - Its diffusion is not restricted to a list of privileged recipients.
    - Its diffusion requires a communication medium, i.e., a mass diffusion medium.
    - Its diffusion requires the intervention of a publisher that is of a publishing business.
    - The value of such a product to a consumer does not lie in its tangible qualities but its information, educational, cultural or entertainment content.
  - Core indicators on the ICT sector and trade in ICT goods: 2 additional indicators: “ICT goods imports as a percentage of total imports” and “ICT goods exports as a percentage of total exports”.
- **2008 and onward:**
  - The introduction of “Information economy sector” which includes the industries in both ICT and Content & Media (C&M) sectors.

From a lifecycle-based perspective, ITU identifies the following ICT goods and their related support goods [ITU – L.1450]:

- Computer and peripheral equipment;
- Consumer electronics for communication purposes (such as mobile phones, smartphones, tablets, stationary and laptop PCs, home network goods, etc.), including IoT devices where applicable;
- Wireline and wireless network goods (including telecommunication core network goods);
- Satellite telecommunication;
- Other telecommunication network goods (enterprise networks, metro/edge/IP core and data transmission networks);

[35] The contrary view against the change in the definition (i.e., the exclusion of the second part of the original definition) claims that such a change represents a significant departure from the existing definition that could be difficult to explain to users and that would change the message given by statistical indicators [OECD – 2011]

- Data centers.
- Support goods (ICT infrastructure such as towers, cables, shelve etc., goods installed on site or at facilities for the grid and non-grid power supply of ICT networks, goods installed on site or at facilities for cooling purposes)

From an economic activity-based perspective, the following list of industries, according to **ISIC Rev.4**, meet the guiding general principle[36] for identifying ICT economic activities. They are grouped into three broad categories[37]: ICT manufacturing industries, ICT trade industries and ICT services industries as shown in Table 7.

Table 7 - Classification ISIC Rev.4

Rev 4.0 ISIC class code	**Title of the industry**
ICT manufacturing industries	
2610	Manufacture of electronic components and boards
2620	Manufacture of computers and peripheral equipment
2630	Manufacture of communication equipment
2640	Manufacture of consumer electronics
2680	Manufacture of magnetic and optical media
ICT trade industries	
4651	Wholesale of computers, computer peripheral equipment and software
4652	Wholesale of electronic and telecommunications equipment and parts
ICT services industries	
5820	Software publishing
61	**Telecommunications**
6110	Wired telecommunications activities
6120	Wireless telecommunications activities
6130	Satellite telecommunications activities
6190	Other telecommunications activities
62	**Computer programming, consultancy and related activities**
6201	Computer programming activities
6202	Computer consultancy and computer facilities management activities
6209	Other information technology and computer service activities
631	**Data processing, hosting and related activities; web portals**
6311	Data processing, hosting and related activities
6312	Web portals
951	**Repair of computers and communication equipment**
9511	Repair of computers and peripheral equipment
9512	Repair of communication equipment

[36] "The production (goods and services) of a candidate industry must primarily be intended to fulfil or enable the function of information processing and communication by electronic means, including transmission and display". [OECD – 2011]

[37] This categorization reflects an alternative aggregation for the ICT sector and does not correspond to the original ISIC classification. This alternative aggregation is used by ISIC, to define the activities of the ICT sector, in order to be consistent with OECD definition of the ICT sector (for example by categorizing ICT manufacturing industries within ICT instead of Manufacturing divisions (Section C)) [ISIC – 2008].

From product perspective, two possible nomenclatures can be used to identify ICT products and E&M products:

- According to the **Central Product Classification (CPC v2.1)**: 98 ICT products grouped into 10 broad level categories[38], 74 E&M products grouped into 6 broad level categories. The relationship between Information Economy products and the sectoral definitions (based on ISIC) is as follows: products that are linked to an ISIC class that is a member of one of the information economy sectors are included, and products that are not linked to an ISIC class that is a member of one of the information economy sectors are excluded, unless there is a compelling case for their exclusion/inclusion respectively[39].
- The **Harmonized Commodity Description and Coding System** (simply "HS") of the World Customs Organization (WCO) was updated in 2022 ("HS22") providing the list of goods classified as ICT goods[40]; they are grouped into 5 broad categories[41].

The complete list of ICT and E&M products according to CPC v2.1 and correspondence with ISIC Rev 4.0 is provided in **Appendix V**.

A. 2 What defines the "Digital Sector"?

In the context of the development of the Internet of Things, artificial intelligence and other related digital technologies have been widely embedded into products. As already pointed out the ARCEP/ADEME Expert Committee Report [ARCEP/ADEME – 2023], these developments pose several challenges related to the current definition of the ICT sector and its boundaries; these challenges can be reflected into the following questions:

- What is the nature of ICT? does it stand for a General-Purpose Technology (GPT) and consequently it would be intended only for mainstream market (B2C or B2B) products or would it rather go beyond to encompass specialized markets/application domains (such industry 4.0 and other verticals of the economy)? Example: the case of connected and smart products.
- Is it still relevant to consider ICT and E&M as distinct sectors while the ecosystem recognizes an increasing merge between the content and the medium? Example: the case of metaverse.
- Is it possible to set clear boundaries between the ICT sector and other sectors whose primary activities are increasingly impacted by ICT? Example: the case of blockchains/crypto-currencies for the financial sector, the case of satellites for the space sector.

With the increasing pace of digitalization, many activities have undergone substantial transformation (in their process/flow or their deliverables) while some activities emerge as new activities (their

[38] Including: Computers and peripheral equipment, Communication equipment, Consumer electronic equipment, Miscellaneous ICT components and goods, Manufacturing services for ICT equipment, Business and productivity software and licensing services, Information technology consultancy and services, Telecommunication services, Leasing or rental services for ICT equipment, Other ICT services.

[39] There is one product linked exclusively to an ICT sector class that is excluded from the ICT products list and four that are included in the Content and media products list. There are nine products not linked to either of the sectoral definitions that are included in the ICT products list and four in the Content and media products list.

[40] The 2022 edition of the HS introduced several substantive new categories of products, many of which are products integrating digital technologies and therefore merit some considerations against the definition of ICT goods.

[41] Computer and ICT peripheral equipment, Communication equipment, Consumer electronic equipment, Electronic equipment, Miscellaneous ICT goods.

existence is enabled through digitalization)[42]. As the ICT sector might not encompass all these activities, one may resort to include them under a wide umbrella referring to the "Digital Sector".

However, we noticed that this concept suffers from a fuzziness around the exact definitional boundary. In the absence of a clear and common definition of the concept of "Digital Sector", instead, the "Digital Economy" is frequently used and quantified in some official reports as an equivalent epistemic object. In its paper [IMF – 2022], IMF stresses that "*lack of a generally agreed definition of the "Digital Economy" or "Digital Sector" and the lack of industry and product classifications for Internet platforms and associated services are hurdles to measuring the Digital Economy*".

In the remaining of this Section, the term "Digital Economy" is thus used as a broad proxy to approach the "Digital Sector"[43].

Supported by the review of [Bukht – 2017] and through an extensive analysis of how Digital Economy has been defined in the literature including National Statistics Organizations (NSO), one may identify three different angles reflected by the authors of the reviewed studies when scoping the concept of Digital Economy:

- **Resource perspective**: Where the definitions identify the technologies on which the digital economy is founded; this includes also a content perspective (the handling of data and information) and a human resource perspective (human knowledge, creativity or skills enabled by ICT).
- **Process/flow perspective:** Where the definitions revolve around the use of ICT to support particular business processes such as transaction/commerce, the flow of data/information that are enabled by ICT, and the changes brought by ICT to existing processes.
- **Structural perspective:** Where the definitions focus on the economic transformation or the identification of the new web/network-based structures that emerge.

Table 11 highlights how the definitions reviewed in the literature are mapped with the three perspectives.

Table 11 points out that little have been devoted to define the concept of Digital Economy through its technology building blocks (Resource perspective). This is because, with the pervasive and dynamic nature of digitalization making it difficult to isolate in a specific domain, it is more convenient to describe how economic activities and ecosystems evolve and being impacted with digitalization (i.e. through a process/flow or structural perspectives).

A notable exception is noticed with NSO publications, where there was a need to recognize digital activities (products and industries) within their national accounting frameworks. Actually, official economic statistics are constructed using international industry and product classification systems such as the International Standard Industrial Classification System (ISIC Rev. 4) and the Central Product Classification System (CPC 2.1). These classification systems are mainly structured around what is being produced rather than how it is being produced, and thus not structured in a way that permits an analytically useful aggregation of digital activities, which for the most part impact how goods and services are being produced and delivered. Given the policy relevance of this information (for instance: ensuring comparability between countries and consistent monitoring within the same country), national accounting frameworks have to evolve.

Actually, scoping a given sector or an economic activity may be achieved through two possible perspectives:

[42] This includes behavioral transformation of households and individuals in terms of consumption and production.

[43] Unless stated, both terms are used interchangeably.

- Through its deliverables, i.e. the set of its output products (goods and services);
- Through its affiliated organizations including economic entities and industries.

As for the definition of the ICT and E&M sectors, the product-based and the organization-based perspectives are two complementary facets of the same coin; ideally, they have to be used together to ensure a consistent picture (for instance for calibration or gap-filling)[44].

A. 2. 1 Scoping the "Digital Sector" through its products

As more and more devices being embedded with smart capabilities (computing, connectivity etc.), the term of smart product becomes fuzzy as there is no agreement or standardized definition on the criteria or attributes for "smart products". Because different studies rely on differing conceptualizations, the current body of knowledge is scattered and patchy and lacks a uniform language and conceptual boundaries, this had led to conflate smart products (i.e., as devices that combine hardware and software components in a particular manner) with the services they render or the wider ecosystem in which they operate and create value.

Through a systematic literature review, Raff *et al.* [Raff – 2020] devised a conceptual framework for defining smart products based on the aggregation of 16 capability-based criteria[45]. These criteria were then synthesized and organized within a comprehensive framework delineating four distinct product archetypes for the digital ecosystem: (1) *Digital*, (2) *Connected*, (3) *Responsive,* and (4) *Intelligent*. The different archetypes build on each other and are defining by a particular orchestration of the criteria. As archetypes increase, so does the versatility of the tangible components (i.e., the hardware), the complexity of the intangible components (i.e., the software), and the potential capabilities (i.e., the hardware and software working together).

Figure 13 illustrates the four architypes of smart products highlighting different bundles of cyber-physical arrangements and examples of real-life such products.

[44] For instance, for the case of ICT and E&M Sector definition, it was recognized that "*when the first ICT sector definition was developed in 1998, it was recognized that the preferred procedure would have been to first define ICT goods and services and then to formulate the ISIC classes that had activities involving those goods and services. However, in order to obtain an initial set of indicators for the ICT sector in a limited amount of time, the approach taken was to first to define the activities and subsequently work on a list of ICT goods and services that could complement and help to refine the activity-based definition"* [OECD – 2011]

[45] The 16 attributes include: IT Equipped, Data Storage, Data Processing and Analysis, Data Provision and Transmission, Unique Identification, Networking and Connectivity, Communication and Information Exchange, Interaction and Cooperation, Sensing, Real-Time Context-Awareness, Reactivity and Adaptability, Automated Actuation, Functionality and Customization, Reasoning and Decision-Making, Autonomy and Self-Management, Proactivity. [Raff – 2020]

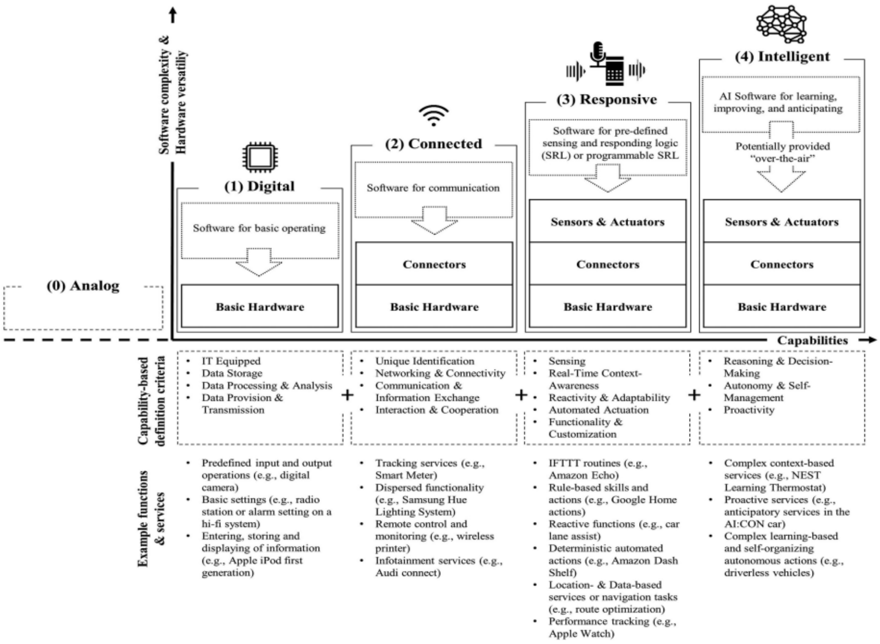

Figure 13 - Smart product archetypes according to Raff *et al.* [Raff - 2020]

In 2019, OECD published its guidelines for measuring the digital activity in the form of Digital Supply-Use Tables (DSUT) [OECD – 2019]. Based on OECD guidelines, IMF Statistics Department in conjunction with the National Statistical Offices (NSO) undertook in 2022 an experimental work to define a standardized method to quantify the effects of digital technologies in the economic activity [IMF – 2022].

According to IMF and OECD, for the purpose of isolating the economic effects of digitalization, products are categorized into four distinct groups:

- digital products (inside the System of National Accounts (SNA) production boundary),
- non-digital products significantly affected by digitalization: They reflect those goods and services whose consumption is significantly facilitated by digital technologies;
- other non-digital products, and
- digital products (outside the SNA production boundary)

The four groups of products are detailed in Table 8, whenever possible, their mapping with Central Product Classification (CPC version 2.1) or Classification of Product by Activity (CPA 2008)[46].

Table 8 - Group of products constituting the Digital Economy according to OECD guidelines

Products group	Product	Comments and additional insights	Part of ICT? (NOTE 4)
Digital products (inside SNA	ICT goods	ICT goods classes according to CPC 2.1, including: Computers and peripheral equipment; Communication equipment; Consumer electronic equipment; and Miscellaneous ICT components and goods.	Yes

[46] The classification of products by activity (CPA) is the European Union's official classification of products by activity. It is the European version of the United Nations' provisional central product classification (CPC). While the CPC is merely optional, the CPA is mandatory in the European Community. The current version is the CPA 2008.

production boundaries)	Priced digital services: ICT services except cloud computing services and digital intermediary services.	Including the following classes according to CPC 2.1: Manufacturing services for ICT equipment; Business and productivity software and licensing services; Information technology consultancy and services; Telecommunications services; Leasing or rental services for ICT equipment; and Other ICT services.	Yes
	Priced cloud computing services	They include a full suite of services related to cloud computing, such as IaaS, PaaS and SaaS models mapped respectively with the following classes: CPA 63.11.1, CPA 62.01 and CPA 58.2.	Yes
	Priced digital intermediary services	They include those kinds of (platform) services providing information on and successfully matching two independent parties to a transaction via a digital platform in return for an explicit fee (paid by the producer and/or the consumer of the product being intermediated). No specific categories within the various international classifications, they generally form part of the various products within CPC 2.1.	Yes
Non-digital products significantly affected by digitalization (NOTE 1) (NOTE 2)	Land transport services and transport services via pipelines	CPA division 49	No
	Accommodation services	CPA division 55	No
	Food and beverage serving services	CPA division 56	No
	Motion picture, video and TV program production services, sound recording and music publishing	CPA division 59	E&M
	Financial and insurance services	CPA section K	No
	Advertising and market research services	CPA division 73	E&M
	Travel agency, tour operator and other reservation services	CPA division 79	No
	Education services	CPA section P	No
	Gambling services	CPA division 92	No
	Publishing services	CPA division 58	E&M
Other non-digital products (NOTE 2)	All other products that are not classified as digital products or non-digital products significantly affected by digitalization.	The remaining 85 products at the CPA division level. According to IMF and OECD, the monitoring of those product is considered as a low priority due to the reduced role they play in the Digital Economy, at least up to now.	No
Digital products (outside SNA production boundaries (NOTE 3))	Data (available for free) and that are used in the production of goods and services.	This may include information that is a by-product of the regular production process as well as information specifically harvested from consumers in return for providing them with a free or discounted service.	No
	Digital services provided by enterprises	This can include, but is not limited to, the easy gathering of information via internet, connecting with others via social media, or being entertained for free by digital means.	No
	Digital services provided by communities	It includes the creation of any free digital assets by communities (a range of independent producers) and available to all for no monetary cost, including the free services that can be derived from these assets. Unlike digital services provided by enterprises and falling outside the SNA boundaries, digital services provided by communities have not been produced by a single entity but are the result of a collective effort. Similarly, any resulting asset is not owned by a single (commercial) entity.	No

NOTE 1 – The products included in this sub-group have been selected on the basis that the way that their associated services are delivered to consumers has been significantly, or soon will be, affected by the digital transformation – either because the services are digitally delivered or because the sector has been significantly affected by digital intermediation platforms [OECD – 2019]. NOTE 2 – This reflects a current identification, the list of products may be updated. According to OECD ". The composition of products in this category will likely change over time, reflecting the developing nature of the digital economy." [OECD – 2019] NOTE 3 – They are beyond SNA frameworks for different reasons, including: their non-monetary nature, the absence of identified ownership of the resulting asset, and lack of harmonized and agreed methodology for their assessment, at least until now. Currently and in order to keep a meaningful aggregation, the products belonging to this group are reported separately for the other three groups. NOTE 4 – According to the current definition of ICT and E&M sectors (ISIC Rev 4.)

A. 2. 2 Scoping the "Digital Sector" through its industries

According to OECD guidelines [OECD – 2019], the DSUT identifies 7 "digital industries". As the understanding of the impact of digitalization is a complex and incremental process, this classification has to been seen as a reflection of the current picture. Depending on data availability and where NSO deem the work relevant for their country, they are free to break down any specific ISIC industry or new additional digital industry into additional subsets suitable for their policy needs.

Table 9 summarizes the 7 identified industries and their corresponding ISIC categories.

Table 9 - Groups of Digital industries constituting the Digital Economy according to OECD guidelines

Digital industries	**Comments, additional insights and Examples**
Digitally enabling industries	Businesses engaging in production that enable the function of information processing and communication by electronic means. Includes: Internet service providers, telecommunications companies, providers and developers of software, Computer manufacturers, and website developers. These are mapped with industries of the ICT sector as defined in ISIC Rev. 4. Examples: Amazon Web Services, Dell, Ooredoo, Orange …
Digital intermediary platforms charging a fee	Businesses that receive an explicit payment for facilitating a transaction between two or more distinct but interdependent sets of users. Includes: food delivery companies, travel booking portals, platforms facilitating online auction or marketplaces that assume no ownership of stock. It may fit within the following ISIC categories: 4799, 4791 and 7990 Examples: Airbnb, Booking.com, Deliveroo, Uber …
Data and advertising driven digital platforms	Businesses that are operating exclusively online that predominately generate revenue via selling data or advertising space. Includes: search engines, social media platforms, developers of zero-priced phone applications and information sharing platforms. Almost likely to not correspond to a formal ISIC category. Examples: Facebook, Google, Twitch, Citymapper …
Firms dependent on intermediary platforms (NOTE)	Independent service providers who source work from digital platforms, and businesses who sell via a third-party digital platform. Includes: businesses who sell predominately digitally but do so via their own website/digital platform. Examples: Bicycle courriers, Uber drivers, Ghost kitchens …
E-tailers (NOTE)	Retail and wholesale businesses engaged in purchasing and reselling goods or services who receive a majority of their orders digitally. Includes: businesses receiving orders digitally that sell their own inventory and/or have set contracts with producers and suppliers. They are likely to be categorized within ISIC category 4791. Examples: JD.com, Sarenza, Zalando …
Digital only firms providing financial and insurance services	Businesses providing financial and insurance services that are operating exclusively digitally, with no interaction with consumers physically. Includes: online only banks and other financial service providers, online only payment system providers. Examples: Open banck, Paybal, Lydia …

Other producers only operating digitally	Businesses that produce their own services for sale but operate exclusively digitally. Includes: priced digital media providers, subscription-based service providers (assuming the service is delivered digitally). Most of them are likely to be categorized within the ICT sector as defined in ISIC. Examples: Bet365, Netflix, Spotify, The Independent newspaper …
NOTE – The categorization of economic unit within this digital industry is not static and subject to determining criteria reflecting the significance of digital in their core processes/business model. For instance; regarding the category of "firms dependent on intermediary platforms", if the unit uses platforms as a secondary channel (i.e. it generates less than 50% of their demand via intermediary platforms) it should remain in its respective original ISIC category. A similar rationale is applied for the category "E-tailers": where retailers and wholesalers who are generating less than 50% of their demand digitally, they have to remain in their respective original ISIC category. In this regard, OECD acknowledges that a significant change in transaction mode may lead to reclassification of entities over time [OECD – 2019].	

Appendix III of OECD [OECD – 2019] guidelines provide a decision tree to support a practitioner in the categorization of units within the seven identified digital industries.

A. 2. 3 A tiered-approach for scoping the "Digital Sector"

Digitalization is a pervasive process driving the emergence of the "Digital Sector" as an object that worth to measure and assess (economically, environmentally etc.) continuously. Definitional (and thus scoping) difference of the "Digital Sector" often owe to the nature of the research questions and the facet of the "Digital Sector" that is analyzed as highlighted in Table 10.

Table 10 - The different perspectives for scoping a Sector and their corresponding Research questions

Perspective used for scoping	**Research questions and main focus**
Product-based definition: Scoping of the sector through its deliverables	*What is the impact of digitalization on production?* Focus on producers' use of digital products (how much products are influenced by digital inputs), including the production of digital products.
Organization-based definition	Focus on the impact of macro-input/output analysis of the entities of the Sector
Organization-based definition	*How digitalization has disrupted value chains?* Focus on the nature of transactions, i.e. whether products are digitally ordered and/or delivered or not.
A new perspective going beyond the current national accounts production boundary	Focus on digitally driven disruption in households' or individuals' behavior (e.g. in terms of consumption and production) will likely include a focus on the non-monetary aspects of the Digital Economy.

In its attempt to balance different tensions and reconcile the various perspectives adopted by NSOs in their respective statistics for approaching a measurement of the "Digital Sector" and the impact of digitalization, a comprehensive (yet relatively broad) definition of the Digital Economy for policy purposes is put forward by OECD as the following [OECD – 2020][47]:

"The Digital Economy incorporates all economic activity reliant on, or significantly enhanced by the use of digital inputs, including digital technologies, digital infrastructure, digital services and data. It refers

[47] This OECD report builds upon previous G20 and other relevant work to develop "*A Roadmap toward a Common Framework on Measuring the Digital Economy"*, including a proposed common agreed definition on the Digital Economy and a set of existing indicators for measuring the Jobs, Skills, and Growth in the Digital Economy. It draws upon various national and international efforts to measure and understand key facets of the Digital Economy and seeks to advance measurement in G20 countries and beyond. Most directly, the report builds upon the G20 Toolkit for Measuring the Digital Economy (G20, 2018), which showcased data available for G20 countries through 36 key indicators across the themes of Infrastructure; Empowering Society; Innovation and Technology Adoption; and Jobs and Growth.

to all producers and consumers, including government, that are utilising these digital inputs in their economic activities".

To address the different research questions aforementioned in a comprehensive single framework, OECD recommended a tiered and flexible approach for scoping the Digital Economy (and beyond):

- **Tier 1:** The **Core measure**: The Core measure of the Digital Economy only includes economic activity from producers of ICT goods, ICT and information services and digital content[48];
- **Tier 2:** The **Narrow measure** includes the core sector as well as economic activity derived from firms that are reliant on digital inputs;
- **Tier 3:** The **Broad measure** includes the first two measures as well as economic activity from firms significantly enhanced by the use of digital inputs;
- **Beyond Digital Economy:** The **Digital Society**: It extends further than the Digital Economy and incorporates digitalized interactions and activities not included in the GDP production boundary, such as the use of free digital platforms (including public digital platforms)[49].

Figure 14 depicts the boundaries of the Digital Economy through its different scope tiers and its relation with the Traditional Economy, the Digital Society and the Traditional Society. With the increasing pace of digitalization (driven for instance by IoT), both Tier 2 and Tier 3 expand their boundaries and even further for Tier 3.

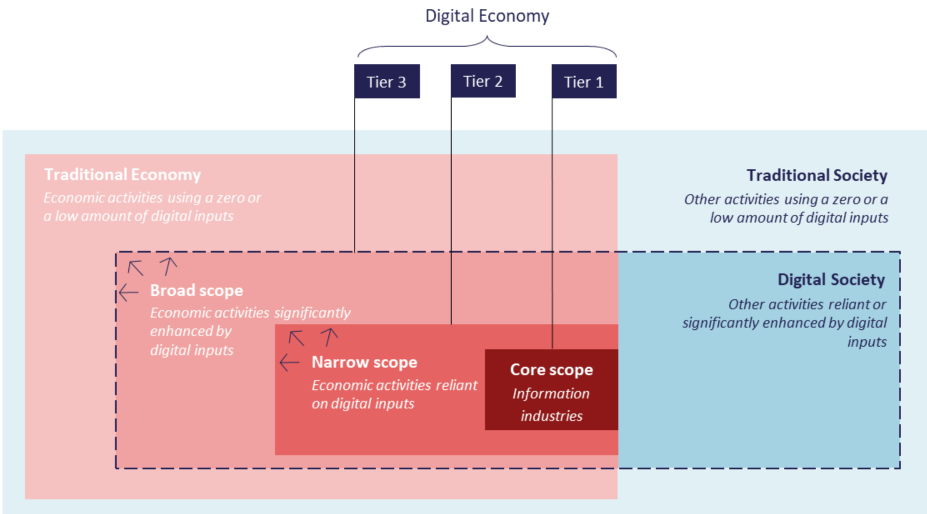

Figure 14 - Illustration of boundaries of the Digital Economy within the Traditional Economy and Society

Figure 15 from [OECD – 2020] illustrates the way in which these tiers fit into the broader economy/society. It places the different tiers of the Digital Economy into a bi-dimensional matrix showing the type of products and the significance of digital inputs used in the production process and its outcome.

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[48] Technically, this corresponds to "Information Industries" (defined by OECD as the combination of the ICT sector and the "content and media sector" (E&M))

[49] This ultimate tier would include digital activity that is not explicitly recorded as economic production but results in additional consumer surplus, welfare and other benefits to society such as the diffusion of information and knowledge.

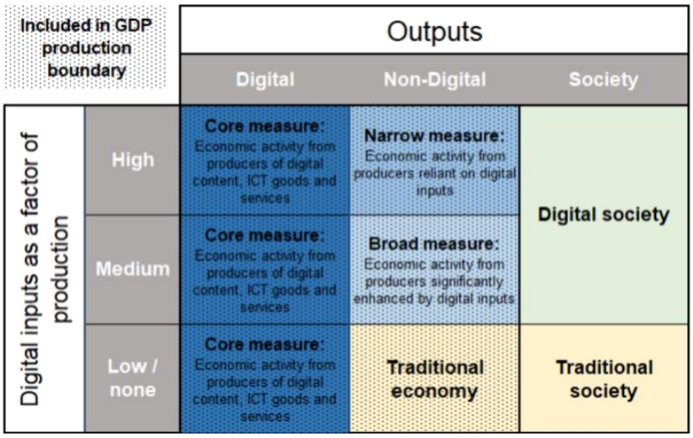

Figure 15- Measuring the Digital Economy within the traditional economy (source: [OECD – 2020])

OECD recognizes that Tier 2 and Tier 3 may allow for subjectivity with the use of words such as "reliant" and "enhanced", however it offers the possibility for asking the following questions "*how the product is produced?*". This choice is deliberate as not only are countries' economies at different stages of the digitalization process, but firms within a given economy are also likely to move between sectors based on how their business and technology continues to evolve.

In general, the output of the economic activities categorized within the Narrow and the Broad measures are not substantially digital in nature. For non-digital output that is included, the decision factor is the level of digital inputs being used in the production process.

The distinction between Tier 2 and Tier 3 would likely be challenging in practice, however a fundamental difference can be made by paraphrasing a question put forth by Bukht and Heeks [Bukht – 2017], "*has this economic activity only arisen due to digital inputs?*" If the answer is "*Yes*", then the firm would be categorized within Tier 2, if the answer is "*No*" and the business model of the firm and the economic activity generated existed previously, albeit in a reduced or more inefficient form, the firm would be categorized within Tier 3. Thus, Tier 2 may correspond to sectors making extensive use of digital, extending the boundaries of the economic activity, while Tier 3 may correspond to sectors making intensive use of digital technologies and improving in some way existing economic activity.

According to OECD, there are two possible approaches for delineating output for each tier of the Digital Economy:

- **A delineation at the firm level:** This approach may be preferred for practical reasons, when classifying firms into the core, narrow or broad measures, the entire output of the firm will be included within the identified Tier.
- **A delineation based on the nature of the transaction:** This approach provides the flexibility and opportunity to split economic activity by product, which is below firm level rather than assigning the entire economic activity of the firm to a given tier. While this may result in a more laborious measure due to difficulties caused by data availability, it will arguable create a more detail picture of the Digital Economy considering that digitalization, not only impacts differently the firms of given sector but also within the same firm (different set of products). A delineation based on the nature of the transaction is already considered when compiling DSUT. OECD distinguishes two types of transactions (refer to [OECD – 2019] [OECD – 2020] for further details):
    - (i) Digitally ordered goods and services and
    - (ii) Digitally delivered services.

Table 11 - Mapping "Digital Economy" definitions with the three angles of approach

Study	Resource perspective	Process/flow perspective	Structural perspective	Definition highlight or relevant extract (partially based on the review of [Bukht – 2017])
Tapscott 1996: The Digital Economy: Promise and Peril in the Age of Networked Intelligence Tapscott, D., 1996. The Digital Economy: Promise and Peril in the Age of Networked Intelligence, McGraw-Hill, New York, NY.	X			"Age of Networked Intelligence" where it is "not only about the networking of technology… smart machines… but about the networking of humans through technology" that "combine intelligence, knowledge, and creativity for breakthroughs in the creation of wealth and social development".
Lane 1999: Advancing the Digital Economy into the 21st Century (Assistant to the US President for Science and Technology) Lane, N., 1999. Advancing the digital economy into the 21st century, Information Systems Frontiers, 1(3), 317-320.		X		"…the convergence of computing and communication technologies in the Internet and the resulting flow of information and technology that is stimulating all of electronic commerce and vast organizational changes".
Brynjolfsson & Kahin 2000: Understanding the Digital Economy: Data, Tools, and Research Brynjolfsson, E. & Kahin, B. 2000. Introduction, in Understanding the Digital Economy, E. Brynjolfsson & B. Kahin (eds), MIT Press, Cambridge, MA, 1-10.	X		X	"...the recent and still largely unrealized transformation of all sectors of the economy by the computer-enabled digitization of information".
Kling & Lamb 2000 Kling, R. & Lamb, R. 2000. IT and organizational change in digital economies, in Understanding the Digital Economy, E. Brynjolfsson & B. Kahin (eds), MIT Press, Cambridge, MA, 295-324.		X		"...includes goods or services whose development, production, sale, or provision is critically dependent upon digital technologies".
Mesenbourg 2001: Measuring the Digital Economy (US Bureau of the Census) Mesenbourg, T.L., 2001. Measuring the Digital Economy, US Bureau of the Census, Suitland, MD. https://www.census.gov/content/dam/Census/library/workingpapers/2001/econ/umdigital.pdf		X		Defined the digital economy as "having three primary components: - E-business infrastructure is the Share of total economic infrastructure used to support electronic business processes and conduct electronic commerce - Electronic business (e-business) is any process that a business organization conducts over computer-mediated networks - Electronic commerce (e-commerce) is the value of goods and services sold over computer-mediated networks"
Economist Intelligence Unit 2010: Digital Economy Rankings 2010 Economist Intelligence Unit, 2010. Digital Economy Rankings 2010 Beyond E-Readiness, Economist Intelligence Unit, London. http://graphics.eiu.com/upload/EIU_Digital_economy_rankings_2010_FINAL_WEB.pdf	X			Ranking of digital economy is based on: "The quality of a country's ICT infrastructure and the ability of its consumers, businesses and governments to use ICT to their benefit".
OECD 2013: The Digital Economy http://www.oecd.org/daf/competition/The-DigitalEconomy-2012.pdf		X		"The digital economy enables and executes the trade of goods and services through electronic commerce on the Internet".

Department of Broadband Communications and the Digital Economy (DBCDE), Australia 2013: Advancing Australia as a Digital Economy: An Update to the National Digital Economy Strategy http://apo.org.au/node/34523			X	"The global network of economic and social activities that are enabled by digital technology, such as the internet and mobile networks".
European Commission 2013: Expert Group on Taxation of the Digital Economy http://ec.europa.eu/taxation_customs/sites/taxation/files/resources/documents/taxation/gen_info/good_governance_matters/digital/general_issues.pdf		X	X	"...an economy based on digital technologies (sometimes called the internet economy)".
British Computer Society 2014: The Digital Economy https://policy.bcs.org/sites/policy.bcs.org/files/digital%20economy%20Final%20version_0.pdf		X		"The digital economy refers to an economy based on digital technologies, although we increasingly perceive this as conducting business through markets based on the internet and the World Wide Web".
European Parliament 2015: Challenges for Competition Policy in a Digitalised Economy http://www.europarl.europa.eu/RegData/etudes/STUD/2015/542235/IPOL_STU(2015)542235_EN.pdf			X	"A complex structure of several levels/layers connected with each other by an almost endless and always growing number of nodes. Platforms are stacked on each other allowing for multiple routes to reach end-users and making it difficult to exclude certain players, i.e. competitors".
House of Commons 2016: The Digital Economy https://www.publications.parliament.uk/pa/cm201617/cmselect/cmbis/87/87.pdf	X			"The digital economy refers to both the digital access of goods and services, and the use of digital technology to help businesses".
G20 DETF 2016: G20 Digital Economy Development and Cooperation Initiative http://www.g20.utoronto.ca/2016/g20-digital-economy-development-andcooperation.pdf			X	"...a broad range of economic activities that include using digitized information and knowledge as the key factor of production, modern information networks as an important activity space, and the effective use of information and communication technology (ICT) as an important driver of productivity growth and economic structural optimization"
Elmasry *et al.* 2016: Digital Middle East: Transforming the Region into a Leading Digital Economy (Digital McKinsey) http://www.mckinsey.com/global-themes/middle-eastand-africa/digital-middle-east-transforming-the-region-into-a-leading-digital-economy		X	X	"less as a concept and more as a way of doing things", but with three attributes: "creating value at the new frontiers of the business world, optimizing the processes that execute a vision of customer experiences, and building foundational capabilities that support the entire structure".
Bahl 2016: The Work Ahead: The Future of Businesses and Jobs in Asia Pacific's Digital Economy (Cognizant) https://www.cognizant.com/whitepapers/the-work-ahead-the-future-ofbusiness-and-jobs-in-asia-pacifics-digital-economy-codex2255.pdf		X		
Knickrehm *et al.* 2016 : Digital Disruption (Accenture) https://www.accenture.com/_acnmedia/PDF-4/Accenture-Strategy-DigitalDisruption-Growth-Multiplier.pdf	X			"The digital economy is the share of total economic output derived from a number of broad "digital" inputs. These digital inputs include digital skills, digital equipment (hardware, software and communications equipment) and the intermediate digital goods and services used in

				production. Such broad measures reflect the foundations of the digital economy".
Rouse 2016: Digital Economy http://searchcio.techtarget.com/definition/digital-economy	X		X	"The digital economy is the worldwide network of economic activities enabled by information and communication technologies (ICT). It can also be defined more simply as an economy based on digital technologies".
Dahlman et al. 2016: Harnessing the Digital Economy for Developing Countries (OECD) http://www.oecd-ilibrary.org/docserver/download/4adffb24-en.pdf	X			"The digital economy is the amalgamation of several general purpose technologies (GPTs) and the range of economic and social activities carried out by people over the Internet and related technologies. It encompasses the physical infrastructure that digital technologies are based on (broadband lines, routers), the devices that are used for access (computers, smartphones), the applications they power (Google, Salesforce) and the functionality they provide (IoT, data analytics, cloud computing)".
OUP 2017: Digital Economy https://en.oxforddictionaries.com/definition/digital_economy		X		"An economy which functions primarily by means of digital technology, especially electronic transactions made using the Internet".
Deloitte: What is Digital Economy? https://www2.deloitte.com/mt/en/pages/technology/articles/mt-what-is-digitaleconomy.html			X	"...the economic activity that results from billions of everyday online connections among people, businesses, devices, data, and processes. The backbone of the digital economy is hyper-connectivity which means growing interconnectedness of people, organisations, and machines that results from the Internet, mobile technology and the internet of things (IoT)".
NSO (United States): Bureau of Economic Analysis (BEA) 2021. G20 Digital Economy Task Force (DETF) Questionnaire on Measuring the Digital Economy [OECD- 2020]	X			"The BEA includes three major types of goods and services in its definition of the Digital Economy: The digital-enabling infrastructure needed an interconnected computer network to exist and operate; the e-commerce transactions that take place using that system and digital media, or the content that Digital Economy users create and access. BEA considers data part of the Digital Economy. [OECD – 2020]
NSO (Canada): Statistics Canada: "Measuring digital economic activities in Canada: Initial estimates." 2021 https://www150.statcan.gc.ca/n1/pub/13-605-x/2019001/article/00002-eng.htm.	X			Statistics Canada applied concepts and definitions of the digital economy similar to the BEA. One important difference was the inclusion of some "partial" digital products that were not included in the BEA estimates. The Canadian estimates make use of the OECD's digital economy measurement framework, grouping digital

				products into the following categories: 1) digitally - enabled infrastructure, 2) digitally - ordered transactions (e-commerce), and 3) digitally - delivered products. [IMF – 2022]
NSO (Australia): Australian Bureau of Statistics: G20 Digital Economy Task Force (DETF) Questionnaire on Measuring the Digital Economy [OECD- 2020]	**X**			“the ABS measured the digital activities in Australia as the production of: Digital enabling infrastructure (computer hardware, software, telecommunications equipment and support services that form and facilitate the use of computer networks); Digital media (digital audio, video and advertisement broadcasting services) and E-commerce.” [OECD – 2020]
NSO (China): G20 Digital Economy Task Force (DETF) Questionnaire on Measuring the Digital Economy [OECD- 2020]			**X**	“The Digital Economy refers to a broad range of economic activities that include using digitized information and knowledge as the key factor of production, modern information networks as an important activity space, and the effective use of information and communication technology (ICT) as an important driver of productivity growth and economic structural optimization.” [OECD – 2020]

Annex B

Guidance for the assessment of the footprint of a connected device

(This Annex is related to Section 4)

This Annex provides practical guidance in the form of a check list to support a practitioner in the modelling of the embodied emissions' attributable share to ICT (Section 1) and in the modelling of the embodied emissions of the connected device (Section 2).

B. 1 Practical guidance for detailed modelling embodied emissions' attributable share to ICT

Table 12 refers to entries from Table E.1 (in Annex E) and Table D.1 (in Annex D) according to [ITU L.1410], by identifying the closest match as possible, but does not consider following strictly Annex E and Annex D since compliance with their requirements may be challenging and not intended for "simplified approach" assessment.

Figure 16 illustrates the generic structure of a universal communication module of mobile (cellular) IoT devices as specified by ITU-T Y.4210 Recommendation. Note that this structure is only indicative, as other IoT devices may not be connected through cellular networks. For an exhaustive set of process/components attributable to the connectivity, the practitioner should refer to Table 12.

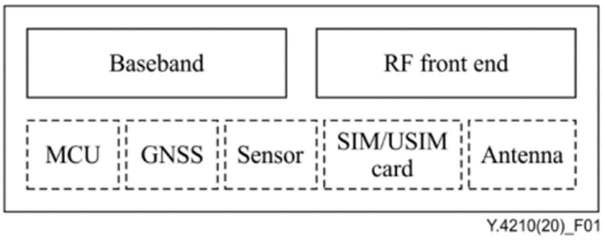

Figure 16 - Example of a generic structure of a universal communication module of mobile IoT devices (from [ITU-T Y.4210]). Dotted line boxes are considered optional components according to the Recommendation.

Table 12 is to be viewed as a check list to consider with regards to the granularity level of assessment and the complexity of the IoT device (e.g. simple objects (RF tags) vs complex objects)

Table 12 - A check list to identify attributable process/components to the Connectivity

Component/process	**Component category**	**Part or generic process (cf. [ITU L.1410])* ****	**Parameters (example of metrics)**

Radio transceiver	IC	B1.1.4 IC*	• IC technology (CMOS technological node [nm]) • Equivalent silicon die area (per surface [mm²]) • IC package type/semiconductor package type (per piece) • IC Input/output (I/O) count (number of I/O) • Semiconductor package (I/O) count (number of I/O) • Semiconductor package weight (per mass)
Memory(1)	IC	B1.1.4 IC*	• Same as Modem • Memory size and type ([MB])
PCB(2)	PCB	B1.1.7 PCB*	• Mass (per [Kg]) • Board layers (number of layers) • Board area (in [cm²]) • Piece (per [piece])
Power supply (battery powered or harvesting system)[11]	Batteries	B1.1.1 Batteries*	• Battery form factor and composition (e.g. coin cells; Alkaline or Lithium ion …) • Mass (per [Kg]) • Piece (per [piece]) • Energy harvester • AC/DC transformer
Power Management Unit (PMU)(8)	IC	B1.1.4 IC*	• Same as Radio transceiver
External antenna	Metal and metallic components/ Polymeric mechanical component	B1.1.5 Mechanics/Materials*	• Weight (per [Kg]) • Piece (per [piece]) • Material type (e.g. aluminum, plastic, steel …)
Embedded antenna(6)	PCB	B1.1.7 PCB*	• Same as PCB
SIM card	IC	B1.1.4 IC	• Same as Modem
SIM tray(3)	Polymeric mechanical component	B1.1.5 Mechanics/Materials*	• Weight (per [Kg]) • Piece (per [piece])
eUICC chipset(3)	IC	B1.1.4 IC*	• Same as Modem
Connectors(4)	Polymeric mechanical component	B1.1.3 Electro-mechanics*	• Weight (per [Kg]) • Piece (per [piece]) • Type of material (gold, copper …)
Dedicated casing	Polymeric mechanical component	B1.1.5 Mechanics/Materials*	• Weight (per [Kg]) • Piece (per [piece]) • Material type (e.g. aluminum, plastic, steel …) • Type of manufacturing process
Cable	Polymeric mechanical component	B1.1.2 Cables*	• Length (per [cm]) • Section of the cable [cm²]
Microprocessors(5)	IC	B1.1.4 IC*	• Same as Modem
Transistors diodes, capacitors, inductors/coils, resistors, crystals etc.	RF Lumped-elements	B1.1.8 Other PCBA components*	• Weight (per [Kg]) • Piece (per [piece])
Electro-magnetic shields for IC	Metallic component	B1.1.5 Mechanics/Materials*	• Weight (per [Kg]) • Piece (per [piece])
Any other component or module(7)	Component/Module	B.1.1.10 Black box module*	• Weight (per [Kg]) • Piece (per [piece])
Assembly process(9)	Assembly	B.1.2 Assembly*	• Weight (per [Kg]) could be appropriate key for allocation • The throughput of the assembly process

Distribution process(10)	Distribution	G.1 Transport and travel**	• TonnexKm (or KgxKm)

* Refer to Table E.1 in Annex E "Part types of ICT goods" in [ITU L.1410]
** Refer to Table D.1 in Annex D "Generic processes" in [ITU L.1410]

(1) If used by the connectivity module. Some high data rate chipsets (e.g. 4G/5G cellular) may require dedicated extra-memory
(2) In case where the connectivity module is mounted on a dedicated PCB. This includes solder paste used to fasten components to the PCB.
(3) In case of cellular connectivity
(4) Including for wireline communication
(5) For some connected devices (low complex devices), connectivity capabilities may be directly embedded in the main processor unit (such as the case of a wireless micro controller with embedded radio transceiver (e.g. iSIM))
(6) For example: printed antenna, ceramic chip etc.
(7) This refers to any product component or product part that cannot be fully and systematically characterized (e.g. need for internal inspection or due to the high variability of configurations). Such product components or parts may be approached as "a black box module". The modem (or even the connectivity module) may be approached as "a black box module" but this should be clearly motivated.
(8) For main-powered devices and for harvesting circuits
(9) It refers to the share of the "connectivity" components in the GHG emissions of assembly of the connected device. Assembly includes also warehousing and packaging.
(10) It refers to the share of the "connectivity" components in the GHG emissions of the distribution of the connected device (from the final assembly facilities to end-use locations)
(11) An adhoc allocation rule shall be required to isolate the share attributed to the connectivity.

NOTE 1 – Some connected devices (for instance LPWAN connected devices) require a gateway to be able to connect to the Internet or to communicate with their surrounding environment. For such devices, the gateway equipment should be considered in the assessment and attributed to the connectivity module. Where the gateway equipment was designed to serve several connected devices, only a share of the embodied emissions of the gateway shall be considered while applying a relevant allocation key (e.g. number of ports, maximum number of connected devices, share of available capacity etc.); if the gateway is to be systematically reported, its contribution should be clearly separated from the total.

NOTE 2 – For connected devices equipped with GPS, the GPS module shall be included if it is designed to support the connectivity model. The architecture of a GPS module is similar to a modem module, otherwise GPS can be modeled as a "Black box module".

B. 2 Practical guidance for detailed modelling embodied emissions of a connected device

Component characterization method could be used as a possible approach for assessing the embodied emissions of a connected device. Based on the architecture depicted in Figure 17, the connected device is constituted by a set of several functional blocks organized into modules (connectivity, actuators, sensing etc.), each module being constituted by several components. The characterization of each module is inspired from [Pirson – 2021][50].

As connected devices show a high diversity of designs and hardware specification profiles, a modular approach is a generic method to conduct the assessment and ensure a wider implementation. To deep dive into the specificities of the device for benchmarking or labelling purposes, specific methodologies or standards (e.g. Specific Product Category Rules) would be more appropriate.

[50] T. Pirson & D. Bol "Assessing the embodied carbon footprint of IoT Edge Devices with a Bottom-Up lifecycle approach" (2021) https://doi.org/10.1016/j.jclepro.2021.128966

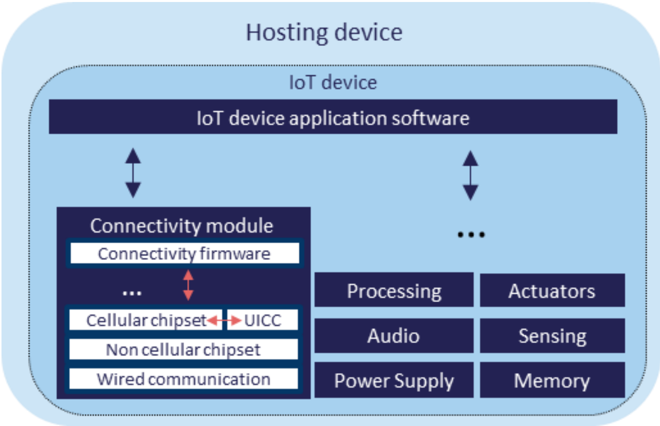

Figure 17 -Modular representation of the architecture of a connected device

Table 13 lists the different modules and components constituting a connected device and may be considered as a check list to be used with regards to the granularity level of assessment and the hardware complexity of the connected device.

Table 13 – A check list for modelling the embodied emissions of a connected device

Module	**Components (example)**	**Part or generic process (cf. [ITU L.1410])* ****	**Types and scaling parameters/product flow unit*****
Actuators	• Electric and non-electric motors(4)), relays, MEMS … • CMOS control circuits/driver	• Electro-mechanics (B1.1.3)* • IC (B1.1.4)*	• Types: by motion (rotary, linear), by source of energy (supercoiled polymer, Hydraulic, electro-mechanical, thermal, pneumatic …) • Mass, piece
Sensing	• CMOS sensor, microphone, resistors, capacitors…	• Electro-mechanics (B1.1.3)* • IC (B1.1.4)*	• Types: ambient conditions (temperature, humidity, pressure, infrared, optical, acoustic …), physical motion or localization (proximity, magnetic, motion, accelerometers, gyroscope, level …), substance specific (smoke, chemical, water quality, air quality, flow and gaz …) • Mass, piece
Connectivity	• Modem (BB and RF) • Ancillary components: memory, MCU … • Antenna and connectors	• IC (B1.1.4)* • Electro-mechanics (B1.1.3)*	• Types: wireless, wireline • Mass, piece
Power supply	• Batteries • PMU (AC/DC and DC/DC converters …) • Power cord • PMU control IC	• Batteries (B1.1.1)* • Cables (B1.1.2)* • IC (B1.1.4)*	• Types: batteries, main powered. • Piece, mass, rating
Memory	• Memory ICs	• IC (B1.1.4)*	• Types : volatile (DRAM…), non volatile (Flash…) • Piece, mass, memory density/die area(1)
Processing	• Processors, DSP, Micro-Controller … • (Embedded) memory	• IC (B1.1.4)*	• Piece, mass, die area

UI/Display	• Switch/push button, speaker … • Display • IC driver (for display, speaker …)	• Electro-mechanics (B1.1.3)* • Display (B1.1.6)* • IC (B1.1.4)*	• Types of display: LCD, LED, OLED … • Piece, mass, active display area, number of display panels
Security	• Processor • Memory	• IC (B1.1.4)*	• Piece, mass, die area
Camera(5)	• Camera objective • Pan-tilt mechanism (motor) • Chassis, housing, dome…	• Electro-mechanics (B1.1.3)* • Mechanics/Materials (B1.1.5)* • IC (B.1.1.4)	• Mass, piece
Casing	Casing materials (metallic components, polymeric components …)	• Mechanics/Materials (B1.1.5)*	• Mass, Size
PCB(2)	PCB cards	• PCB (B1.1.7)* • Other PCBA components (B1.1.8)*	• Mass, piece, board area, board layers count
Cable set(2)	• Cables • Connectors	• Cables (B1.1.2)* • Electro-mechanics (B1.1.3)*	• Types: power cord, signal cable … • Size, length, piece
IoT device application software	• Development and production of the software(3)	• Software (B1.1.11)*	• Megabyte
Hosting device		• Black box module (B1.1.10)*	• Piece, mass, size
Assembly process	Assembly, warehousing and packaging	• Assembly (B1.2)*	• Piece, mass, size
Distribution process	Distribution from final assembly facilities to end-use locations	• Transport and travel (G.1)**	• tonnexKm (or KgxKm()(6) • Type of transport (boat, lorry…)

* Refer to Table E.1 in Annex E "Part types of ICT goods" in [ITU L.1410]
** Refer to Table D.1 in Annex D "Generic processes" in [ITU L.1410]
*** To the best of the knowledge of the Committee and the state of current practices

(1) For memory ICs where dies are stacked in a single package, die area may underestimate the assessment.
(2) This item may not be considered as a functional block as it may be included within other modules (for instance when a Connectivity or a Sensing module is mounted onto a PCB, Cable set is included within the Power Supply module or within the Connectivity module)
(3) Refer to Annex A of [ITU L.1410] and Chapter 6 (Guide for assessing GHG emissions related to Software) of the Supplement ICT of the GHG Protocol [ICT Guidance – 2017] for further guidance. It should be reported separately.
(4) Potential presence of rare earth due to magnets.
(5) This item is isolated in the check list with regards to its importance but it can be modelled as a "black box module".
(6) It may be relevant to consider depending on the transport loading factor and the empty truck return rate.

NOTE 1 – In relation to Table E.1 of [ITU L.1410], one may consider that all these modules, can be modelled as a "Black box module" as they are generally bought as a "complete product" by the connected device producer or its provider from any other actor in the supply chain, but a stated in [ITU L.1410] this needs to be transparently motivated.

NOTE 2 – The modular view would not elude the fact that some modules are not totally disjoint (for instance, for connected devices with low complexity, Security module or Connectivity module may be embedded within Processing module).

Annex C

Guidance for a system of connected products

(This Annex is related to Section 2.3)

C. 1 On the importance of boundaries setting

The primary functionality of a system of connected products is dependent of the products of this system. However, each of those products taken individually has its own primary functionality. Hence, when it comes to categorization, changing the boundaries of the studied system may change the primary functionality analyzed. Thus, it can lead to different outcomes of the decision tree.

For instance, infotainment services in a connected car is a system that can be composed of several connected products and one can chose to study either the whole system or break it down in several connected products (e.g. a car radio, an on-line music player, a video streaming display, a GPS assisted navigation system, etc.). Thus, one may need further guidance regarding boundaries' setting.

To focus on the "intended" primary functionality, a first general rule when establishing the boundaries of a system of connected products consists in checking whether such a system exists on the end-user market, that is, if it's intended to be sold as it is on the last segment of the value chain. Thus, intermediary products shall be excluded.

NOTE 1 – End-user market products include aftermarket products and secondary market products.

An additional rule that could be checked by the practitioner when setting the boundaries of the system would be that connectivity between the constituting connected products is part of the device layer. Such connectivity is supported by "internal interface" (see below part II) i.e., connected products intended to communicate between themselves at the device layer. Beyond the general rule, boundaries setting depends on the objective of the study and the assessment type; the practitioner should follow the general guidance below:

- For micro-level studies/assessments (such as assessing the carbon footprint of IoT-based ICT solutions etc.), the general rule is recommended, however the practitioner may deviate from the general rule by setting the boundaries with regards to the goal of the study and its assessment needs. **In any case, boundaries setting choices shall be transparently motivated and justified.**
- For meso- or macro-level studies/assessments (such as establishing PCR for environmental performance labelling for IoT devices; defining GHG emissions budget for the ICT and the E&M sectors considering a 2°C or lower trajectory etc.), the practitioner should stick to the general rule, while any deviation shall be justified.

C. 2 Specific guidance on implementing the heuristic for a connected products system

The example below considers the case of connected products system composed of three connected products A, B and C. As illustrated in the Figure 18, the product system interacts with its outer-environment through external (logical) interfaces including interaction with device D through logical interface A2.2/D1 and interaction with the communication network through logical interface A2.1/Network. With regards to the boundaries of the product system, the other logical interfaces (A1.1/C1, A1.1/B1, A2.3/B2) are local to the product system. It is worth noting that the physical interface A2.*x* is used for both external and local logical interfaces.

NOTE 1 – The Connected products system may interact with other connected products systems.

NOTE 2 – Several connected products systems may form a wider connected products system; in this situation, they would be considered as subsystems. When addressing the case of a system of connected products subsystems, external interfaces of each product subsystem would be considered as external interfaces for the (wider) system unless these interfaces are used only for the interaction between the subsystems within the system.

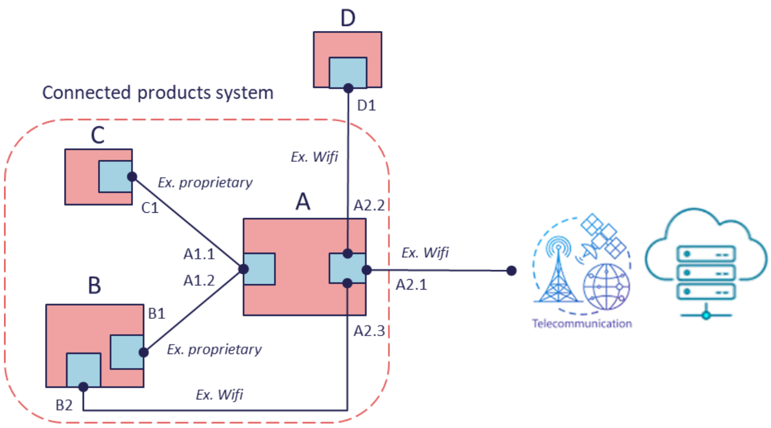

Figure 18 – Theoretical illustration of an example of a connected products system interacting with its outer environment (device D and the network/server platform). Connectivity modules (physical interfaces) are represented by blue squares.

To implement the heuristic for the case of a connected product system, unless stated, the practitioner shall consider the assessment from the perspective of the whole system and not from its specific constituting products.

Table 14 provides specific guidance on how to implement the heuristic for the case of this example; the approach can be generalized to other connected product systems.

Table 14 – Specific provisions for the case of a connected products system

Test of the heuristic	Guidance
Preliminary IoT test	To qualify as an IoT, the practitioner should consider the connected products system as a whole single self-contained product without consideration of its internal composition (in this example: A, B, C) or working, i.e. as a “black box”. The product system would be considered as part of the device layer. Communication capabilities involve external interfaces (in this example: A2.2/D1 and A2.1/Network).
Test 1.1: Qualify as ICT	To qualify as an ICT product, every constituting product (in this example: A, B, C) shall be qualified as an ICT product.

Test 1.2: Qualify as E&M	To qualify as an E&M product, every constituting product (in this example: A, B, C) shall be qualified as an E&M product.
Test 1.3: testing primary functionalities	Primary functionality of the product system. The product system is tested whether it is isolable or not by applying the negation test only on external interfaces (in this example: A2.2/D1 and A2.1/Network).
Intermediate market test	The test is applied by challenging the importance devoted to connectivity featured by external interfaces. Connectivity featured by local interfaces are irrelevant for the test.
Test 2.1: share of the connectivity in the CF of the device	The assessment shall consider only connectivity modules and other attributable processes featured by external interfaces. If a connectivity module is shared between local and external interfaces, allocation rules shall be applied. The share of the CF is calculated with respect to the CF of the product system. In this example: the assessment considers only a part of the CF of the connectivity module of physical interface A2.*x* (shared between 1 local interface and 2 external interfaces); the share is derived with respect to the sum of the CF of devices A, B and C. NOTE - Depending on the communication technology, the appropriate allocation rule should be applied (ex. based on data-rate for broadband technologies or number of requests/connections for low-power/narrow band technologies).
Test 2.2: incremental share of connectivity in the CF of the service	The hypothetical equivalent non-connected product system is a product system assuming no external interfaces; connectivity featured by local interfaces should be maintained. In this example: the equivalent non-connected product system has no interfaces A2.2/D1 and A2.1/Network, while keeping local interfaces.
Test 3.1: Hardware obsolescence	Hardware obsolescence considerations should be challenged with respect to the connectivity featured by external interfaces only.
Test 3.2: Software obsolescence	Software obsolescence considerations should be challenged with respect to the connectivity featured by external interfaces only.

Annex D

"Critical functionality" of a connected product

(This Annex is related to Section 4.1)

The heuristic developed in this Report follows a product perspective through the concept of functionality (of the product). To understand the service delivered by a product, primary functionalities are a canonical approach, however, in the case of connected products (including IoT) safety and regulation compliance are among the incidental characteristics. Indeed, some regulations may apply to those devices in order to include considerations, *inter alia*, related to (according to ISO/IEC 30141 standard):

- "*Safety regulations: These might include flight safety standards for IoT devices operating in aircraft, or regulations covering the manufacture and sale of devices intended for consumer use in the home, regulations for automotive systems, or regulations for devices or systems used in a medical context.*
- *RF related regulations: This category might include national or international regulations governing RF emanations, adherence to frequency band restrictions, signal strength, spurious signals (such as side channels, noise, or harmonics produced outside of the device's nominal frequency allocation), etc.*
- *Consumer protection regulations– These might include national and international regulations invoked whenever an IoT system involves a consumer anywhere in its operation*".

To reflect these considerations, the concept of "critical functionality" of a product may be relevant. Critical functionality may refer to a functionality considered as essential by regulatory/law requirements or with regards to safety, security or health considerations. Critical functionality may not be necessarily a primary functionality. The concept of "Constraint functions" defined in AFNOR Standard [NF EN 16271 -2013] could be an entry for identifying Critical functionality. The practitioner may refer to **Appendix I** for further guidance on this topic.

A critical functionality of a product may depend on the market where the product is put. Indeed, a functionality qualified as "critical" in a given market/jurisdiction may not still be critical within another market/jurisdiction. Therefore, such functionality to be considered as "critical", shall refer to a functionality considered as essential by regulatory/law requirements or with regards to safety, security or health considerations at worldwide scale.

While in most cases, critical functionalities of a connected product may be embarked within its primary functionalities, there may be some cases where the connectivity is necessary to fulfill the critical functionalities but not the primary ones. This theoretical situation advocates for the inclusion of the critical functionality as a supplementary element to be challenged by the negation test (test 3 of stage 1). As it stands, even though the Committee acknowledges that there are no examples of connected products illustrating such a case, it should not be *de facto* excluded by a practitioner considering the ever-dynamic nature of connected products.

Appendix I

Guidance on the implementation of the heuristic

(This Appendix is related to Section 4.1 and Section 4.2)

This appendix provides guidance for a practitioner to support the implementation of the heuristic of a connected product, including:

- Examples of methodological frameworks that could be used by a practitioner for modelling a connected product;
- Guidance on the definition and identification of functions and functionalities of a connected product, as well on the characterization of the functionalities of a connected product using existing normative standards;
- Guidance on the assessment of the incremental share of connectivity in the carbon footprint of the service delivered by the device;
- Guidance on the assessment of hardware/software-related obsolescence considerations;
- Guidance on the implementation of the intermediate test.

I. 1 Examples of methodological frameworks for modelling a connected product

With the rise of IoT, the need for interoperability between IoT solutions and providers motivated the development of methodological frameworks[51] to support the modelling of a connected device and its interaction with its close (other surrounding devices) and far (Cloud and distant service platform) environment, including the user.

This section highlights some examples of these methodological frameworks, which can be used by a practitioner to formalize how a connected device interacts with its environment thus helping to understand the role of the connectivity in enabling the functionalities of the device.

These methodological frameworks include:

- **SAREF**: The Smart Applications REFerence ontology (refer to [SAREF – 2020])
- **OneM2M** (refer to [oneM2M – 2016])
- **Open Connectivity Foundation** (OCF) (refer to [ISO/IEC 30118-1 – 2021])
- **Function-Means Tree** (refer to [Viola – 2012])
- **Function Interaction Model** (refer to [Ramachandran – 2011])

These methodologies could be considered as a tool supporting the implementation of the two tests of Stage 1 of the heuristic. While SAREF, OneM2M and OCF frameworks describe semantically entities (here connected products) in a given system to make them "discoverable" irrespective of their

[51] This appendix uses the general term of "methodological frameworks" to refer either to ontologies (i.e. formal specifications of conceptualization, used to explicitly capture the semantics of a certain reality; in a nutshell it refers to a vocabulary with a structure) or functional design modelling methods.

underlying technologies or vendor; the Function-Mean Tree is a proven technical method used in engineering design to derive a functional skeleton of a device (whether being connected or not).

NOTE 1 – Only a description of the concepts of these methodological frameworks that are relevant to the purpose of this document is provided below. A practitioner should refer to the reference documents of each framework for an exhaustive description.

NOTE 2 – By convention, wherever a core concept X related to a given methodological framework has been used, it was cited in blue between less than/greater than signs as follows: **<X>**.

SAREF [SAREF – 2020] is a reference ontology specifying recurring core concepts in smart applications and the main relationships between these concepts. SAREF focuses on the concept of a <device> (such as an actuator, an appliance, a sensor …), defined as a tangible object designed to accomplish a particular task in households, common public buildings or office. A <task> in SAREF is defined as the goal for which a device is designed from a user perspective (e.g. <task: Washing>, <task: Lighting>, <task: Drying> …). In order to perform this task, the device performs one or more <function> (e.g. actuating function, sensing function, metering function …). A device can be used for the purpose of offering or manipulating a <commodity> (such as water, gas …) and it can also measure a <property> (such as temperature, energy, smoke, light …). A function shall have at least one <command> (e.g. Start, Stop, Pause, On, Off, Notify, Step-up, Step-down etc.), the latter can act upon a <state> to represent that the consequence of a command can be a change of a state of the device. One of the prominent concepts in SAREF deals with a <service>; a device offers a service which is a representation of a function to a network that makes this function discoverable, registrable and remotely controllable (e.g. a <device: light switch> can offer the service of remotely switching the lights in a home through mobile phone devices that are connected to the network. This <service: remote switching> represents the <function: OnOffFunction> of the device).

Figure 19 provides an overview of the SAREF ontology, the relevant core concepts in relation to the implementation of the heuristic and the scope of this document are framed.

Departing from these core concepts, SAREF was extended to specific vertical IoT domains to deal with their particularities including: Energy IoT domain for smart grid applications, Environment IoT domain, Building IoT domain for smart building applications, Agriculture IoT domain for smart farming, Smart City IoT domain, Wearable IoT domain, Automotive IoT domain, Industry and manufacturing IoT domain etc. The practitioner should refer to ETSI Standard [SAREF – 2020] for further details.

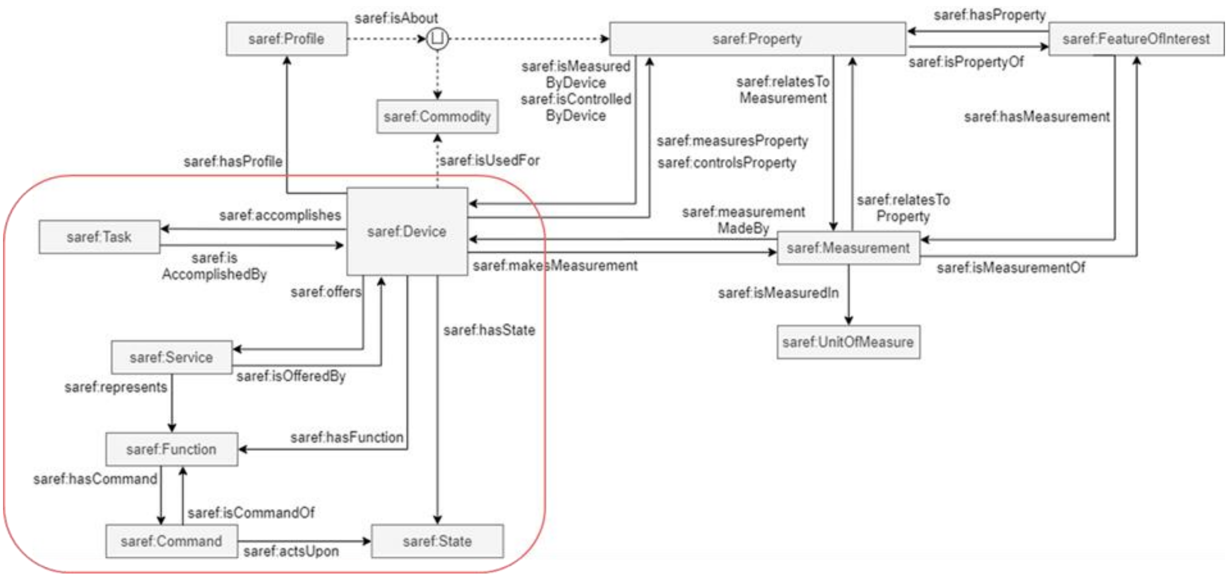

Figure 19 - Overview of the SAREF Ontology (from [SAREF - 2020]). Core concepts relevant to the scope of this document are framed in red color.

OneM2M is the global standard initiative launched in 2012 that covers requirements, architecture, API specifications, security solutions and interoperability for M2M and IoT technologies. Like SAREF, the core concepts of oneM2M include: a <device> which is able to interact electronically with its environment, it contains some logic and is producer and/or consumer of data that are exchanged via its <Services> with other entities. In order to accomplish a particular task, the device performs one or more functionalities (<functionality>), the latter are classified into <measuring functionality> and <controlling functionality>. These functionalities are represented in the network as Services (<service>) of the Device to make them discoverable, registrable and remotely controllable by other devices or the Cloud. A <command> represents an action that can be performed to support the functionality and it is exposed to the network via <operations>. While <service> and <operation> describe machine/technology dependent concepts, <functionality> and <command> describe human understandable concepts of a device. For further description on oneM2M concepts, the practitioner should refer to ETSI Standard [oneM2M – 2016]. In oneM2M ontology, services are provided/consumed between entities through a client/server paradigm where the service provider (for instance a connected fridge) is called oneM2M Common Service Entity (OneM2M CSE) and the client entity (for instance the cloud server platform or the smartphone web application) is called oneM2M Application Entity (AE).

While oneM2M is meant to be agnostic to specific application domains, there is a mapping between SAREF and oneM2M ontologies detailed in [SAREF - 2020] which helps a practitioner proceed easily between both frameworks. In particular, the correspondence between the core concepts relevant to the scope of this document is shown in Figure 20.

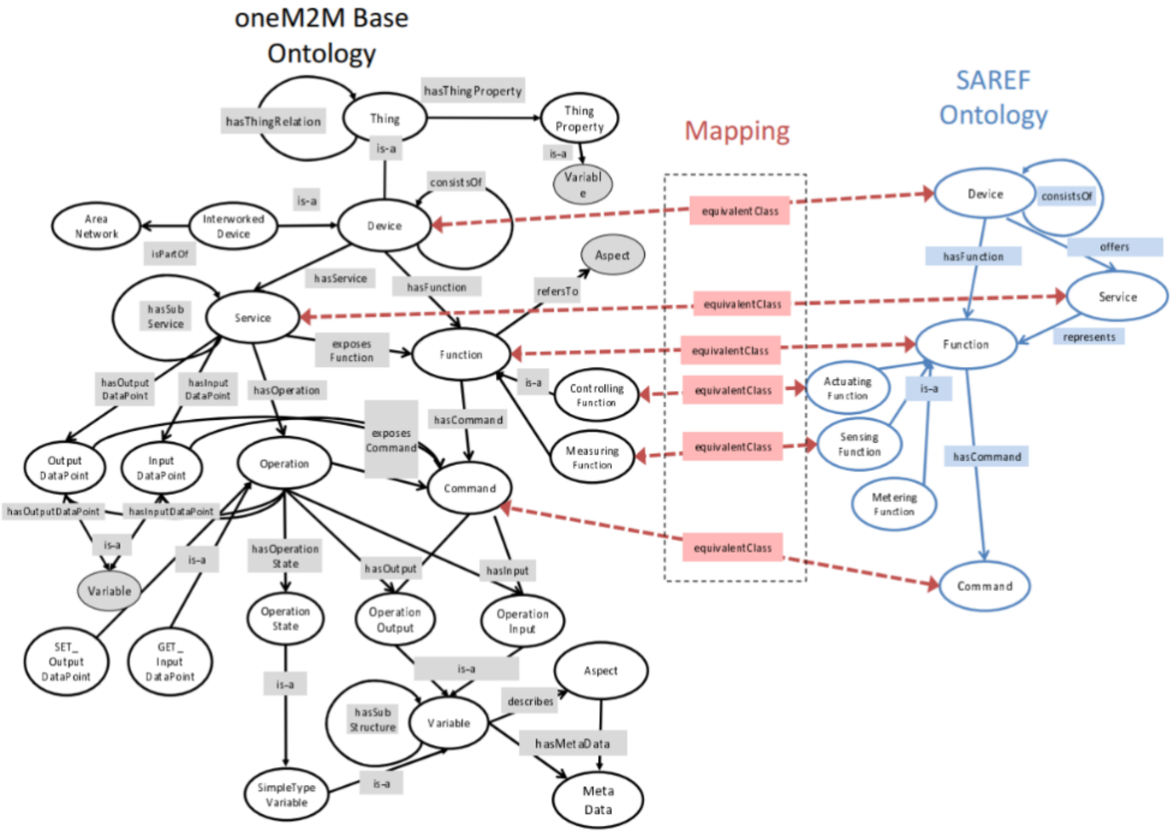

Figure 20 - Mapping of the core concepts between SAREF and the oneM2M Base Ontology (from [SAREF - 2020])

Open Connectivity Foundation (OCF) specifies an architecture enabling resource-based interactions among OCF Devices thus achieving interoperability across a wide range of networked devices, including IoT. An <OCF device> is an entity in the physical world such as a light bulb, a temperature sensor or a connected appliance and represented as a <Resource>. OCF Devices can expose aspects of the physical world like a lightbulb and/or logical entities like an application. Like in oneM2M, an <OCF device> can be in a client (to access and consume a resource) or in a server (to expose and provide a resource) role, OCF devices interact through CRUDN[52] operations. In OCF, a resource model specifies how to represent in terms of <Resources> the capabilities of entities and defines mechanisms for manipulating those Resources.

Figure 21 illustrates the general architecture of OCF and indicates the specific part of this architecture, dealing with the abstraction layer, which is relevant to the scope of this document.

OCF core specifications architecture are detailed in [ISO/IEC 30118-1 – 2021] supplemented by other ISO/IEC standards from the ISO/IEC301118-x series. Specifically, [ISO/IEC 30118-5 – 2021] specifies the required resources supported by each device type for some selected vertical domains including smart home device types, health care devices types, industrial device types, energy (photo-voltaic) system device types.

To enable interworking between OCF and OneM2M standard, a mapping between both architectures is also provided by ETSI[53].

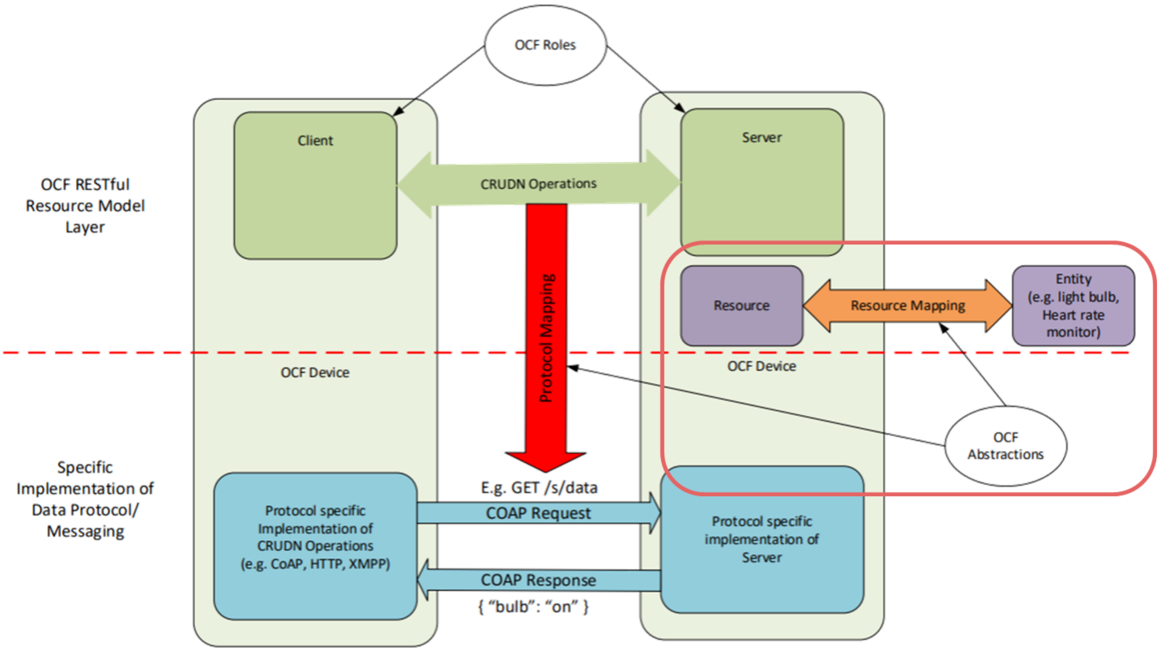

Figure 21- OCF Architecture (from [ISO/IEC 30118-1 - 2021]). The part of the architecture relevant to the scope of this document is framed in red.

The **Function-Means Tree** [Viola – 2012] is a method of modelling a product by the systematic decomposition of functions and considering causal relations between functions and means used for achieving those functions. Consequently, the function/means tree has a hierarchical structure of functions and means arranged on different levels and connected according to the causal relations. The

[52] CRUDN designates a set of Representational State Transfer (REST) architectural style referring to a small set of generic operations namely CREATE, RETRIEVE, UPDATE, DELETE and NOTIFY. Refer to [ISO/IEC 30118-1 – 2021] for more information.

[53] Refer to ETSI 118 124 "OneM2M; OCF Interworking" for more detailed guidance : https://www.etsi.org/deliver/etsi_ts/118100_118199/118124/03.02.02_60/ts_118124v030202p.pdf

hierarchical structure of the framework highlights, at the top of the hierarchy, the primary functions of a product, next the various means by each primary function may be implemented, then determining the secondary functions that would result from implementing each of these means and so on by alternating between means and functions until reaching a reasonable termination point (where no further decomposition is no longer possible in this case these functions are called “basic functions”). The move from the top to the bottom of the tree, the practitioner asks “how” while moving from the bottom to the top by asking “why”. When applying the Function-Means Tree method for the functional analysis of connected product, “Connectivity” would be identified as a mean for achieving a given function.

In functional analysis, a practitioner may complement the function-means tree by the **function-devices matrix** [Viola – 2012]. The latter is used to map functions to physical components of the product. In practice, the matrix is built simply by matching the bottom of the function-means tree (i.e. all identified “basic functions”), with one column of components able to perform those functions., by answering the question: “*which component is able to perform this (basic) function?*”. For the case of connected products, thanks to the function-devices matrix, a practitioner would be able to identify whether is a connectivity component (e.g. transmitter, receiver …) is necessary to perform a given basic function (cf. Figure 22).

NOTE 1 – The function-means tree and function-devices matrix do not distinguish between primary function and non-primary functions, thus in order to use these tools for the purpose of the heuristic, the practitioner needs to identify whether a given basic function is mapped with primary/critical functionality or other functionality.

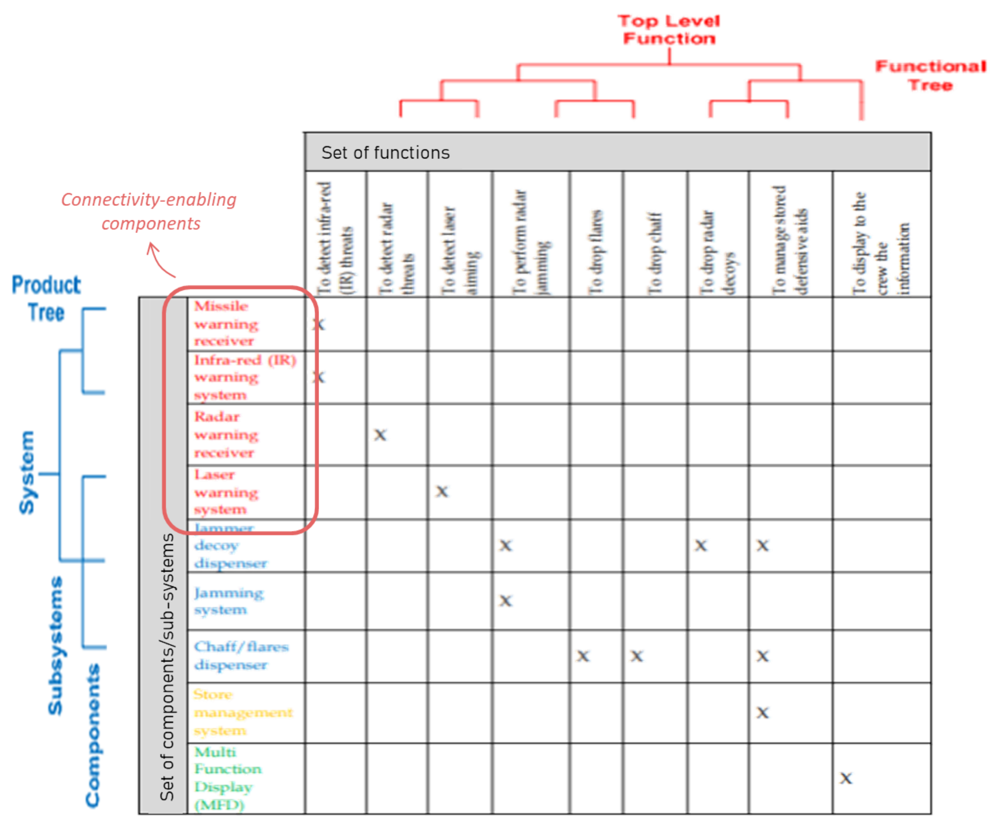

Figure 22- Example of functions/devices matrix for the case of "Defense system" (from [Viola – 2012]). Connectivity-enabling components are framed in red.

Function Interaction Model [Ramachandran – 2011] A product interacts with the environment and may interact with other artifacts (products) and users. The function interaction model (FIM) tries to capture both the transformational (functional) and non-transformational (non-functional) aspects of a product during the product development stage, in a single model. “Connectivity” generally increases the level of interactions between the product and its environment[54], the level of functionalities is increased as well. While the functional aspects are represented through “active functions” that act on/transform a set of input flows into output flows (material, energy, signal/information), the non-functional aspects are represented as passive functions that do not carry material flows but only energy or signal/information flows thus describing actions over the product. The interaction model helps understanding and modelling user behavior towards the product when proceeding to the realization of its tasks (called also *a Through-line*[55]), it usually contains the following pieces: how to launch or terminate of function, how to navigate between product’s functions/options, transitions between functions etc.

Figure 23 illustrates an example of Function Interaction Model of a “conventional” Rice Cooker from [Ramachandran – 2011]. Considering the case of a “connected” Rice Cooker, where the user is able to remotely operate the device through its mobile app using its smartphone, some functions/activities would be modified to reflect the new design such as: <Use Human Energy to operate Rice Cooker>, <Convert Human Energy to Control Signal> as well as the consideration of new functions/activities performed by new artefacts including at least: a smartphone (for mobile app), an IoT platform server (for remote command of the connected appliance) and the IoT network/gateways.

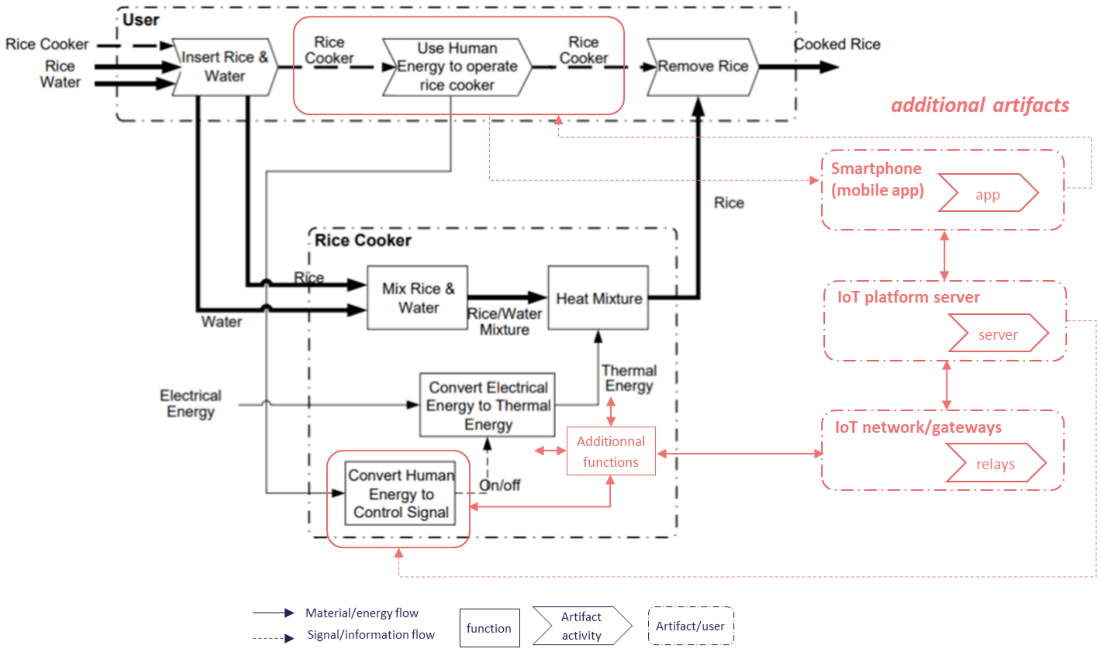

Figure 23- Illustration of the Function Interaction Model for a “conventional” Rice Cooker (from [Ramachandran – 2011]). Items depicted in red are required modifications/additions in the model to represent the case of a “connected” Rice Cooker.

How these methodological frameworks could be improved to fit the purpose of the heuristic?

[54] Although connectivity (and automation) may decrease the level of interactions between the product and the user, they are generally substituted with interactions with other artifacts (interaction with smartphones, gateways, other connected products, IoT servers etc.).

[55] *A Through-line* is figuring out the likely pathways the user would follow through the product to perform at it was intended. *A Through-line* reflects the conventional usage scenario of the product and is generally documented through a “User manual” or a “Usage instruction”.

SAREF, OneM2M and OCF ontologies share some common principles at the basis of their creation including: modularity (i.e. defining building blocks that can be combined to accommodate different needs and points of view), extensibility to allow further growth of the ontology (i.e. different stakeholders can specialize the concepts, add more specific relationships to refine the reference ontology, and even create new concepts as long as any extension/specialization comply with the existing principles), and maintainability (i.e. accommodating new requirements and coping with changes in the ontology). Thanks to these considerations, possible improvements on the core concepts could be envisaged to better fit the purpose of the heuristic:

- To be able to characterize a task, a new propriety "type" (referring to the type of a task) could be introduced. It may take the three following values: "primary", "critical" and "other". In SAREF, the class <task> would be characterized for instance with the following proprieties: <saref: task: oftype:: *primary*>, <saref: task: oftype:: *critical*>, <saref: task: oftype:: *other*>. This characterization would be useful for the case of multi-task connected device and for which the knowledge of the primary vs non-primary task is useful for a practitioner (e.g. for a connected washing-draying combo machine).
- To be able to identify whether a function associated with a task could be fulfilled even when the device goes offline, a new binary propriety "offline_mode" could be introduced. In SAREF, the class <function> would be characterized with the following proprieties: <saref: function: offline_mode:: *yes*> and <saref: function: offline_mode:: *no*>.

NOTE – While the aforementioned proposals refer to the case of SAREF ontology, OneM2M and OCF could be addressed similarly leveraging on the mapping between the different ontologies.

I. 2 Guidance on "function" and "functionality" of a connected product

The heuristic features the concept of "functionality" of the product instead of "function". While both concepts are intertwined, they are not totally equivalent.

As defined by IEC standard [IEC 62301 -2011], function is "*a predetermined operation undertaken by the energy using product*". While AFNOR standard [NF EN 16271 -2013] defines function as *"an action of a product or one of its constituents expressed exclusively in terms of purpose".*

There are several approaches to categorize functions:

- In the discipline of Value Analysis [Aurisicchio et al. – 2011], the practitioner distinguishes between *use functions* split between *basic functions* (necessary to the customer and for which he/she buys the product) and *secondary functions* (complementing or enabling the basic function) and *aesthetic functions*.
- From a functional analysis normative perspective, AFNOR standard [NF EN 16271 -2013] identifies 3 categories of functions: *main functions* (reflecting the actions performed by the device), *constraint functions* (reflecting the adaptation of the device to its environment), *complementary functions* (improving the provisioned service featured by the main functions); the two latter categories are not necessarily related to a request or a need expressed by the user of the product. The standard defines *technical functions*, understood as enabling the realization of other functions and are generally masked or unknown to the user.
- From an energy performance measurement perspective, [IEC 62301 -2011] Standard classifies functions either as *primary functions* – i.e. relate to the primary purpose of the product – or *secondary functions* which can include remote switching, sensing, network and protective type functions. For some products, network functions or sensing functions can be a primary function. Similar to [IEC 62301 -2011], EC Eco-design Regulation [EC Eco-design – 2023] refers to *main function* – i.e. a "function delivering the main service(s) for which the equipment is designed, tested and marketed, and which corresponds to the intended use of the equipment"

and to standby mode functions including *reactivation function*[56] and *information or status display function*.

For the case of connected products, the augmentation of product's capabilities (by being connected) makes the focus on a given function (albeit primary or basic) as a standalone too restrictive to assess the added value of the connectivity in provisioning the product's functions. Authors in [Siderius/Meier – 2014] indicate how the combination of software – playing a major role in the function of the product and dependence on connectivity for the functionality of the product, pose challenges on the classical way of approaching products functions and functionalities. Considering the example of Internet-connected thermostat, as opposed to classical thermostat where its function can still be delivered without being connected to a network and the software is not definitive for its function, Siderius and Meier point out an increasing trend where classical products would migrate into "virtual"[57] products. Such a migration results in products having multiple functions, solicited differently according to the context of the usage (functionality). Authors proposes to apply a modular functional approach evolving around the construction of a "basket of functions" to operationalize the functionality of a product.

[IEC 62301 -2011] acknowledges that "*functions may be controlled by an interaction of the user, of other technical subsystems, or the system itself (for instance in case of automated self-controlling systems)"*, from measurable inputs from the environment and/or time. Instead, the concept of functionality is more appropriate for the purpose of this document as it is a powerful mechanism for exploring the relationship between the product under study and its environment (including the user).

In a given scenario/context of product's usage, the primary functionality could be expressed as the primary function deployment with the support of a set of complementary functions. These complementary functions (could be either primary or secondary functions) constitute **the minimum set of necessary supporting functions** to faithfully reflect the usage of the product in a given context. This context refers to the conventional usage scenario of the product (usually specified by the manufacturer or system integrator).

[IEC 62301 -2011] lists some examples of secondary functions (where these are not a primary function of the device), including:

- Remote control of power to the operating load (Remote power switch) through low voltage (wired) or radio signals (wireless)[58];);
- Secondary control of the load (auto off, delay start or delay off);
- Sensing functions such as light, occupancy, heat, smoke, temperature, water flow …;
- Display (could be status, program, state or clock etc.)[59];.);
- Memory and timer functions;
- Electronic controls, locks and switches;
- Battery charging;
- Electromagnetic compatibility (EMC) filters;
- Sensors for protection of products and/or users;
- Safety switches (for products and/or users protection);
- Software functions (OS, program …);

[56] It refers to "a function that via a remote switch, a remote control, an internal sensor or timer provides a switch from standby mode to another mode, including active mode, providing additional functions" [EC Eco-design – 2023]

[57] To be understood as products featuring an increasing role of the software and growing dependency on connectivity [Siderius/Meier – 2014].

[58] This is similar to "Reactivation function" defined in [EC Eco-design – 2023].

[59] This is similar to "Information or status display" function defined in [EC Eco-design – 2023].

- Processing functions (for AI inference, AI training etc.);
- …

NOTE – [IEC 62301 -2011] considers that Thermostats or temperature control devices which control the operating load in order to maintain a constant condition are usually considered as part of the operating load (i.e. primary function) and not as a power switch or a secondary function.

Figure 24 illustrates how the primary functionality of a product is approached through its (anchor) primary function completed with its supporting set of secondary functions.

<table>
<tr><td rowspan="2">Scenario/context of conventional usage of the product</td><td colspan="3">Primary function</td></tr>
<tr><td>Secondary function 1</td><td>Secondary function 2</td><td>Secondary function 3</td></tr>
</table>

Figure 24- Primary functionality: expressed as the primary function deployment in a given scenario with the support of the minimum set of necessary secondary functions (complementary functions).

Some Examples are provided:

Example 1: Primary functionality of an Automatic Braking System (ABS) from ISO SOTIF standard [ISO 21448 -2022]

<table>
<tr><td rowspan="2">Scenario/context of conventional usage of the ABS product</td><td colspan="2">Braking</td></tr>
<tr><td>Detection (sensing)</td><td>Processing (Inference)</td></tr>
</table>

Example 2: Primary functionality of a connected appliance, equipped with a screen as the only mean enabling the user to check whether the operating load is functioning or not.

<table>
<tr><td rowspan="2">Scenario/context of conventional usage of the connected appliance</td><td colspan="2">Operating load</td></tr>
<tr><td>Switch on/off</td><td>Display</td></tr>
</table>

Example 3: Primary functionality of an In-Vehicle System (IVS) used for eCall, also known as Automotive Emergency Detection Device (AEDD). When a collision is detected by the AEDD sensors, the AEDD can be prompted by the user, or automatically, to initiate an E112 emergency voice call and transmit the Minimum Set of Data (MSD) which is routed to the appropriate automotive emergency response center. The MSD includes the location information of the vehicle, direction of travel, number of passengers within fastened seat belts and vehicle information.

<table>
<tr><td rowspan="2">Scenario/context of conventional usage of the AEDD (aka eCall device)</td><td>Providing emergency voice call (e.g. E112)</td><td colspan="2">MSD transmission</td></tr>
<tr><td>Detection (sensing) et analysis</td><td>Position acquisition</td><td>Other components of MSD</td></tr>
</table>

NOTE – **Appendix III** provides further details on the implementation variants of an AEDD and how it can be approached as a connected products system.

A similar approach for the case of critical functionality is illustrated in Figure 25.

	Constraint function ([NF EN 16271 -2013])

Scenario/context of conventional usage of the product	Secondary function 1	Secondary function 2	Secondary function 3

Figure 25 - Critical functionality: expressed as the constraint function deployment in a given scenario with the support of the minimum set of necessary secondary functions (complementary functions)

Characterizing a functionality

One may consider that the functionality is to be considered as "fulfilled" as long as a specific associated quality of service is respected. Thus, when implementing the second step (of Stage 1) of the heuristic, it is important to describe as detailed as possible the functionality being tested, especially with regards to its targeted quality or other related constraints. AFNOR Standard [NF EN 16271 -2013] provides the practitioner with guidance on product's functions characterization; this could be leveraged for functionality characterization.

The standard defines the template illustrated in Table 15. The studied functionality is defined with criteria, levels, flexibility and tests to be performed.

Table 15 – Template for functionality characterization inspired from AFNOR Standard [NF EN 16271 -2013]

Functionality	Criteria/standard	Levels	Flexibility/limits	Tests
Functionality 'X' (primary or critical)	Criteria with respect to which the functionality fulfillment is tested	Scale/range for a given criterion	Describes the tolerance[60] or setting strict boundaries (min, max)	Description of relevant protocols to be performed for test conformance

I. 3 Guidance on simplified methods for assessing the share of the connectivity in the carbon footprint of the device

When the implementation of a simplified LCA is not possible (due to lack of data or unavailability of resources etc.), the following 4 alternative simplified approaches could be envisaged. They are sorted by order of preference, according to the decision tree as recommended by ILCD Handbook [ILCD - 2011] when it comes to allocation strategy:

(1) **Using physical proxies:** Approximating the share of the carbon footprint by the ratio of the mass between the connectivity module and the connected device;

EXAMPLE – The connected device weighing 500g, equipped with a modem card weighing 50g, thus the share is estimated to 10%.

(2) **Using Quality Function Deployment:** Approximating the share of the carbon footprint by the share of the connectivity attribute of the product using the Quality Function Deployment (QFD) approach. In the context of LCA, QFD can be interpreted as identifying the relevance that the different co-functions/co-attributes of a multifunctional/multi-attribute product are assumed to have for its average user [ILCD - 2011].

[60] How negotiable can be the results expected in "Criteria" and "Levels".

NOTE – QFD helps transforming customer needs ("Voice of customer") into engineering characteristics of a product or service, prioritizing each function/attribute (and characteristic that support the function/attribute) into development targets for the product or service. For further details, refer to the specific literature.

EXAMPLE – The connected device is characterized by a set of 5 user-oriented attributes ranked according to their respective share. These shares, derived generally through market surveys, represent how much each attribute is privileged (or perceived as a major reason for buying or using it) by an average user, thus translating customer needs/preferences. The set of 5 user-oriented attributes of the connected product are ranked as follows: Security and data privacy (40%), resiliency and durability (20%), connectivity (10%), processing performance (10%) and esthetics and User experience (20%).

(3) **Using Economic approaches:** Use of economic approaches such as the Economic Input Output (EIO) analysis which leverages on monetary value of the significant inputs of the device/item combined with GHG emission factors (derived from Input-Output tables) representing the total upstream production GHG emission impact per monetary unit.

NOTE – When deriving the monetary value of a device/an item, basic price is privileged over purchase price as the latter encompasses trading margins and miscellaneous taxes which may distort the assessment.

EXAMPLE 1 – Considering a fictive example of a connected device made of the following significant materials (M1, M2 and M3, respectively), associated with these relevant sectors/categories as entries in EIO tables (A, A and B, respectively). The connectivity module part is made of the following significant material (M1) associated with the relevant sector/category as entry in EIO tables (A). Using the monetary value (price) of the different materials considered in the product and the corresponding EF (derived from EIO tables) the calculation of the share is:

Significant material	EIO Category	Price (in €)	EIO EF (kg CO2/€)	GHG (kg CO2)
For the connected device				
M1	A	5	1	5 (=1*5)
M2	A	5	1	5 (=1*5)
M3	B	10	0.1	1 (=0.1*10)
For the connectivity module part				
M1	A	2	1	2 (=1*2)
Estimated share				18% (=2/11)

EXAMPLE 2 – If the monetary value (price) of the material in the product is not known, the practitioner may consider the weight of the material supported with its trading price to estimate the price of the material. The reminder of the calculation process is similar to EXAMPLE 1.

Significant material	EIO Category	Weight (g)	Trading rate (in €/g)	EIO EF (kg CO2/€)	GHG (kg CO2)
For the connected device					
M1	A	100	0.05	1	5 (=1*100*0.05)
M2	A	100	0.05	1	5 (=1*100*0.05)
M3	B	300	0.03	0.1	1 (=0.1*300*0.03)
For the connectivity module part					
M1	A	50	0.04	1	2 (=1*50*0.04)
Estimated share					18% (=2/11)

(4) **Using monetary proxies:** Approximating the share of the carbon footprint by the ratio of the cost between the connectivity module and the connected device.

EXAMPLE – The connected device costs 20 euros, equipped with a modem card valued at 2 euros, thus the share is estimated to 10%.

I. 4 Guidance on the assessment of the incremental share of connectivity in the carbon footprint of the service delivered by the device

The incremental share refers to the ratio of the additional carbon footprint of the connectivity with respect to the carbon footprint of a non-connected version of the device. This ratio is expressed as the following equation:

$$\frac{\Delta \mathrm{CF}_{sys}}{\mathrm{CF}_{device}^{\overline{conn}}} = \frac{\mathrm{CF}_{sys}^{conn} - CF_{sys}^{\overline{conn}}}{\mathrm{CF}_{device}^{\overline{conn}}}$$

Where:

- $\mathrm{CF}_{device}^{\overline{conn}}$: stands for the carbon footprint of the non-connected version of the device
- CF_{sys}^{conn} : stands for the carbon footprint of the product system featuring the connected device
- $CF_{sys}^{\overline{conn}}$: stands for the carbon footprint of the product system in alternative scenario where the device would not have been connected
- ΔCF_{sys}: stands for the additional carbon footprint of the connectivity, i.e. the incremental emissions attributable to the communication capabilities of the device.

To assess the additional carbon footprint of the connectivity (i.e. $\Delta \mathrm{CF}_{sys}$), the practitioner shall undertake a comparative assessment based on the following considerations:

- It considers two scenarios: an actual scenario, called baseline case (reference product system), featuring the service provisioned by the connected device and an alternative scenario (hypothetical product system) featuring the service provisioned by an hypothetical non-connected version of the device;
- As the purpose of the comparative assessment is to assess the difference between the two products systems rather than the total impact of each product system, processes and input/output data may be excluded if they are the same in both product systems;
- In-line with part II of [ITU L.1410] Recommendation, both product systems are assessed using equivalent methodological considerations, including: the same functional unit, system boundary, data quality, allocation procedures and cutoff rules. Any differences between systems regarding these parameters shall be reported;

  NOTE – One may advocate that these requirements would not hold anymore when comparing a connected product with respect to its non-connected counterpart, particularly with regards to the definition of the functional unit. This shortcoming calls for rethinking the functional unit definition to be able to reflect how the connectivity may impact the usage behavior.

- Two system boundaries are defined which are applicable for the reference product system and the hypothetical product system. The system boundaries include, wherever relevant: the device under study, non-connectivity related support goods and supporting goods (e.g. power supply/charger device, cooling systems, monitoring systems, cables/feeders, mechanical structures/shelters etc.), connectivity related support goods and supporting goods (e.g. smartphones, companion devices, gateways, relays/amplifiers, communication cables and connectors etc.), networks and DC/service platforms;

- It focuses only on first order effects (i.e. the GHG emissions occurring from the physical existence of the product system);

In the comparative assessment, the service provisioned by the connected device (and its hypothetical non-connected counterpart), is expressed in LCA through the Functional Unit. The comparative assessment considers two approaches for scoping the functional unit:

- A narrow scoping where only primary functionalities of the product under study are considered, thus the functional unit is expressed as: *"To provision the primary functionalities of the device"*.
- A wider scoping where both the primary functionalities and other functionalities of the product under study are considered, thus the functional unit is expressed as: "*To provision the primary functionalities and other functionalities of the device"*. In that case, the practitioner shall specify the other functionalities included in the functional unit.

  NOTE – In both approaches, the practitioner shall follow the best practices in terms of functional unit definition in LCA (i.e. specifying the questions "what", "how much", "how well", and "for how long"). Refer to ISO 14040/44 and [ILCD – 2011] for more guidance.

NOTE – The practitioner may complement with other supporting technical documents including the IEC TR 62726:2014 [IEC TR 62726:2014 – 2014], ISO 14064-2:2019 [ISO 14064-2:2019 – 2019] or a future guidance being developed by IEC on the Quantification and communication of Carbon Footprint and GHG emission reductions/avoided emissions from electric and electronic products and systems (expected for mid- 2025).

Table 16 provides an overview of the difference in terms of GHG impact between the reference product system and the hypothetical product system depending on the approach chosen by the practitioner to define the functional unit in the comparative assessment. In both cases, the comparative assessment assumes a single product scale for the sake of simplification.

Table 16 - Difference in terms of GHG emissions between the two product systems depending on the scope of the functional unit

Functional Unit scope	Primary functionalities	Primary + Other functionalities
(Connected) device	Either no GHG difference(1) or there may be a GHG difference due to difference in device's performance(2)	There may be a GHG difference due to difference in device's performance(2) and/or difference in the set of Other functionalities(3)
Non-connectivity related support goods and supporting goods	Either no GHG difference(1) or there may be a GHG difference due to difference in device's performance(2)	There may be a GHG difference(4)
Connectivity related support goods and supporting goods	Either no GHG difference(1) or there may be a GHG difference due to difference in device's performance(2)	There is a GHG difference (emissions generated by connectivity related support goods)(5)
Networks	Either no GHG difference(1) or there may be a GHG difference	There is a GHG difference (emissions generated by used networks)(5)

	due to difference in device's performance(2)	
DC and service platform	Either no GHG difference(1) or there may be a GHG difference due to difference in device's performance(2)	There is a GHG difference (emissions generated by used DC)(5)

(1) In the case where connectivity is not needed at all to provide the primary functionality of the device.
(2) In the case where the connectivity is used by the device to improve the outcome of the primary functionality (delivering a better quality of service) or to reduce its cost (e.g. lower energy consumption), but it is still not necessary to fulfill the primary functionality according to the specified level (refer to Functionality Characterization).
(3) The existence of all or some of Other functionalities (relying on connectivity) is not justified anymore.
(4) A suppression of an "Other functionality" may induce a suppression in some related non-connectivity support goods or supporting goods.
(5) Attributable emissions by considering relevant allocations.

Guidance on consequences identification through a consequence tree approach

A consequence tree could be used as a possible approach by a practitioner to identify relevant consequences. Consequences to be considered in the assessment include:

- Consequences featuring GHG emissions sources (no sinks, no avoided emissions);
- Consequences attributable to the fact that the product has been connected;
- Consequences stemming from the fulfillment of the functionality of the connected product (as expressed in the functional unit considered in the comparative assessment);
- Consequences contributing cumulatively to the carbon footprint of the product system with a substantial share. The practitioner may cutoff specific consequences based on quantitative screening or qualitative assessment (for instance consequences with a cumulative contribution below a threshold of 5% could be discarded from the assessment).

  NOTE – Rebound effects stemming from the consequences aforementioned should be included, subject to data availability.

The practitioner should distinguish between consequences belonging to the foreground system from those belonging to the background system of the product system. Foreground processes are those processes that are, regarding their selection or mode of operation, directly affected by decisions analyzed in the study (here the product being connected). Foreground processes are hence those that are under direct control of the producer of the product or operator of the service or user of the product or where she/he has decisive influence. For the case of a connected product, this may include a dedicated gateway, a specific companion device, a support good of the connected product etc. that are supplied specifically by the product supplier and/or deployed exclusively to support the connected product.

In contrast, Background processes comprises those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the connected product (or operator of the service, or user of the product); they are thus outside the direct influence or choice of the producer or service operator of the analyzed system. For the case of a connected product, this may include a publicly available existing communication network (e.g. a cellular network).

These definitions of Foreground and Background processes are in-line with the management perspective definition of these two concepts from ILCD LCA Handbook (JRC). The management perspective aims at identifying which processes can be managed by direct control or decisive influence from the point of view of the decision-context of a study (in our case "connecting a product"), this variant of foreground / background definitions is relevant for eco-design purposes and aligned with the philosophy of the heuristic.

The identification of background and foreground processes and how to account them are dependent on the scenario modelling in the comparative assessment.

As a general rule, emissions stemming from background processes are non or partially additional and thus would be accounted using allocation rules (taking the share of the impact attributable to the functionality provisioned by the connected product) while emissions generated from foreground processes are fully additional and thus would be accounted without apportionment (as their existence is generally attributable to the connected product).

NOTE – The impact of process identified as a foreground process might also be assessed through allocations. For instance, the impact of a proprietary service platform interacting with the connected device, has to be shared between several connected devices with which the platform is communicating.

Figure 26 depicts a possible representation of the consequence tree when embedding a connectivity in a product; it identifies actions (dashed lines) and their direct consequences (first level consequences), leading to other consequences (second and higher-level consequences) etc.

Different colors can be used to differentiate between foreground and background consequences. Other representations of the consequence tree or alternative conventions to support the consequential approach could be used by the practitioner.

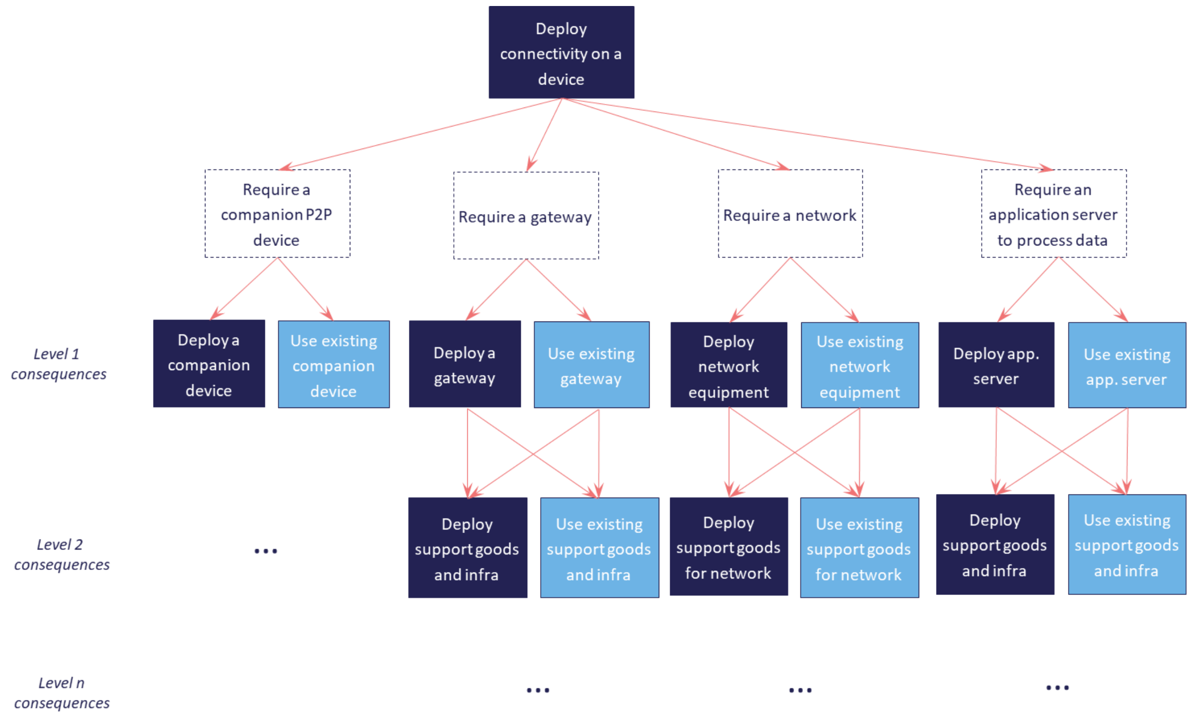

Figure 26 – *A possible representation for the consequence tree showing the range of consequences once the product being connected; Light blue color spots on consequences featuring background processes, Dark blue color spots on consequences featuring foreground processes.*

An example of implementation: the case of surveillance IP Camera

The case of a connected Surveillance IP Camera with a build-in storage is considered as an example to assess the incremental share of connectivity in the Carbon footprint of the service delivered by the device.

<u>Description of the IoT solution and specification of functionalities:</u>

In-train connected IP camera are mounted at several locations within the train to record the inner environment of the train. Cameras capture the scene along the trip and record the images within its build-in storage component (ex. build-in SD card slots or hard drive). Once the train arrives at the railway station, the fleet of cameras, are automatically polled by the Railway Information System Control Center. The cameras connect through available 4G/5G cellular networks to a server in a Datacenter where the recorded video will be processed and stored for a predefined period.

- The primary functionality of the connected camera: To film and record footage in a build-in storage component.
- The secondary (add-on) functionality of the connected camera: To transfer, upon automatic polling, the stored footage to a Datacenter (where the content will be processed and stored for a predefined period)

The assessment compares two product systems featuring the same primary functionality:

- Product system of a non-connected equivalent product = {non-connected surveillance IP camera with build-in storage}
- Product system of a connected camera = {connected surveillance IP camera with build-in storage, network, Datacenter/service platform}
- Scope of the assessment: one surveillance IP camera with build-in storage deployed in a train.

Assessment assumptions:

The assessment considers a simplified/screening approach with the following assumptions:

item	assumption	Source/reference; comments
Connected surveillance camera embodied carbon (KgCO2eq/unit)	390	APL model (2023)
Connected surveillance camera power rating (active and standby) (KW/unit)	0,01 active 0,001 standby	Decision, APL (2023)
Non-connected surveillance camera embodied carbon (KgCO2eq/unit)	387	APL model (2023); no connectivity module (the latter assumed to account for 3 KgCO2eq.)
Non-connected surveillance camera power rating (active and standby) (KW/unit)	0,01 active 0,001 standby	Decision, APL (2023); Assumption that the power difference is not significant.
Average data volume processed and stored per camera per trip (GB/camera)	10	Decision, APL (2023); adaptation of the model for high-rate processing during a 2 hours trip.
Data compression ratio for data transfers	0,3	Decision, APL (2023) assumption[61].
Average number of days of use of a TGV per year (days)	260	Assumption
Average duration of storage in datacenters (days)	21 days	Decision, APL (2023)
Number of scheduled trips per day (2-hour long)	6	Assumption; 3 2-ways trips per day
Datacenter allocated embodied carbon emissions per GB stored.year (KgCO2eq/GB stored.yr)	0,001	Decision, APL (2023) model; adaptation to 1 GB stored
Cellular Network allocated carbon emissions per transferred GB.year (KgCO2eq/GB transferred.year)	0,008	ADEME Base Empreinte (2020 year) [62]
Average camera lifespan (years)	10	Hillerström (2010) [Hillerstrom – 2010]
Average grid carbon intensity – France (KgCO2/KWh)	0,07	NegaOctet/CODDE

[61] Using a compression factor of 30%, this leads to a data volume consistent with a 5MP IP camera with motion sensitivity set at 50% and recording at a full 25 frames per second using H.265 : refer to: https://domar.com/collections/ip-cameras-with-memory-card-support

[62] https://base-empreinte.ademe.fr/documentation/base-impact?idDocument=167

Assessment:

The impacts of a non-connected surveillance camera are calculated as follows:

$CF_{sys}^{\overline{conn}}$ *= Embodied impact + Use impact*

- *Embodied impact =* ***387 kg CO2 eq***
- *Use Impact = (Power (active) * active_time + Power (standby) * standby_time) * camera lifetime*Grid carbon intensity*

*= (0,01 * 6 * 2,5 * 260/365 + 0,001 * [(24 – 6 * 2,5) * 260/365 + 105/365)]) * 365 * 10 * 0,07*

= 29 kg CO2 eq

$CF_{sys}^{\overline{conn}}$*= 387 + 29 =* ***<u>416 kg CO2 eq</u>***

The impacts of a connected surveillance camera are calculated as follows:

CF_{sys}^{conn} *= Embodied impact + Use impact + Network impact + Storage Impact*

- *Embodied impact =* ***390 kg CO2 eq***
- *Use impact = (Power (active) * active_time + Power (standby) * standby_time) *camera lifetime* Grid carbon intensity*

*= (0,01 * 6 * 2,5 * 260/365 + 0,001 * [(24 – 6 * 2,5) * 260/365 + 105/365)]) * 365 * 10 * 0,07*

= 29 kg CO2 eq

- *Network impact = Data transferred per trip * number of trips * Network allocated carbon emissions per GB transferred per year*camera lifetime*

*= 10 * 0,3 * 6 * 260 * 10 * 0,008*

= 375 kg CO2 eq

- *Storage impact[63] = Data stored per trip * number of trips * duration of storage (in years) * Datacenter allocated embodied carbon emissions per GB stored per year*camera lifetime*

*= 10 * 6 * 260 * 10 * 21 / 365 * 0,001*

= 9 kg CO2 eq

CF_{sys}^{conn} *= 390 + 29 + 375 + 9 =* ***<u>803 kg CO2 eq</u>***

Assessment results:

The incremental share of the connectivity in the carbon footprint of the service delivered by the device is calculated according to the following equation of **Appendix I**:

$$\frac{\Delta\mathrm{CF}_{sys}}{\mathrm{CF}_{device}^{\overline{conn}}} = \frac{\mathrm{CF}_{sys}^{conn} - CF_{sys}^{\overline{conn}}}{\mathrm{CF}_{device}^{\overline{conn}}}$$

where:

[63] The storage impact at the Datacenter does not account for any multiplier factor related to data duplications or other cloud-related additional overhead.

– $\mathrm{CF}_{device}^{\overline{conn}}$: stands for the carbon footprint of the non-connected version of the device;

– CF_{sys}^{conn} : stands for the carbon footprint of the product system featuring the connected device;

– $CF_{sys}^{\overline{conn}}$: stands for the carbon footprint of the product system in alternative scenario where the device would not have been connected;

– ΔCF_{sys}: stands for the additional carbon footprint of the connectivity, i.e. the incremental emissions attributable to the communication capabilities of the device.

$$\frac{\Delta \mathrm{CF}_{sys}}{\mathrm{CF}_{device}^{\overline{conn}}} = \frac{803 - 416}{416} = 0{,}93$$

For the case of a connected surveillance camera and subject to the considered assumptions, the screening assessment leads to an incremental share of: **93 %**

NOTE – The assessment considers an attributional LCA approach and focuses only on first order effects. As a screening assessment approach, a sensitivity analysis may complement the assessment to challenge the influence of assumptions and parameters.

I. 5 Guidance on the assessment of hardware/software-related obsolescence considerations

This section provides guidance for assessing hardware and software-related obsolescence considerations (Stage 3 of the heuristic). The methodology, based on [ITU-T L.1023] and some selected EN 4555x series standards, constructs a scoring system to approach each criterion for characterizing hardware and software obsolescence.

NOTE – The methodology does not define an aggregation method for the attributed scores for each criterion defined below, the practitioner can devise an appropriate aggregation method (for instance where all criteria are equivalent, the practitioner may take the simple average, otherwise, a weighted average could be preferred).

For Software-related obsolescence criteria:

- **Criteria:** Availability of software and firmware- connectivity related updates and upgrades. Updates and upgrades encompass operating system updates dealing with the connectivity and security patches.

Score	Requirement for fulfillment
1	Software and firmware updates and upgrades availability can be categorized as long-term. Referring to [EN 45554] standard, this corresponds to Class A product, i.e. for a duration time that reflects the expected maximum useful life of the product or beyond.
2	Software and firmware updates and upgrades availability can be categorized as mid-term. Referring to [EN 45554] standard, this corresponds to Class B product, i.e. for a duration time that reflects the expected average useful life of the product.
3	Software and firmware updates and upgrades availability can be categorized as short-term. Referring to [EN 45554] standard, this corresponds to Class C product, i.e. for a duration time that reflects the time of sale of the product.
4	No information on duration of availability is provided on software or firmware upgrades and updates. Referring to [EN 45554] standard, this corresponds to Class D product.

For Hardware-related obsolescence criteria:

- **Criteria:** Disassembly depth (number of steps necessary to reach connectivity-related parts without damaging the product[64]) [ITU L.1023]

Score	Requirement for fulfillment
1	All targeted parts for repair operations are accessible after one or two disassembly steps.
2	All targeted parts for repair operations are accessible after three or four disassembly steps.
3	All targeted parts for repair operations are accessible after five or six disassembly steps.
4	All targeted parts for repair operations are accessible after more than six disassembly steps.

- **Criteria:** Types of fasteners and connectors, and tools used to disassemble the connectivity-related parts inspired from [ITU L.1023]

Score	Requirement for fulfillment
1	- Fasteners and connectors associated to the connectivity part can be categorized as reusable (Class A, i.e., an original fastening system that can be completely re-used and or any element of the fastening system that cannot be reused are supplied with the new part for repair, reuse or upgrade process [EN 45554]). - Tools: no tools are needed or only basic tools (Classes A to B as defined in [EN 45554])
2	- Fasteners and connectors associated to the connectivity part can be categorized as removable (Class B, i.e., an original fastening system is not reusable, but can be removed without causing damage or leaving residue which prevents reassembly (in case of repair or upgrade) or re-use of the removed part (in case of reuse) for a repair, reuse or upgrade process [EN 45554]). - Tools: Product specific tools are needed (Classes C as defined in [EN 45554])
3	- Fasteners and connectors associated to the connectivity part can be categorized as removable or reusable - Tools: Proprietary (commercially available) tools are needed (Classes D as defined in [EN 45554])
4	- Fasteners and connectors associated to the connectivity part can be categorized as neither removable nor reusable, i.e. fasteners and connecters are permanent (e.g. use of glues and welds for permanent fixings) (Class C as per [EN 45554]) - Tools: Proprietary (either commercially available or not) tools are needed (Classes D as defined in [EN 45554])

NOTE – In line with the approach proposed by JRC's Report on Product Reparability Scoring System[65], the assessment of type of fasteners and connectors (respectively of type of tools) is based on the disassembly process to remove the specific targeted part, starting from the previous part in disassembly sequence already removed. In case different types of fasteners (respectively different type of tools) are encountered in the disassembly of parts, the worst score should be considered.

I. 6 Possible approaches for implementing the intermediate test

Highlighting whether "Connectivity" is a decisive criterion for acquiring (from a consumer point of view) or selling (from a provider point of view) a connected product may be challenging. As there might be no compelling and self-sufficient single approach, the practitioner may combine different approaches, thus the outcome of the test could be derived through a set of concordance items of evidence.

Possible approaches may include:

- The use of Quality Function Deployment (QFD) which helps transforming customer needs ("Voice of customer") into engineering characteristics of a product or service, prioritizing each function/attribute of the product into development targets for the

[64] The counting of the steps for each part, starts from the product fully assembled.

[65] Product Reparability Scoring System: Specific application to smartphone and slate tablets, JRC (2022) https://publications.jrc.ec.europa.eu/repository/bitstream/JRC128672/JRC128672_01.pdf

product. Through QFD, a practitioner may be able to identify how "Connectivity" is "highly relevant" for an average user of the product. QFD is generally derived from various means including consumer surveys, focus groups, market analysis or field reports.

- Market research and surveys on consumers' purchase willingness of connected products vs their equivalent non-connected products (intent to purchase).
- Market research or field reports unveiling the take up rate of connected products in the market such as the JRC Report on the State of the art of Smart Home and appliances in the EU market[66].
- Other items of evidence showing how connectivity is a key feature or a marginal feature when purchasing/putting the product on the market, collected from market research or provider's feedback. These may include for instance feedback from manufacturers of smart appliances on the ratio of appliances being effectively and constantly connected[67]. Appliances connected to the Internet at their initial setting but ending up disconnected[68] would not be considered as "constantly" connected.
- …

To investigate how impactful "connectivity" would be in the decision acquisition process of a customer, it may be more relevant to focus the analysis on the functionalities enabled through "connectivity" as illustrated in Figure 27 since a customer would acquire a product for its functionalities rather than its design parameters, components or build-in capabilities.

Connectivity enabled functionalities may include: enabling power savings through appliance remote control, extending the appliance lifetime through preventive maintenance and OTA update, unlocking new features through OTA upgrade etc. At this stage of the heuristic (stage 2 and 3), Connectivity-enabled functionalities generally deal with performance features and excitement features[69] of the product.

[66] Serrenho, T., Bertoldi, P., "Smart home and appliances: State of the art - Energy, Communications, Protocols, Standards", EUR 29750 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-03657-9, doi:10.2760/453301, JRC113988

[67] For instance, according to LG, smart appliances being effectively and constantly connected represent 40%-45% of its sold appliances: https://arstechnica.com/gadgets/2023/01/half-of-smart-appliances-remain-disconnected-from-internet-makers-lament/

[68] This may happen for different reasons because of a customer changing their service provider, or router or even their password causing the device to disconnect.

[69] Performance features and excitement features are defined in the Kano framework of product quality relating product functions with customer satisfaction, they refer to specific types of customer requirements of a new products (www.Kanomodel.com)

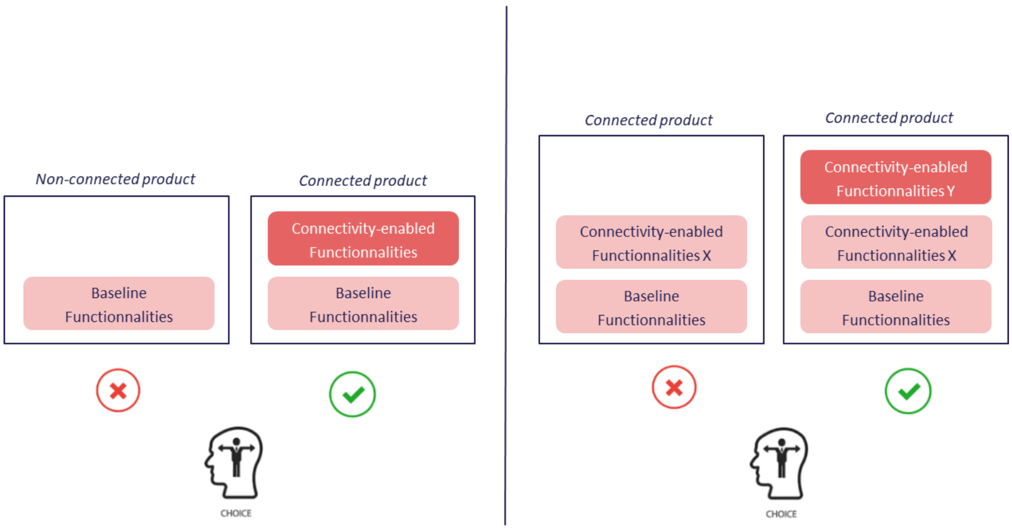

Figure 27 - Illustration of the two situations where "connectivity" drives the customer's choice: comparing a connected product vs a non-connected product; comparing two connected products

It may be challenging to derive very conclusive analysis when working with such approaches as there may possible bias of interpretations, e.g. an observed increase in sales volume of connected fridge during a given period does not systematically entail that the connectivity would have been the decisive criteria for acquiring those connected fridge, other reasons could be a signification rarefaction of the traditional fridge (because manufacturers do not produce them anymore) while the demand for fridges is still present or specific subsidiary policies enticing the purchase of connected fridges.

According to the outcome of a survey conducted by CREDOC on the French market from 2019 to 2022 [CREDOC – 2022], an increase is reported in the adoption and the intent of acquiring connected devices related to smart health, security, smart appliance and smart home. However, it is not straightforward to derive systematic conclusion whether the connectivity or related functionalities are the decisive criteria for purchase.

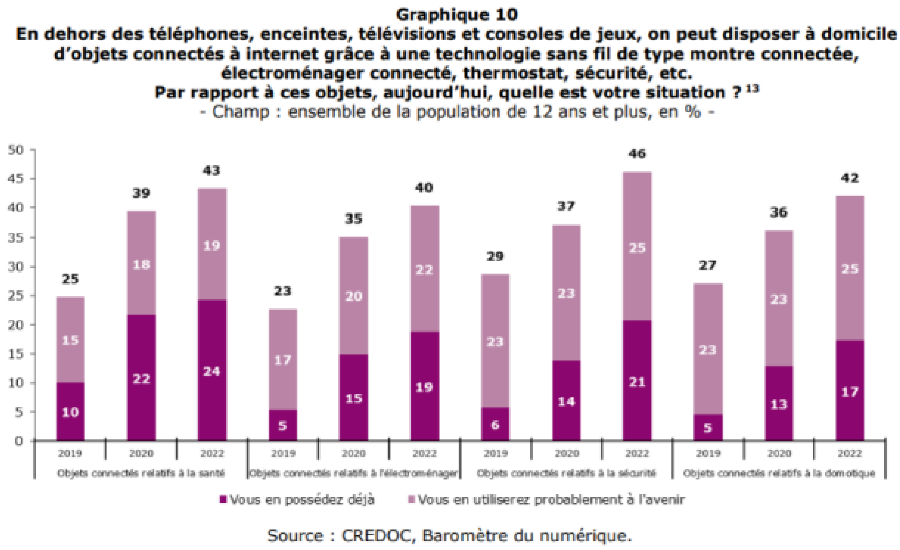

Figure 28 - Survey on IoT adoption in the French market (from [CREDOC - 2022])

In some cases, the purchase of a connected product is motivated by smart features other than the connectivity (e.g. a touch screen build-in on a smart fridge) while one may argue that "indirectly" Connectivity could be considered as a decisive criterion for purchase, simply because such smart features would not have existed in a smart device in the absence of build-in connectivity.

Ultimately, a conclusion drawn from a given geographical market could not be systematically transposed onto another market, the JRC Report on the State of the play of Smart Home appliances in the EU market shows differences in maturity level and adoption rate of connected devices between a selection of comparable EU countries although featuring the same development levels. The age of the consumer base and the socio-economic category may constitute another source of discrepancies when it comes to analyze the appeal potential of connected devices; for instance [CREDOC – 2022] reports a higher adoption rate of IoT devices within younger generations than older ones (and in particular, a steeper increase between 2020 and 2022 for the youngest (i.e. aged 12-17-year-old)).

Appendix II

An approach for connected products categorization and carbon allocation rules

(This Appendix is related to Section 4.3)

This Appendix aims at addressing the question of carbon accounting based on the different outcomes of the heuristic's decision tree and also how to extend the heuristic to handle all possible cases (IoT or not part of IoT) for the purpose of comprehensiveness, while harmonizing with the OECD Digital Economy framework described in **Annex A**.

The rationale of this appendix is anchored onto the following principles:

- The approach does not challenge product categorization by the international standard classification frameworks (ISIC, CPC, …).
- Carbon footprint of device belonging to ICT is allocated to ICT, carbon footprint of device belonging to E&M is allocated to E&M.
- For the case of connected devices that does not clearly belong to these sectors (whether part of IoT or not), a carbon footprint allocation approach is defined that considers the spots where the information economy sector has a degree of influence.

II.1 Connected products categorization and heuristic extension

The aim of this section is to harmonize the heuristic with the OECD framework of Digital Economy (refer to **Annex A**). Aside of the current outcomes of the heuristic, a proposal is developed below to extend it under the paradigm of the [OECD – 2020] framework.

As described in **Annex A**, OECD recommended in 2020 a tiered and flexible approach for scoping activities within (or not) what it calls the "Digital Economy". Starting from this *economic activities-oriented* approach from OECD, this appendix adapts it to fit a product categorization which keeps the same partition of the Economy but through a *product-oriented approach* while focusing on "Connectivity" as among the main pillars of the ICT sector/product definition, as below:

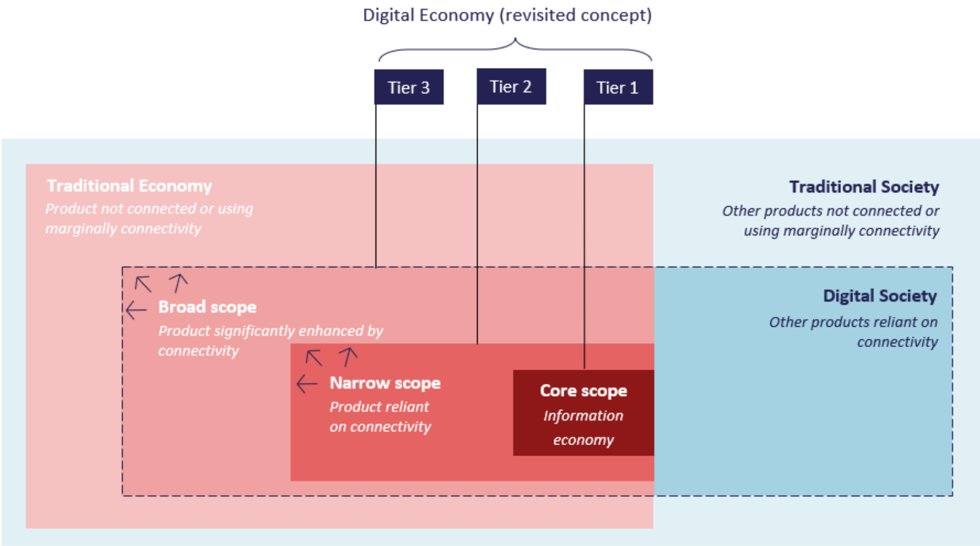

Figure 29 - Categorization of connected products inspired by OECD framework for the Digital Economy [OECD- 2020]

Based on this approach, we seek to harmonize the heuristic's outcomes with the partition mentioned in Figure 29.

II.1.1 ICT – native good

When the heuristic leads to "ICT-native good", the product can be scoped in the ICT sector which is within the Information economy. Hence, one can categorize "ICT-native good" outcomes in the product category "core scope" (Tier 1 in Figure 29)

II.1.2 E&M Good

Similarly, if the heuristic leads to "E&M good", the product can consequently be scope in the E&M sector which is part of Information Economy. That is, the product can be categorized in the "core scope" (Tier 1 in Figure 29)

II.1.3 ICT-enabled good

When the heuristic leads to "ICT-enabled good", it implies that the product is not ICT nor E&M, at some stage of the heuristic at least one test was positive (to leave the tree and be categorized as "ICT-enabled good"). Thus, it is the role of connectivity and the reliance of the product on it that can induce the outcome "ICT-enabled good" for a product. Hence, one can categorize "ICT-enabled good" outcomes in the product category "narrow scope" (Tier 2 in Figure 29) as this kind of product is reliant on connectivity.

II.1.4 Non-ICT-enabled good

When the heuristic leads to the outcome "Non-ICT-enabled good" it implies two possibilities for the path which was followed along the tree:

- Option 1: The answer to the market test was "not likely" (for the connectivity to be the decisive criterion for buying/selling the product);

- Option 2: Except for the market test and once entered into the tree, every test was answered negatively

For these two cases, it implies that the connected product is not reliant on connectivity. Hence, one can categorize "Non-ICT-enabled good" outcomes in either the product category "Broad scope" or "Traditional economy" (i.e. Tier 3 or beyond as it won't be core or narrow scope).

Being able to categorize between "Broad scope" and "Traditional economy" means to understand if the product is significantly enhanced by connectivity or if the product is using connectivity as an additional and marginal feature as per Figure 29.

For that purpose, the heuristic could be extended with two additional tests (see the right part of the extended tree in Figure 32). The aim of those tests would be to investigate first if it relies or not on connectivity (i.e. test "X" already depicted in the tree) and if not, if connectivity enhances the functionalities of the product (test "Y"). The precise content of the test "Y" could be discussed within the committee members to meaningfully define it with more details.

NOTE – Test "X" is redundant for a product that falls under option 2 (as it already has passed through it) but it is necessary for a product falling under option 1 as it left the tree before stage 2 and 3.

II.1.5 Non IoT goods

When the heuristic leads to the outcome "Non-IoT good", it implies that the product is not part of the IoT (hence negative answer to the associated test).

For the purpose of categorizing this kind of device that may encompass a large variety of products: first of all, the product might be an E&M product hence we include an E&M test, in such a case, it is categorized within the core scope (Tier 1), otherwise, we need to go through the extended part of the tree in order to assess the influence of connectivity on its functionalities. Following the same reasoning and in order to stay harmonized with [OECD -2020] framework, if the product is "reliant on connectivity" (i.e. test "X" is positive), one can categorize this kind of device in the "narrow scope" (Tier 2). On the other hand, if the outcome is "not reliant on connectivity" (test "X" is negative), one can conduct the "Y" test in order to understand the role of connectivity in the product's functionalities, thus, it can be categorized in the "Broad scope" or in the "Traditional economy" (Tier 3 or beyond).

II.2 Carbon allocation rules

Based on the harmonization conducted between the outcomes of the heuristic plus its proposed extension and [OECD -2020] framework for scoping digital Economy, the current section discusses some elements on ways to allocate the carbon footprint of a product to the Information Economy sector (Tier 1) depending on its outcome and thus, its product category.

If the product falls in the "core scope" category (Tier 1), it belongs to the "Information economy" and **one can attribute its whole carbon footprint to the Information Economy sector**.

If the product falls in the "Traditional economy" category (beyond Tier 3), it means that it is using connectivity as an additional and marginal feature. Thus, connectivity has zero or low influence on its functionalities. Hence, **proposal is to account none of its carbon footprint to the Information economy sector**.

If the product falls in the "Broad scope" category (Tier 3), it means that it is significantly enhanced by connectivity but not reliant on it. Hence, **proposal is to allocate to the Information Economy's carbon footprint only the share of connectivity in the product's carbon footprint.**

If the product falls in the "Narrow scope" category (Tier 2), it means that it is reliant on connectivity. Two possible situations may occur:

- The product has been categorized as an "ICT enabled" product and it is an IoT product ("ICT enabled")
- The product has been categorized as "product reliant on connectivity" (but it's not an IoT product)

To consider the difference between the 2 situations, proposal is made to precise the content of the narrow scope (tier 2) with a sub-category within it. That is, a tier 1+ which would be the extension of the core scope (tier 1) for ICT enabled products. On the contrary, "products reliant on connectivity" would fall in Tier 2 but not within Tier 1+ (refer to Figure 30).

In addition, being categorized with Tier 2 or Tier 1+ raises the question of allocating the whole carbon footprint of such product to Information economy. However, the degree of control of Information Economy organizations on the product may vary and not be sufficient to engage in an effective decarbonization strategy of the later. **The bottom line would be to consider to allocate to the Information Economy only the share of the connectivity in the product's carbon footprint** (Figure 31).

The choice of a full allocation could be supported by a set of concordance items of evidence, for example:

- Long-run financial indicators showing the importance of connectivity in the concerned business (e.g. one could imagine some additional tests or considerations to objectify this question such as R&D expenses in ICT sector, share of annual revenues / value added in the product attributable to connectivity, etc.)
- Leverage on existing concepts in the GHG protocol standard and mimic the "control approach" (financial or operational or equity share approaches) which provides guidance on how to account for the impact of activities when they are outside of the original organization's boundaries (i.e. ICT)

This research question is an open question and constitutes an overture of the workflow and a possible supplementary work for future workflows.

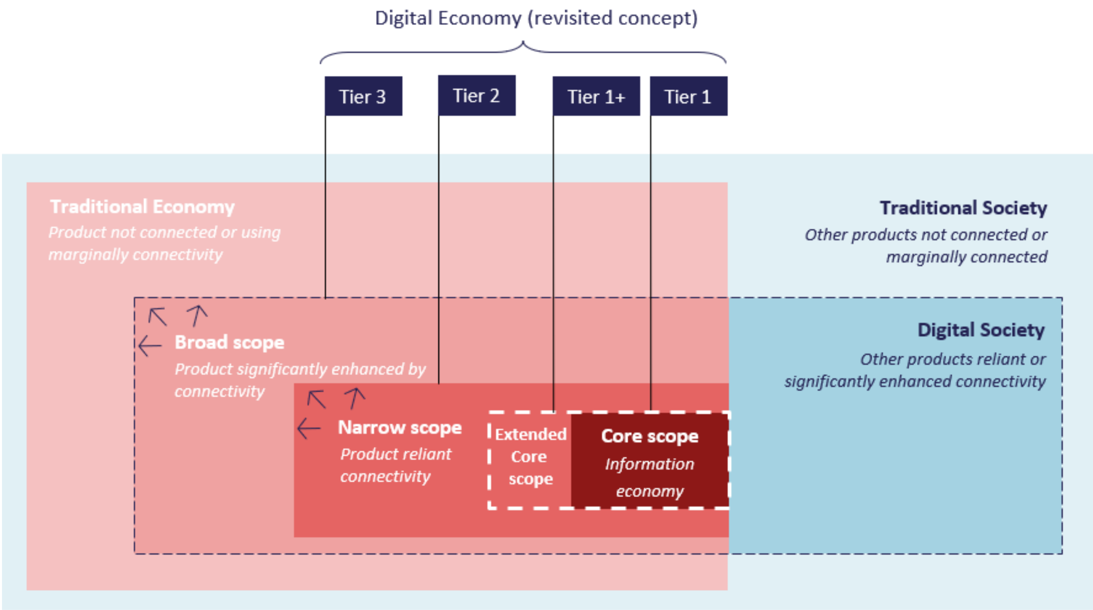

Figure 30- Subdivision of the narrow scope (Tier 2)

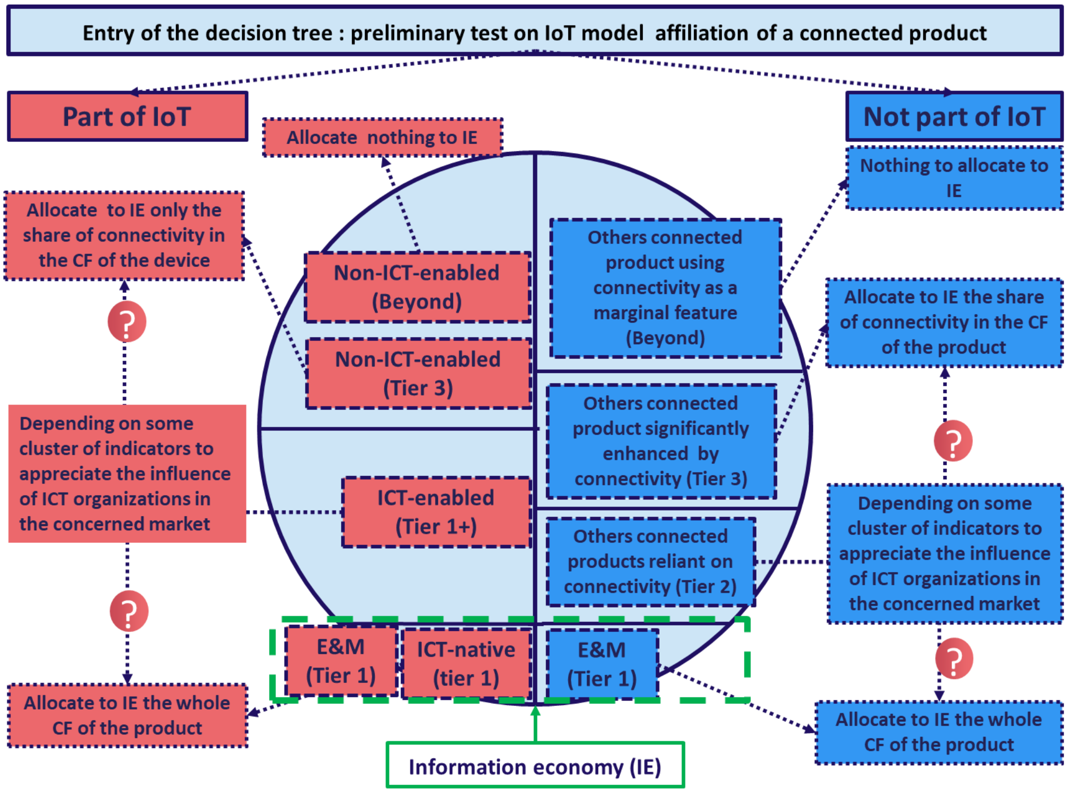

Figure 31- Cartography of connected devices clustering and carbon allocation rules proposal

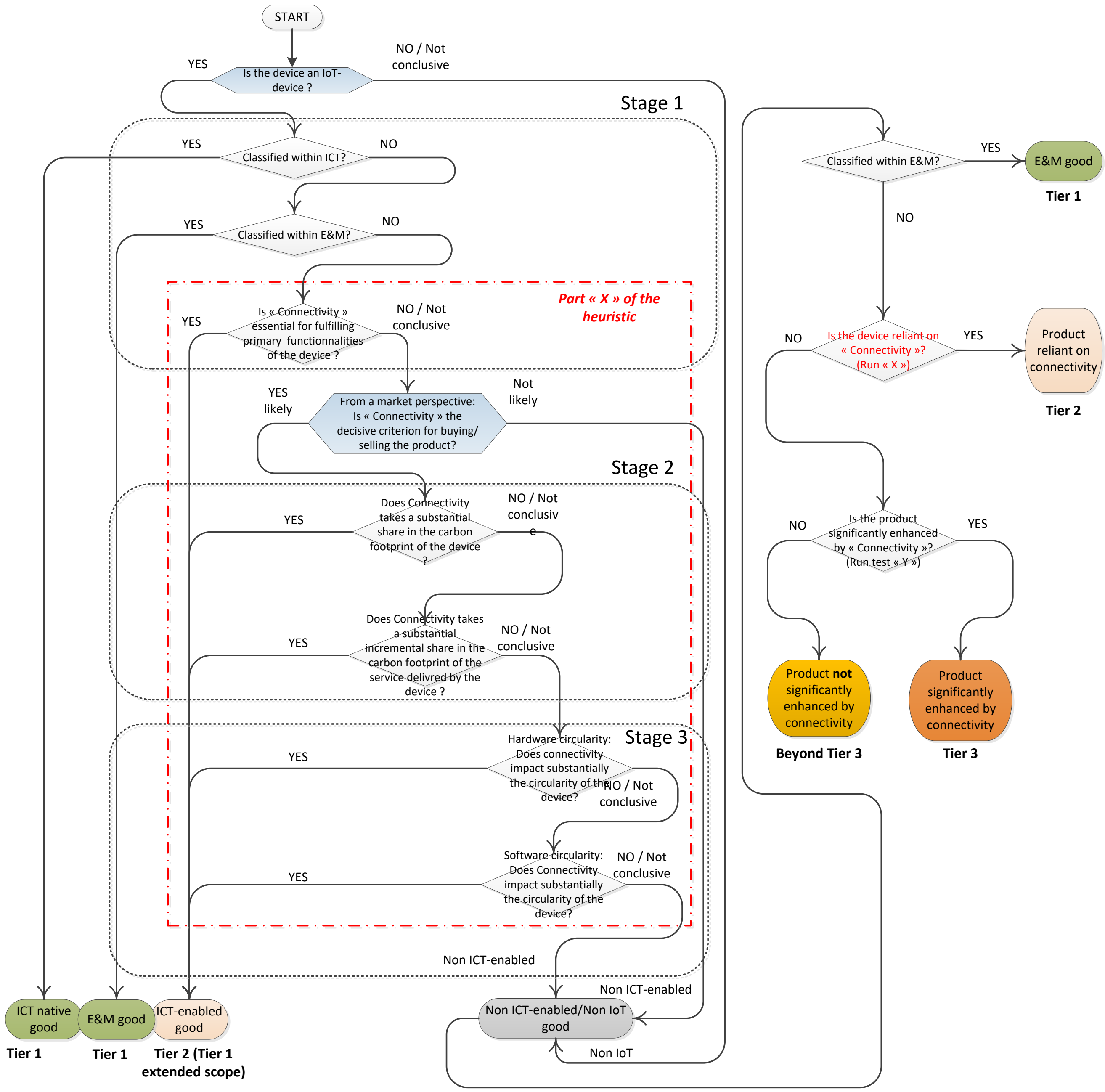

Figure 32- Extended decision tree

Appendix III

Examples of implementation

(This Appendix is related to Section 4.2 and Section 4.3)

This appendix provides examples of implementation of the concepts developed in the core part of the Report and related annexes, in particular:

- Examples of implementation of the heuristic;
- Examples of concrete use cases implementing the carbon allocation rule approach developed in **Appendix II**;
- Examples of system of connected products reflecting the guidance provided in **Annex C**.

III.1 Examples of implementation of the heuristic

The heuristic's implementation proposed below aims to be used as further guidance for an LCA practitioner. It does not intend to have a normative range but rather to illustrate practically the different theoretical outcomes of the heuristic's decision tree depicted in this report. Between two generic devices small variation in the conception of the product or context of usage may lead to different outcomes when implementing the heuristic thus, the practitioner is highly encouraged to define the analyzed product and its usage context as precisely as possible.

The outcome of the heuristic, as illustrated by the examples addressed below, focuses on qualifying the product as: ICT-native product, ICT enabled product or not part of the IoT. This Section does not address how to allocate the carbon impact of the product under study. Section II of this appendix provides examples on how to implement carbon allocation rules.

Table 17 illustrates the implementation of the heuristic at its different tests/stages by considering a set of 15 connected devices as illustrated in Figure 33:

(1) Pet/ankle/quarantine/dementia tracker;

(2) A cashless vending machine: a vending machine where transactions are cashless, Connectivity enables the transaction process.

(3) Connected Nicotine spray for smokers with its smartphone monitoring mobile application. The user uses the spray in its mouth when the will to smoke kicks in. The spray connects to the smartphone which records the use through the application. The progress to quit smoking and usage frequency are then, available through the application. This example considers a unique nicotine dose by use and not real time recalibrating related to the frequency of use.

(4) Connected IP camera with build-in memory/video storage capabilities. The considered example is a security camera installed within a train, a platform, etc. The recording content can be transmitted at will.

(5) Connected car for infotainment services. The car is equipped with connectivity capabilities to serve infotainment purposes (radio, music download, GPS, local Wi-Fi hotspot for internet access for passengers).

(6) Coins only vending machine with remote stock management capability.

(7) Smart alarm system: Three variants of smart alarm systems (of different complexity levels) are considered: An isolated smoke detector (a simple alarm system); A set of sensors connected to/controlled via a smartphone (a system with medium complexity); A home security system (sophisticated alarm system).

(8) An aerial unmanned drone equipped with a camera for photos and video, using for its control, alarms and data communications a direct point to point wireless connection between the drone and its remote control.

(9) An aerial unmanned drone equipped with a camera for photos and video, using for its control, alarms and data communications a 5G mobile network.

(10) Internet-connected door lock using Wi-Fi or cellular connectivity to lock or unlock a door.

(11) A key finder/tracker (ex. "Airtag" tracker for Apple, "Tile" tracker for android devices etc.): a handy connected device using Bluetooth to help keep track and locate the item it is attached to.

(12) Non-Internet connected smart door lock using NFC and Bluetooth wireless communication to lock or unlock a door.

(13) Remote door closer equipped with an UWB chip to remotely control a mechanical arm in charge of closing/opening the door which the arm is attached to.

(14) Automatic boarding gantry station (e.g. in a railway/metro station, in parking system) equipped with an NFC reader to let in/refuse the access to a user after showing its smart card/tag.

(15) A Zigbee-connected window sensor equipped with an acoustical peep capability that can detect the opening and closing of a window and submits its state via Zigbee network to a Zigbee hub. This example is taken from [ETSI EN 303.645].

The process starts by identifying the primary functions and the primary functionalities of the connected device under study, the practitioner then proceeds with the different stages of the heuristic by considering the extended approach (going through all stages of the heuristic, but tests of Stage 3 were not performed as they are optional).

As this is used only for illustrative purpose, the assessment developed below for tests of Stage 2 remains qualitative. When the connected product has been identified as an IoT product, its type according to Section 2.1.2 is also mentioned.

NOTE – The table below focuses only on the primary functionality of the device and does not explicit the critical functionality.

Pet/ankle/quarantine tracker	Cashless vending machine	Connected nicotine spray for smokers	Connected camera with build-in storage	Connected car for infotainment services
				
Coins-only vending machine with remote stock management	Smart alarm system	Aerial unmanned drone using point-to-point communication	Aerial unmanned drone using 5G mobile network	Internet connected smart lock
				
Key finder/tracker	Non Internet connected Smart lock	Remote door closer	Automatic boarding gantry station	Zigbee window sensor
				

Figure 33- Illustration of the selected use cases

Table 17 - Analysis of the implementation of the heuristic through selected use cases

Connected device	Pet/ankle/quarantine cellular tracker	Cashless Vending machine	Connected car for In-Vehicle Infotainment (IVI) services
Primary functionality	To monitor the location of the pet / the individual (primary function)	To vend and distribute a snack: - To distribute food (primary function) - To operate transaction	To transport passengers safely from a point A to a point B: - To move from point A to point B (primary function) - To adapt and correct in real-time the trajectory between point A and point B in order to guarantee safe driving
Architecture of the solution	The tracker contains a tiny GNSS (Global Navigation Satellite System like GPS) chip, that determines the position. A transmitter also located in the device then sends this location data through the cellular network to an application server. Algorithms in the application server can increase the accuracy of the position by using Wi-Fi and cellular signals. With a connection to the application server, the location of the pet / the individual can be monitored	The vending machine is equipped with a bank card chip reader. The chip reader is connected through a fixed or mobile access network to internet and communicates with a server in a bank or a payment platform in charge of clearing the transaction with the bank.	The car is equipped with an infotainment system where the connectivity is used by the infotainment system for multimedia support, GPS assisted navigation and analog/digital tuning for multi-standard radio reception. Specifically, the In-vehicle infotainment system provides: - A transfer of audio and video content to display screens, speakers and headphones via Bluetooth. Through this connectivity, the system enables advanced features like hand free calling, call log visibility and integrating drivers/passengers' smartphones within the car infotainment. - GPS assisted optimized navigation: Connects with GNSS and downloads information from a city traffic service platform about the real-time status of the city traffic and the roads to process the overall information and recommends to the driver the best path to follow from A to B. - Analog and digital tuning: Enables scanning for available radio stations and reception of the broadcasted target channel - Downloading audio or video content streams: With its integrated native App, the infotainment system connects through cellular to an audio or video service platform to download the chosen content.
Preliminary test	Yes, the device is directly connected through a cellular network and the relying network infrastructure. The object includes the different layers defined in the IoT reference model including the application part. An application server is	Yes, the transaction to be validated by the banking system, needs to be transmitted through a communication network (where the vending machine is uniquely identified by the platform payment server). All relevant items of the IoT reference layers are identified including:	Yes, as the services provided by the IVI system comply with the IoT reference model.

	connected to an IP networks, and interacts with the IoT device application.	- The payment application layer embedded within the cashless payment module of the vending machine and the payment application layer hosted at the payment platform server. - The cellular or fixed IP communication network connecting the vending machine with the payment platform server.	
Type of IoT device	General device; LPHC device	General device; HPHC device	General device; HPHC
Stage 1: test 1/test 2	Yes, the device is primarily intended to be used for information processing and communication purposes (including transmission and display).	No, because the device is not primarily intended to be used for information processing and communication purposes.	No, because the device is not primarily intended to be used for communication purposes
Stage 1: test 3	N/A	Yes, because connectivity is necessary to fulfill the primary functionality which is vending snack (payment which needs connectivity a function part of the minimum set of functions to fulfill its main purpose)	No, because the car is connected for infotainment services and connectivity is not essential to fulfill its primary functionality.
Intermediate test	N/A	N/A	Not likely because smartphone penetration on the market is now very high and this good can be a substitute for infotainment services (this conclusion could be different if this test was conducted 20 years ago)
Stage 2: test 1	N/A	N/A	N/A
Stage 2: test 2	N/A	N/A	N/A
Stage 3: test 1	N/A	N/A	N/A
Stage 3: test 2	N/A	N/A	N/A
Outcome of the heuristic	The connected product is an ICT-native product.	The connected product is ICT-enabled product.	The connected product is not an ICT-enabled product.

Connected device	**Connected nicotine spray for smokers (+ smartphone monitoring app)**	**Connected camera with build-in storage (e.g. inside a train)**	**Coins-only Vending machine with remote stock management**
Primary functionality	To support relieving addiction for smokers by nicotine inhalation through a scheduled program: - To inhale nicotine (primary function) - To record taken doses - To monitor progress through app	To film and record images in a build-in memory component: - To film the scene (primary function) - To record images in a build-in memory	To vend and distribute a snack: - To distribute food (primary function) - To operate transaction
Architecture of the solution	The spray connects to the smartphone via NFC which records the use through the application (the progress to quit smoking and usage frequency are then, available through the application). This example considers a unique nicotine dose by use and not real time recalibrating related to the frequency of use. The user can compare the performance of its usage compared	In-train connected camera are mounted at several locations within the train to record the inner environment of the train. Cameras film the scene along the trip and record the images within its build-in memory component. Once the train arrives at the railway station, the fleet of camera connects through available 4G/5G cellular or Wi-Fi networks to a server in the Railway	The vending machine is connected to a service platform through a wireline (FTTH or xDSL) or a wireless communication network (e.g. cellular radio) where a server maintains the real time status of the items stored in the vending machine and their expiry date, this would help the technician schedule efficiently its intervention to refill the stock when exhausted or change items.

	with the ideal frequency of usage, the latter was set up according to the user profile and its objective.	Information System Control Center to transfer the recorded footages where they will be processed. The server interacts with the fleet of camera through APIs to retrieve the images in a pull mode and eventually other kinds of interaction (update status of the camera …)	
Preliminary test	This is not an IoT device as this type of interaction between the NFC terminal (the smartphone) and the spray connected with NFC could not be considered as an interaction at the application layer. In addition, the IoT DCE Reference model requirements are not fulfilled.	The camera is an IoT device: The data transfer between the connected Camera and the server is carried out through a communication network (cellular or Wifi); the camera application and the server application interact together through a set of APIs as part of the application layer.	Yes, the vending machine is connected to an application server via the cellular or fixed network. The object includes the different layers defined in the IoT reference model. The connected device is an IoT product.
Type of IoT device	N/A	General device, HPHC device	General device, HPHC device
Stage 1: test 1/test 2	N/A	No, because the device is not primarily intended to be used for communication purposes	No, because the device is not primarily intended to be used for communication purposes
Stage 1: test 3	N/A	No, because if the connected camera goes offline, the recording can still be done (build-in recording capabilities)	No, because primary functionality can still be fulfilled even when the vending machine goes permanently offline and stock management is not part of the minimum set of functions to fulfill the primary functionality
Intermediate test	N/A	It is likely that connectivity is one of the decisive criteria to buy the product especially for a huge fleet of camera.	It is likely that a stock management capability (enabled through connectivity) represents a decisive criterion for a service provider aiming at optimizing the supply and refill of the vending machine.
Stage 2: test 1	N/A	It is not likely that the connectivity part may represent a significant share of the CF of the device	It is unlikely that the connectivity part may represent a substantial share of the CF of the vending machine (big appliance)
Stage 2: test 2	N/A	The incremental share of the connectivity may be substantial compared to the CF of the service delivered by the connected camera, this is because of the high volume of data generated by the product and to be handled by the backyard digital infrastructure.	It is unlikely that the connectivity part may represent a substantial incremental share of the CF of the service delivered by vending machine (associated mobilization of the digital infrastructure supporting the service is low (low volume data))
Stage 3: test 1	N/A	N/A	Implementation dependent
Stage 3: test 2	N/A	N/A	Implementation dependent
Outcome of the heuristic	The connected product is not part of the IoT.	The connected product is an ICT-enabled product.	The connected product is not an ICT-enabled product.

Connected device	**An aerial unmanned drone equipped with a camera for photos and video, using for its control, alarms and data communications a direct point to point wireless connection between the drone and its remote control.**	**An aerial unmanned drone equipped with a camera for photos and video, using for its control, alarms and data communications a 5G mobile network**

Primary functionality	To record video through from a mobile position in the three dimensions that can be remotely chosen with an on-ground control console: - To fly - To send command orders to the drone - To record filmed footages and taken pictures - To send alarms to the user	To record video through from a mobile position in the three dimensions that can be remotely chosen with an on-ground control console: - To fly - To send command orders to the drone - To record filmed footages and taken pictures - To send alarms to the user
Architecture of the solution	An aerial unmanned drone equipped with a camera for photos and video, using for its control, alarms and data communications a direct point to point wireless connection between the drone and its remote control.	The aerial unmanned drone equipped with a camera for photos and video, using for its control, alarms and data communications a 5G mobile network to communicate with a server platform. The user connects to the server platform to control and to pilot the drone thanks to the interaction at the application layer between the drone and the server.
Preliminary test	No, there is no connectivity-based identified network as the drone is controlled remotely with point-to-point communication. The drone and its remote control are part of an isolated system. This drone is not part of IoT.	The object includes the different layers defined in the IoT reference model: There is clearly a communication network (5G cellular) and an IoT network infrastructure. The drone is clearly identified. The object includes the different layers defined in the IoT reference model. This drone is part of IoT.
Type of IoT device	N/A	General device, HPHC device
Stage 1: test 1/test 2	N/A	No, because the device is not primarily intended to be used for communication purposes
Stage 1: test 3	N/A	Yes, because if the connected drone goes offline there is no possibility to send command orders
Intermediate test	N/A	N/A
Stage 2: test 1	N/A	N/A
Stage 2: test 2	N/A	N/A
Stage 3: test 1	N/A	N/A
Stage 3: test 2	N/A	N/A
Outcome of the heuristic	The connected product is not part of the IoT.	The connected product is an ICT-enabled product.

Connected device	**Smart alarm system: An isolated smoke detector**	**Smart alarm system: sensors connected to a smartphone**	**Smart alarm system: A Home security system**
Primary functionality	To detect changes in the target environment and emit an alarm signal - To monitor variations on a set of variables (temperature, smoke, motion, glass break, etc.) in the target environment (primary function) - To analyze and decide the relevance of monitored variations - To emit an alarm signal	To detect changes in the target environment and send alert: - To monitor variations on a set of variables (temperature, smoke, motion, glass break, etc.) in the target environment (primary function) - To analyze and decide the relevance of monitored variations - To send alert notifications when relevant	To detect changes in the target environment and send alert: - To monitor variations on a set of variables (temperature, smoke, motion, glass break, etc.) in the target environment (primary function) - To analyze and decide the relevance of monitored variations - To send alert notifications when relevant

Architecture of the solution	The solution consists of an isolated sensor (smoke detector) emitting an alarm signal when relevant. The product is not connected at all.	Different sensors (air quality, humidity, temperature) connected via Bluetooth to a smartphone/mounted tablet. The smartphone/mounted tablet manages the connected sensors, the latter expose their respective capabilities to the smartphone/mounted tablet. The smartphone/mounted tablet is able to alert the user either visually (displaying a specific message on the device's screen) or by emitting an alarm signal.	The home security system includes a gateway connected locally to motion and intruder detectors, smoke detector, sirens, CCTV using wireless protocols (e.g. Bluetooth, Wi-Fi …). The gateway is connected to fixed access network (e.g. FTTH) and/or a cellular network (e.g. 4G). An application server is connected to the gateway through a communication layer network (IP) to process the notifications and trigger an emergency call/send a notification to the relevant external entity (the user's smartphone, the police call center or the security agency service provider).
Preliminary test	The product is not an IoT product.	Sensors are connected to the smartphone/mounted tablet via local area network (here Bluetooth). The smartphone/tablet acts as an IoT Device Capability Exposure (DCE) dynamically discovering, connecting and accessing to sensors in an IoT area network. As an IoT DCE, the smartphone/tablet exposes capabilities of the connected sensors to upper IoT applications natively hosted in the DCE device. The solution architecture is in-line with the reference architecture of the IoT DCE (which is in line with IoT reference model). In this example, the IoT application in the DCE device subscribes and accesses to the IoT device capabilities in a local permission mode as specified in ITU L.4115 Recommendation, thus there is no need to get through a communication network beyond the local IoT area network. The connected sensors in this solution are considered as IoT devices.	All the different layers of the IoT reference model are identified. The solution is an IoT solution and the sensors are IoT devices (the gateway is an IoT gateway).
Type of IoT device	N/A	Sensing/actuating device; LPLC device	Sensing/actuating device; LPLC device
Stage 1: test 1/test 2	N/A	Connected sensors are not primarily intended to be used or enable information processing and communication purposes.	Connected sensors are not primarily intended to be used or enable information processing and communication purposes.
Stage 1: test 3	N/A	The primary functionality could not be fulfilled if the sensors went offline.	The primary functionality could not be fulfilled if the sensors went offline.
Intermediate test	N/A	N/A	N/A
Stage 2: test 1	N/A	N/A	N/A
Stage 2: test 2	N/A	N/A	N/A
Stage 3: test 1	N/A	N/A	N/A
Stage 3: test 2	N/A	N/A	N/A

Outcome of the heuristic	The connected product is not an IoT product.	The connected product is an ICT-enabled product.	The connected product is an ICT-enabled product.

Connected device	**Key finder/tracker**	**Non-internet connected smart lock**	**Remote door closer**
Primary functionality	To monitor the location of the pet / the individual (primary functionality): - To transmit its Bluetooth signal to a nearby recognized device - The nearby recognized device determines the relative position of the tracker (based on the Bluetooth signal strength) - The nearby recognized device relays this information and its own position to the service platform which determines the exact absolute location of the tracker (primary function) - The service platform sent it back to the user's device which indicates the tracker location through a specific application.	To lock/unlock remotely (a door, a window …): - To read and authenticate the code transmitted the application installed on the smartphone (using Bluetooth) and optionally by an NFC smart key (using NFC). - To lock or unlock the access once the code is authenticated (primary function).	To close/open the door remotely (primary functionality): - To activate the sensor-equipped motorized arm through a control signal from a paired remote controller using a low frequency radio signal. - To open or close the door using the activated and sensor-equipped motorized arm attached to the door (primary function).
Architecture of the solution	The tracker emits a Bluetooth signal (UWB) that connects to any nearby recognized/registered device within a specific range (ex. for the case of Airtag, any nearby iPhone or other Apple device in the "Find My" network within about 10 meters), the tracker location is triangulated based on the strength of the Bluetooth signal received by the nearby device; the latter sends the tracker location, through the Internet, to a cloud service platform (for the case of Airtag, it is the iCloud). The user connects to a specific application displaying the location of the tracker.	The Smart Lock is inherently not connected to the Internet, but equipped with a Bluetooth chip and an (active) NFC chip. The opening/closing is done close to the door via secure, fully encrypted Bluetooth communication with a smartphone (using the mobile application), or via provided (passive) NFC Smart Keys (the smart Lock acts as a Read/Writer operation mode). For the first utilization of the system, the NFC smart key attached code need to be added into the code portfolio maintained by the application. Upon successful pairing between the application and the smart lock, the NFC smart key could be recognized by the smart lock and is ready for use. The application enables also to de-activate a given smart key if the latter has been stolen or lost.	The connected product is composed of a sensor-equipped motorized arm, that can be mounted onto the door, attached to a processing unit controlling its operation. The processing unit is equipped with a build-in 433MHz receiver and an antenna to be able to pair with a pad hand-held remote controller using P2P RF communication. The wireless remote control transmits a ciphered coded signal, decoded and interpreted by the processing unit enabling to open and close the door.
Preliminary test	Yes; the tracker is an IoT device, using an IoT local network (Bluetooth between the tracker and the nearby device) and a WAN communication network (Internet connection to the Cloud) and a service platform. An application service is identified both on the service platform (iCloud) and on the user's device. The user's device acts as a DCE	- There is a communication network between the smart lock and the smartphone using a local IoT network (Bluetooth). - There is an IoT device application (at the smart lock) and an IoT application at the smartphone interacting together as part of the application layer of the IoT solution.	Although there is a local area network (P2P radio communication between the build-in 433MHz receiver and the remote control), there is no interaction identified at the application layer between the remote control and the processing unit of the remote door closer. This is not an IoT device (NOTE 1).

	device. The solution is consistent with the IoT DCE reference model defined in ITU Y.4115.	This is an IoT device.	
Type of IoT device	General device, LPLC device	Sensing/actuating device, LPLC device	N/A
Stage 1: test 1/test 2	The device is neither an ICT product nor an E&M product	The device is neither an ICT product nor an E&M product	N/A
Stage 1: test 3	Yes; because without connectivity the tracker could not be detected by a nearby device.	Yes, because if the smart lock goes permanently offline (no Bluetooth connection), the smart lock is unable to fulfill its primary functionality.	N/A
Intermediate test	N/A	N/A	N/A
Stage 2: test 1	N/A	N/A	N/A
Stage 2: test 2	N/A	N/A	N/A
Stage 3: test 1	N/A	N/A	N/A
Stage 3: test 2	N/A	N/A	N/A
Outcome of the heuristic	The connected product is an ICT-enabled device.	The connected product is an ICT-enabled device.	The connected product is not an IoT product.
NOTE 1 – For some advanced variants of a remote door closer, the system is equipped with a cellular connectivity to be able to open/close/lock the door using an application installed on a smartphone/tablet. In this case, the device would be qualified as an IoT device.			

Connected device	**Internet connected smart lock**	**Automatic boarding gantry station (e.g. in a railway/metro station, in parking system)**	**A Zigbee-connected window sensor with an acoustic peep capability**
Primary functionality	To lock/unlock remotely a door: - To send a command for locking/unlocking through a smartphone's mobile app using Wi-Fi. - To lock or unlock the access once the associated command is received (primary function).	To control automatically the access: - To poll a smart card/tag using NFC (Read/Write operation mode) and retrieve information data (identification code) - To consent or refuse the access (ex. open/close the door) upon code validation (primary function).	To detect opening of the window the sensor is attached to and emit an alarm notification: - To detect opening of the window (primary function) - To notify the user upon detection by sending an alarm message to the user's app through a server platform (via the Zigbee local network and the WAN) - To notify the user upon detection by emitting a short acoustical peep sound in case where the connectivity cannot be detected.
Architecture of the solution	The Smart Lock is equipped with a Wi-Fi Chipset and connects through the Internet to a server. Through its mobile app downloaded from the Smart Lock provider, the user is able to remotely send a command to a server which relays it to the smart Lock. Upon reception, the smart Lock activate a motorized mechanism to lock or unlock the door. The Smart lock reports its locking status to the server, which maintains the real-time status of the door so that	The boarding gantry station is equipped with an NFC reader and uses NFC (through a Read-Write operation mode) to consent/refuse access to the user when it shows its smart card/tag in proximity.	A Zigbee window sensor can detect the opening and closing of a window; it connects through Zigbee to a Zigbee hub to submit its state, the latter is transferred through a WAN to a server platform which sends an alarm notification to the user on the user's mobile app. In case where the window sensor is disconnected (on purpose, due to network interface malfunctioning or due to network outage) the sensor is able, upon window's opening detection, to emit a short acoustical peep sound to notify the user.

	the user is able to check if the door is locked or not once he/she has left the home (not primary function).		
Preliminary test	The smart lock connects to a communication network (Wi-Fi + WAN) to a server. There is an interaction at the application layer between the smart lock and the server (to command the locking/unlocking, to report the real time status of the smart lock).	The smart card/tag is passively connected to the NFC reader equipping the boarding station. There is no interaction at the application layer between the NFC reader at boarding station and the smart card/tag. This is not an IoT device.	The solution features a sensor connected through local IoT network (Zigbee) to a Zigbee hub acting as a gateway to a WAN network in order to reach a server. There is an interaction at the application layer between the sensor and the server. The window's sensor is an IoT device.
Type of IoT device	Sensing/actuating device, LPHC device	N/A	Sensing/actuating device, LPLC device
Stage 1: test 1/test 2	The device is neither an ICT product nor an E&M product	N/A	The device is neither an ICT product nor an E&M product.
Stage 1: test 3	Yes; because without connectivity (Wi-Fi & WAN) the smart lock would not be able to be controlled at will.	N/A	The window sensor can be disconnected from the ZigBee® network in the Smart Hub it is connected to. Afterwards the signals from the window sensor cannot affect the network anymore. In this case the window sensor remains its primary functionality to notify a user about the opening or closing of a window by a short acoustical peep sound emitted in case of such an event. The Window sensor in this example is an isolable IoT device as connectivity is not necessary to fulfill the primary functionality of the device (thanks to the acoustical notification capability as a fallback mean of the device).
Intermediate test	N/A	N/A	As the device under study is a simple sensor device, being connected is likely to be a differentiating positioning feature on the market (compared to non-connected sensors providing an equivalent main functionality). Thus, connectivity is likely to be a decisive criterion for purchasing or selling the device.
Stage 2: test 1	N/A	N/A	Sensors are generally tiny devices, where the connectivity part is likely to be non-negligible from the entire carbon footprint of the device even though the device communicates through a gateway/network hub.
Stage 2: test 2	N/A	N/A	N/A
Stage 3: test 1	N/A	N/A	N/A
Stage 3: test 2	N/A	N/A	N/A
Outcome of the heuristic	The connected product is an ICT-enabled device.	The connected product is not an IoT product.	The connected product is an ICT-enabled device.

III.2 Examples of concrete use cases

The implementation of the approach developed in **Appendix II** is illustrated through 3 examples:

- The case of Wearable IoT-devices for Healthcare
- The case of a smartwatch for mainstream consumer IoT market
- The case of "Linky" Smart metering

III.2.1 Case 1: Wearable IoT device for Healthcare

a) Description[70]

IoT is implemented in many healthcare ways, including detecting disease as a precaution, treating a disease as a healing solution, and monitoring a disease during the healing process. As part of IoT, wearable health devices have been developed to help people get the right treatment for themselves.

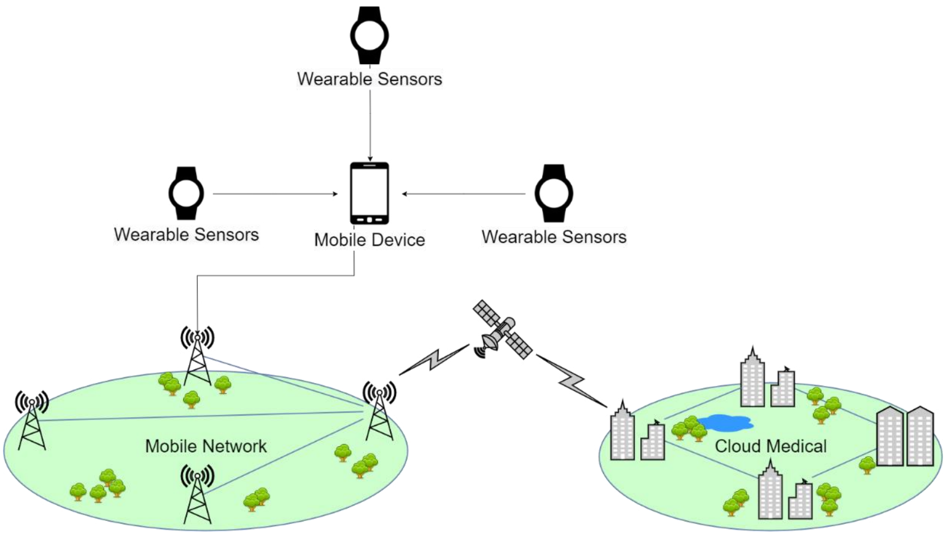

Figure 34- General Architecture of IoT for Healthcare

Figure 34 shows the complete generic architecture of wearable-IoT for healthcare. The architecture consists of the wearable sensors, mobile device, mobile network, and the medical cloud platform. The data obtained from the sensors are transmitted to a mobile device via Bluetooth or Wi-Fi. Mobile device acts as an edge device that preprocesses the sensor's data before transmitted to the medical cloud platform via a mobile network. In the medical cloud platform, data analytics and data storage are conducted. The insight from data analytics will be visualized in the mobile application to give users insights into their health.

There are many kinds of sensors which are used like measuring blood pressure embedded in watches or glasses, detecting Parkinson tremors and actuation system to reduce the Parkinson vibrations.

[70] See "A Review of Wearable Internet-of-Things Device for Healthcare a,b,c,d Computer Science Department, issued for 5th International Conference on Computer Science and Computational Intelligence 2020

Wearable devices are also implemented in other aspects of healthcare like scoliosis, breast cancer, monitoring multiple patients, nutrition monitoring, stroke, sleep quality.

The case is focused on the wearable sensors.

b) Analysis

This is clearly an IoT case, with an application running in the medical cloud, and in the different objects (wearable sensors). There is a gateway (mobile device), which gathers and preprocesses the data from the wearable sensors. A mobile network is the layer 3 communication network between the gateway (mobile device) and the application server.

The whole case belongs to "Human health"[71], but connectivity is necessary to fulfill the primary functionality of this wearable sensor: based on the heuristic, it is qualified as "ICT enabled" product.

c) Carbon impact allocation

The gateway is a mobile device, part of ICT as defined by ITU-T L.1450, and is already counted within ICT. One interesting question, not tackled in this memo, is whether the health sector would have to perform some double counting of carbon impact for this mobile device. It should be noted that the different wearable sensors don't belong to ICT[72].

No one will challenge the high benefit of IoT for the described case, but the increased use of these solutions will be triggered by the health sector, not by ICT stakeholders For Carbon accounting of the healthcare wearable sensors in this use case from an ICT perspective, only the connectivity part of the wearable sensor is considered (the wearable sensor is part of Tier 1+ scope).

III.2.2 Case 2: Smartwatch for mainstream consumer market

a) Description

General-purpose smartwatches are wearable devices equipped with various sensors, such as heart rate monitors, accelerometers, and gyroscopes. Smartwatches provide other features such as fitness tracking, notification alerts, Apps, GPS and media management. Most of these devices need to be paired with smartphones and they are dependent on it while others can be stand-alone devices and connect directly to the network (notably cellular). Smartwatches allow users to stay connected and monitor their well beings in real time, but also enable establishing communication calls and receive messages. According to market reports and data from Statista[73], the major suppliers in this market are ICT players including Apple, Samsung, Sony, Google and others.

Figure 35- Illustration of a smartwatch paired with its companion device (smartphone)

[71] Section Q of ISIC Rev 4 « Human health and social work activities »

[72] Class 2651 of ISIC Rev 4 "Manufacture of measuring, testing, navigating and control equipment" [manufacture of laboratory analytical instruments (e.g. blood analysis equipment)]. ICT manufacturing industries includes the following ISIC classes: 2610, 2620 ,2630, 2640 and 2680.

[73] https://www.statista.com/statistics/910862/worldwide-smartwatch-shipment-market-share/

b) Analysis

The Smartwatch use case is clearly an IoT use case, either through direct interaction with the cellular network (for standalone smartwatch models) or through indirect interaction with the WAN via a smartphone for instance (for the simplest/constrained models, the smartwatch exposes its capabilities to the smartphone in accordance with the IoT Device Capabilities Exposure (DCE) framework); thus, smartwatches are IoT devices.

Either connected directly or indirectly to the WAN network, the smartwatch needs connectivity to perform its primary functionalities. According to the heuristic, it is qualified as "ICT-enabled" product.

c) Carbon impact allocation

For Carbon accounting of the smart watch from an ICT perspective, the entire carbon footprint of the smartwatch shall be considered as the IoT device is under the control of ICT considering main market suppliers and that ICT players are drivers for the adoption of General-purpose mainstream consumer market smartwatches (the smartwatch is part of Tier 1+ scope).

III.2.3 Case 3: Linky smart metering

a) Description

More than a meter, Linky is a complete system (cf. Figure 36). The case is focused on the Linky smart meter.

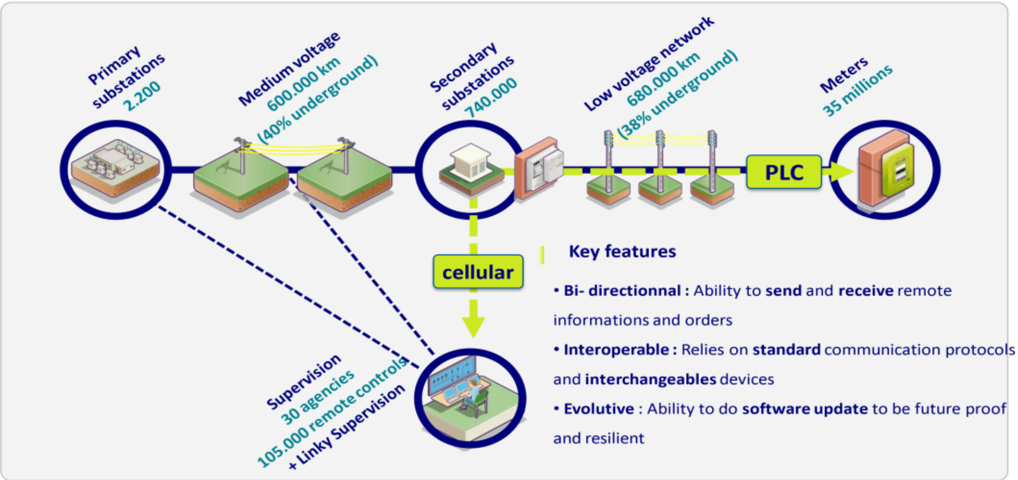

Figure 36– Illustration of the Linky smart metering system (end-to-end view)

The Linky Gateways are located in the secondary substations, at the edge of the low voltage networks. PLC (Power Line Communication) is used over the low voltage network to connect the gateways with the Linky smart meters. Linky uses G3-PLC technology, which operates independently from telecom operators and facilitates communication over existing powerlines, making it ideal for smart grid applications. By leveraging the existing powerline infrastructure, G3-PLC eliminates the need for additional communication paths, reducing installation and maintenance costs.

G3-PLC is an open, international standard published by the International Telecommunication Unit ITU (https://www.itu.int/rec/T-REC-G.9903).

Communications between the gateways and Linky Information System use cellular networks.

b) Analysis

This is clearly an IoT case, with an application running in Linky Information System, and in the different objects (Linky smart meters). There are gateways at the edge of low voltage networks, which gather and preprocess the data from the Linky smart meters. A mobile network is the layer 3 communication network between the gateways and the Linky information system.

The whole case belongs to "Electricity"[74], but connectivity is necessary to fulfill the primary functionality of the Linky smart meter: based on the heuristic, is the smart meter is qualified as "ICT enabled" product.

c) Carbon impact allocation

It should be noted that the different Linky smart meters don't belong to ICT[75] and that the increased use of these smart meters is triggered by the power grid operator (Enedis), not by ICT stakeholders.

For Carbon accounting of the Linky smart meter from an ICT perspective, only the connectivity of the Linky smart meters (G3-PLC chips) should be considered (the Linky smart meter is part of Tier 1+ scope).

III.3 Examples of system of connected products

This appendix is inspired from material developed in ITU-T Y.4119 Recommendation specifying requirements and capability framework for IoT-based automotive emergency response system for aftermarket devices and examples its implementation.

An IoT-based automotive emergency response system (AERS), as illustrated in Figure 37, reports automobile accidents to an automotive emergency response centre (AERC) by an automotive emergency detection device (AEDD) using vehicle sensors of the automobile and/or internal sensors installed on aftermarket devices such as the navigation system, dash cam, smartphone, etc.

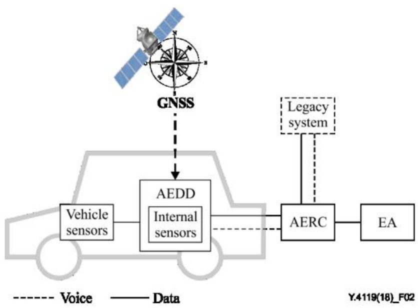

Figure 37- Overview of the AERS (figure extracted from [ITU Y.4119]). 'EA' stands for the Emergency Authority.

[74] Section D of ISIC Rev 4 « electricity, gas, steam and air conditioning supply ». The class is n°3510 Electric power generation, transmission and distribution

[75] Class 2651 of ISIC Rev 4 "Manufacture of measuring, testing, navigating and control equipment" [manufacture of consumption meters (e.g. water, gas)]. ICT manufacturing industries includes the following ISIC classes: 2610, 2620 ,2630, 2640 and 2680. Linky smart meter manufacturers are Sagemcom, Itron, Landis+Gyr, Ziv, Cahors et Elster.

AERS for original equipment manufacturer (OEM) pre-installed AEDD devices, such as the pan-European e-Call can be considered as a third-party service provider system.

According to [ITU Y.4119], AEDD is a unit (or a set of units) expected to perform at least the following functions:

- receiving sensing data, from internal sensors and/or vehicle sensors, for determining whether or not the accident occurred needs emergency recovery or receiving manual triggering signals,
- determining whether or not the accident occurred needs emergency recovery,
- receiving information about, or determining, the vehicle location,
- sending minimum set of data (MSD) which is related to the accident and
- providing bidirectional voice communication.

Thus, the primary functionality of AEDD is to perform an automotive emergency call to an AERC upon collision detection; it is fulfilled through the minimum set of required functions aforementioned. AEDD can be any type of device equipped with sensors for shock detection and a GNSS receiver, which can be installed after the purchase of the vehicle, for example, with the support of a navigation system or dash cam.

The general functional architecture of a typical AEDD is depicted in Figure 38, where several Functional Entities (FE) and components are identified and their role is mapped with the AEDD requirements for the AERS as follows (according to ITU Y.4119):

- Location FE: in charge of vehicle geographical location information acquisition using satellite (e.g. through GNSS) or cellular networks;
- Voice call FE: to perform voice call capabilities including phone number identification;
- Minimum Set Data (MSD) generating FE: to generate and transmit MSD if AEDD detects automotive accidents or SOS button is pressed;
- Vehicle status monitoring FE: in charge of obtaining information from vehicle sensors to aid AEDD (On-board diagnostic system-II (OBD-II) scanner is an example of the implementation of this FE);
- Internal sensors: sensor installed in or physically connected to AEDD to provide information for automotive accident detection;
- Vehicle sensors: sensors such as collision sensor, accelerometer, airbag deployment sensor, etc., that are installed in the vehicle to be used in automotive accident detection for providing information needed for vehicle accident detection. These sensors report their status for the vehicle status monitoring FE and the MSD generating FE through local connectivity technologies (for instance in-car Ethernet, Controller Area Network (CAN) etc.)

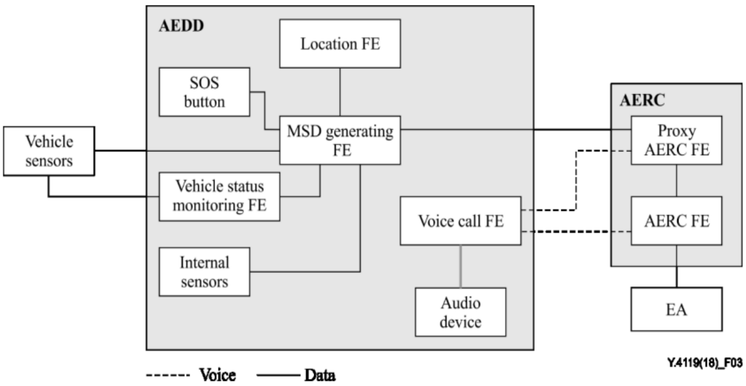

Figure 38- Functional architecture of AEDD (extracted from [ITU-T Y.4119])

According to ITU Y.4119, in terms of data and voice communication capability with the AERC, the AEDD may fall into three categories: an AEDD device without data and voice communication capability, an AEDD device with data communication capability only and an AEDD device with data and voice communication capability.

Because there may be different implementation forms of aftermarket AEDD devices, the AEDD can be considered as a connected products system, where – depending on its category – boundaries setting is an important pre-requisite for the analysis:

(1) AEDD with data and voice communication capabilities:

An aftermarket AEDD with data and voice communication capabilities interacts with its outer-environment through external connectivity interfaces.

This category of AEDD, as depicted in Figure 39, represents the most integrated and complete form of implementation. The external connectivity interfaces include: interface A used by the location FE component where the connectivity is either cellular or satellite (ex. GNSS); interface B featuring cellular connectivity used by the MSD generating FE and the voice call FE respectively for data and voice communication with the AERC; interface C used by the MSD generating FE and the vehicle status monitoring FE to collect data from vehicle sensors through CAN for instance. Internal sensors may not be physically embedded within the AEDD device but remotely connected to it through an "internal" connectivity technology (considering AEDD as a connected products system) in that case interface D should be considered as internal to the AEDD.

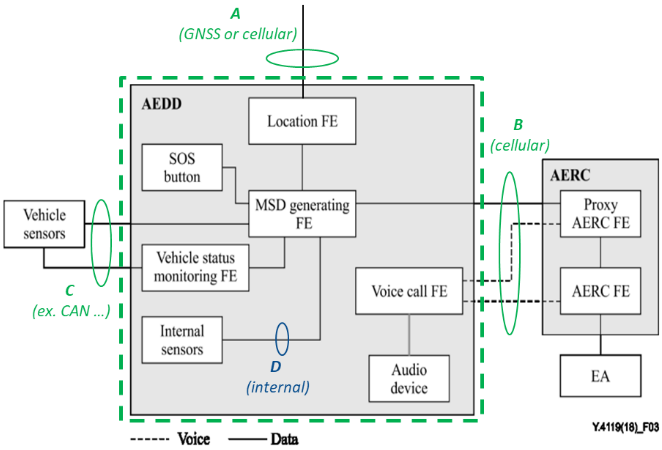

Figure 39– Connected products system for AEDD with voice and data communication capabilities (extracted from [ITU-T Y.4119] and modified for the purpose of this Report).

The AEDD is considered as an ICT-enabled device as its primary functionality would not be fulfilled as soon as one of the aforementioned external interfaces (A, B and C) goes permanently offline. Internal interface D is out of scope of the negation test.

(2) AEDD with data communication capabilities:

In this implementation variant, the AEDD could be a navigation system/dash cam, it uses its data communication modem and the user's phone for voice communication. According to ITU Y.4119, the MSD generating FE should be able to obtain the call back number of the user's phone in the vehicle. The AEDD may be considered as a connected products system where the interface between the phone and the navigation system (interface D) is internal.

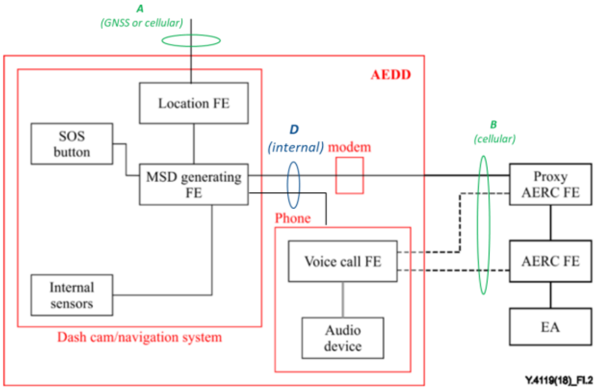

Figure 40 - An implementation variant of an AEDD with data communication capabilities (extracted from [ITU-T Y.4119] and modified for the purpose of this Report)

(3) AEDD without data and voice communication capabilities:

This form of implementation of the AEDD features a navigation system or a dash cam, using data communication and voice communication capabilities of the user's phone in the case of MSD transmission. The MSD generating FE should be able to obtain the call back numbers of the user's phone in the vehicle. From connected products system perspective, the connectivity between the phone and the navigation system would be considered as internal.

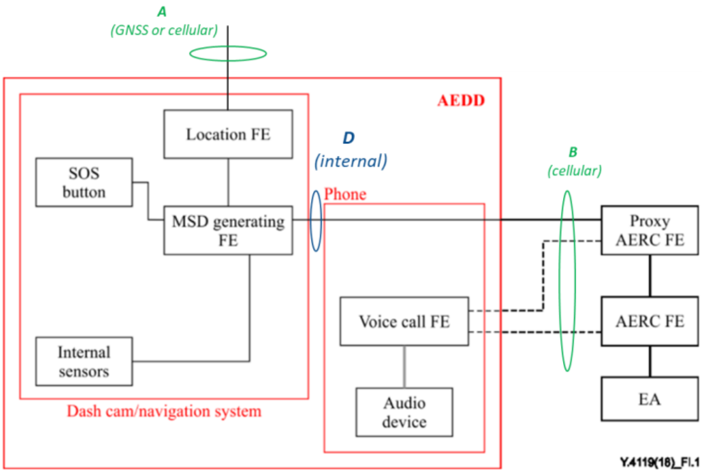

Figure 41 - An implementation variant of an AEDD without data and voice communication capabilities (extracted from [ITU-T Y.4119] and modified for the purpose of this Report)

Appendix IV

Example of contextual parameters for IoT devices

(This Appendix is related to Section 5)

IV.1 Determining the number of connectable devices through contextual parameters for IoT devices

The number of connectable IoT devices can be derived by calculating the market penetration of the IoT application/service through relevant contextual parameters (e.g. proportion of users, proportion of households, proportions of cars etc.), and adjusting with an appropriate contextual factor (α) as shown by the formula above:

$$\#\ connectable\ IoT\ devices_y = share\ of\ contextual\ parameters \times\ \alpha_y$$

Table 18 provides examples of contextual parameters for some selected IoT devices, ranges/values of the contextual factors (ρ and α) provided are indicative only.

Table 18 - Examples of contextual parameters for some selected IoT devices

IoT vertical – application domain	**IoT device**	**Contextual parameters**	**Contextual factors**
Consumer IoT - Smart home	Smart appliances	# households	$\rho < 0.5$: A majority of smart appliances might not be effectively connected to the network. $\alpha > 1$: More than one smart appliance may be attributed to a household.
Consumer IoT- Wearables	Wearable device-related multimedia services (Smart watches, smart glasses …)	# users	$\rho \approx 1$ $\alpha > 1$: More than one smart device may be attributed to a user.
Consumer IoT- Wearables	Wearable device-related sports services (smart bracelets, smart rings, sensors …)	# users	$\rho \approx 1$ $\alpha > 1$: More than one smart device may be attributed to a user.
Consumer IoT- Wearables	Wearable device-related health management services (medical/physiological sensors, pacemakers …)	# patients	$\rho \approx 1$ $\alpha > 1$: More than one smart device may be attributed to a patient.
Consumer IoT - Smart home	Smart meters for residential	# households	$\rho \approx 1$ $\alpha \approx 1$
Consumer IoT - Smart city	Smart meters for professional building	# professional dwellings	$\rho \approx 1$ $\alpha >1$: A professional dwelling may be equipped with more than a single meter (as many enterprises may share the same facility)
Industrial IoT – Smart manufacturing	Sensors/actuators in smart robots or automation floors	# factories	$\rho \approx 1$ $\alpha >1$: A smart robot/an automation floor may be equipped with several sensors/actuators.
Consumer IoT – Smart city	Surveillance IP camera	# dwellings	$\rho \approx 1$ $\alpha >1$: Several IP cameras may be installed in a given facility (depending on the geographical footprint of the facility)

Mobility IoT-Automotive	E-Call emergency car modules	# cars	ρ ≈ 1 α ≈ 1
…	…	…	…

IV.2 Determining the number of connectable devices through the volume of shipments

The number of connectable devices could be derived using statistics from sales or shipments of devices with a methodology similar to the Bottom-Up Energy Analysis System (BUENAS) model developed by Lawrence Berkeley National Laboratory[76]. BUENAS estimates global energy-efficiency potential for residential, commercial and industrial equipment (thus including IoT devices), it is used by the Total Energy Model (TEM) developed by IEA [EDNA-TEM – 2019] to estimate through bottom-up modelling the stock of devices and their projections.

The number of connectable devices at a given year 'y' can be calculated using the following formula:

$$\#\ connectable\ IoT\ devices_y = \sum_{age=0}^{30} Shipments(y - age) \times Surv(age)$$

Where '*Shipments(y)*' refers to the number of sales of IoT devices at year '*y*' as reported by statistics/market reports; '*Surv(age)*' refers to the probability to surviving to '*age*' years.

The probability to surviving to "y" years could be derived using typical parametric survival (called also reliability) functions such as Weibull survival functions. By considering estimates of average service life (per IoT device type) as the years of life at which 50% of the connected IoT devices remain in service, the practitioner is able to derive the number of IoT devices operational at a given year.

Figure 42 provides an example from the TEM model [EDNA-TEM – 2019] of an IoT device with a 4 year-average life (i.e. where 50% of the fleet of connected devices are still in service).

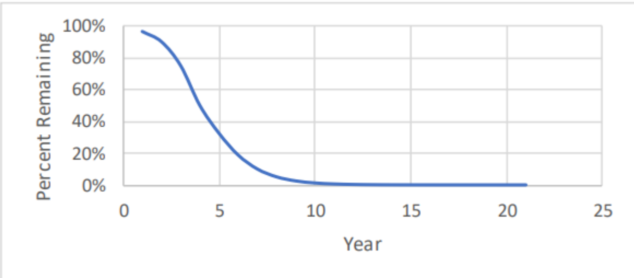

Figure 42– Example of a survival function of an IoT device with a typical 4 year-average life expectancy (from [EDNA-TEM – 2019])

IV.3 Example of traffic models for IoT devices

Several approaches exist to design traffic models for IoT devices. Traffic volume generated from IoT devices can be estimated using the rate of data generation per device '*R*' and the yearly activity factor '*A*' of the device (the typical profile of device's operation representing the proportion of time where the device is active vs inactive/standby):

$$Traffic\ volume = R \times A$$

[76] Bottom-Up Energy Analysis System (BUENAS) | International Energy Analysis (lbl.gov)

Besides data rate generation (R) of an IoT device, one may distinguish between the required processing frequency (P) to perform the basic operations and processing tasks of the device as well as the minimum required frequency (C) for a micro-controller to encrypt and transmit the unprocessed data to the network. While the former (P) highlights the load on the processing part of the IoT device, the latter (C) highlights the load on the connectivity part of the IoT device. [Samie – 2016] provides plausible value ranges of R, P and C for different typical non-cellular IoT devices, for example:

- Health monitoring sensors for heart-rate (e.g. pace makers) would generate data at a rate (R) 0,1 - 0,8 Kbps, processing would be carried out at a rate (P) 0,5 - 1,1 MHz and communication with the LPWAN (e.g. Bluetooth) network would be done at a rate (C) 5 – 50 KHz.
- A security IP surveillance camera (SD video) would generate data at a rate (R) 0,8 - 5 Mbps, processing would be carried out at a rate (P) 0,5 - 1 GHz and communication with the LPWAN (e.g. Bluetooth) network would be done at a rate (C) 50 – 100 MHz.

Appendix V

List of ICT and E&M products according to International classification systems

(This Appendix is related to Annex A)

International classifications provide a common recognized framework enabling the compilation and the presentation of statistics. As any economic activity or product, ICT and E&M activities and products are classified statistically according to two types of classifications:

- Classification of economic activities are designed to categorize data that can be related only to the unit of activity (e.g. individual plant or group of plants). Examples of such classifications include: ISIC for the United Nations' International Standard Industrial Classification of all Economic Activities, NACE for the statistical classification of economic activities in the European communities etc.
- Product classifications are designed to categorize products (goods and services) that have common characteristics providing the basis for preparing statistics on the production, trade, consumption, and transport of such products. Examples of such classifications include: The United Nations' Central Product Classification (CPC), the European Classification of Products by Activity (CPA), the Harmonized Commodity Description and Coding System (HS) managed by the World Customs Organization, the Combined Nomenclature (CN) – a European classification of goods used for foreign trade statistics etc.

All these classifications correspond to different hierarchical levels (World-wide level, EU level, National level). They are linked together either by the structure (for instance when a classification is mapped from one hierarchy level to another) or by conversion tables (for instance from one classification type to another) as illustrated in Figure 43 which indicates the current version of each nomenclature and the year since it has been enforced.

Information Economy (ICT and E&M) sector/products are defined by the Working Party on Indicators for the Information Society within OECD as an alternative aggregation. This aggregation uses complete CPC subclasses and ISIC classes respectively to define the scope of Information Economy products and industries.

NOTE – At the time of the consent on this Report, the complete structure of ISIC Rev.5 has been endorsed in 2023 with adoption of the explanatory notes and implementation plan expected in 2024. CPC v3.0 is undergoing a consultation process before full endorsement in 2024. OECD has initiated since November 2023 a task-force with the aim to study the opportunity to review ICT and E&M sectors and products definitions with regards to the aforementioned complete/ongoing revisions (ISIC Rev5.0, CPC v3.0, HS22).

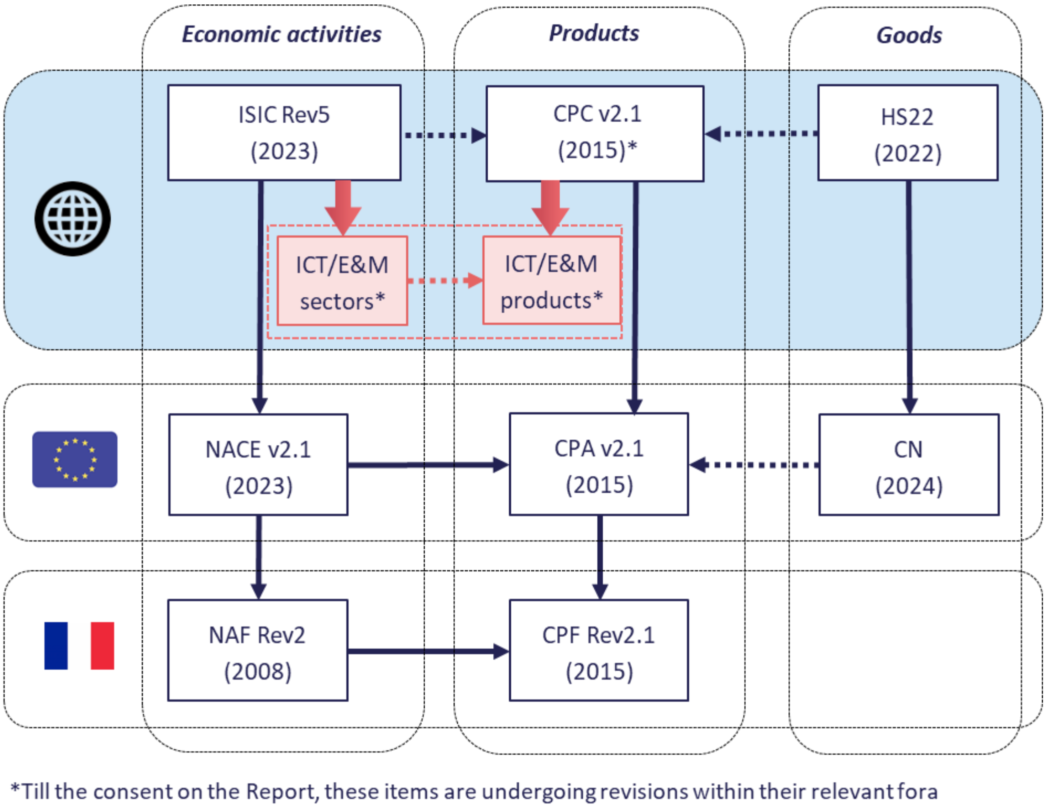

Figure 43– Relationship between the different nomenclature systems at world-wide, EU and National levels. Boxes in red represent Information Economy sectors and products as "alternative aggregations" provided by WPIIS/OECD.

The list of ICT and E&M products and their mapping with the current versions of CPC and ISIC is detailed in **a supplementary material provided on request**.

This list is provided for indicative purpose only to support a practitioner, other relevant sources including ITU L.1450 (Annex A) should be considered.

Appendix VI

Considerations on Artificial Intelligence of Things

(This Appendix is related to Section 6)

Artificial Intelligence of Things (AIoT) refers to the integration of AI capabilities into IoT devices and systems. AIoT combines the power of AI algorithms with the connectivity and data collection capabilities of IoT devices to create intelligent and autonomous systems and unlock the value of data. AIoT is a generic term referring to an umbrella of several forms of solutions embedding AI into IoT. Thus, in such cases, AI supports the primary functionality of a device.

This appendix provides some insights on how to approach the case of AIoT systems through the heuristic described in **Section 4**. It is worth noting that the work on standardization of AIoT is ongoing within work fora including ITU (through a dedicated Correspondence Group (CG) on AIoT and other relevant Study Groups[77]) and ISO/IEC Committees (JTC1/SC 42).

AI technology can be applied within the end-to-end IoT infrastructure, in particular in the device and the edge, while considering existing limitations of some IoT systems (e.g. implementing Tiny Machine Learning (ML) systems into constrained IoT devices).

Figure 44 illustrates, at a high-level, a possible typical chaining of lifecycle stages of an AIoT solution. It includes: data pre-processing, model training/learning, model refinement/tuning, model run/inference, results delivery and update.

NOTE – Tuning may encompass many forms including smaller scale learning, for instance local training in the context of Federated ML systems.

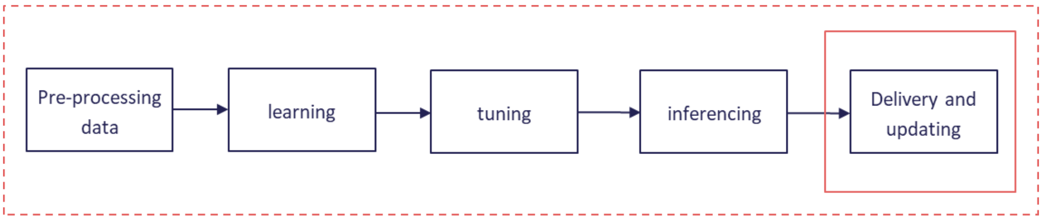

Figure 44– Typical lifecycle stages of an AIoT solution: solid line and dashed line represent respectively the minimum and the maximum scope of an AIoT implementation model

Different models of AIoT deployment can be identified depending on several considerations (device capabilities, environment capabilities, use case requirements, usage context etc.), they range between two extreme cases:

- AIoT may deploy AI at the IoT device to reduce latency, protect data privacy and enhance user experience. In this model, the device pre-process data, performs inference and interacts with the edge or cloud for model training. Other forms of lightweight AI/ML (called “Tiny AI”) are designed specifically to be trained and run on the device itself.

[77] Including SG13, SG16 and SG20

- AIoT may deploy AI at the Edge; where an Edge platform (with the support of the cloud) is responsible of the development and the deployment of the algorithm, it may also perform contextual inference and push the outcome to the IoT device.

In a more general deployment model, the device, the Edge/other companion device and the cloud work together to provide AIoT services to the application.

Because of the variety of deployment models of AIoT, it is important when implementing the heuristic for an AIoT system to figure out (1) whether any stage of the life-cycle of the AI system intervenes in the provisioning of the primary/critical functionality of the IoT device and (2) whether the identified lifecycle stage of the AI system occurs within the device or being offloaded elsewhere (for instance on an Edge device or on the Cloud).

Table 19 identifies the potential for offload for each stage for 4 typical models of AIoT solutions.

Table 19 - Example of four typical models of AIoT implementation and qualifying the impact of the connectivity

Stage	**Model #1**	**Model #2**	**Model #3**	**Model #4**
Pre-processing	On-device	On-device	On-device	Offloaded
Learning	On-device	Offloaded	Offloaded	Offloaded
Tuning	On-device	On-device	Offloaded	Offloaded
Inferencing	On-device	On-device	On-device	Offloaded
Delivery/update	On-device	On-device	On-device	On-device
Example of AIoT devices	This model fits well with devices supporting full lifecycle stages of AI such as HPHC IoT devices. It fits also the case of constrained IoT devices implementing lightweight Tiny ML[78].	This model may fit well with a HPHC or LPHC as long as the processing capabilities are sufficient for tuning/model refinement but not enough for training, such as an IP Camera or autonomous Unmanned Aerial Vehicles (UAVs).	This model may fit well with a LPHC device with enough processing capabilities for inference but not for model training or tuning, such as a smart glass or wearables.	This model fits well for LPLC or LPHC IoT devices.
Impact of the connectivity with regards to AI in fulfilling the primary functionality	Connectivity would not be considered as necessary	Connectivity would be considered as necessary	Connectivity would be considered as necessary	Connectivity would be considered as necessary

[78] https://arxiv.org/pdf/2206.15472.pdf

Appendix VII

Extending the revisited tiered framework of the Digital Economy to the other pillars of the ICT sector

(This Appendix is related to Section 6)

With the increasing digitalization of our society, more and more products might systematically be embedded with connectivity or processing or display features; making the boundaries of Information Economy (and ICT in particular) fuzzy as explained in **Annex A.**

Going beyond connected products, this appendix proposes to leverage on the heuristic developed in the core of the Report and opens further perspectives supporting the generalization of the revisited framework of the Digital Economy to any kind of product.

VII.1 Adapting the heuristic paradigm for a generalized categorization

According to OECD [OECD -2011], the following guiding principle is used to identify ICT products (adapted from the agreed guiding principle of the ICT sector):

"*ICT products must primarily be intended to fulfil or enable the function of information processing and communication by electronic means, including transmission and display*".

Based on this guiding principle which defines the notion of ICT, the Committee understands that it may be summed up under three key pillars: connectivity (referring to "communication by electronic means, including transmission"), processing and display.

NOTE – One may notice that the three pillars are not strictly independent from each other particularly between "connectivity" and "processing"; for instance, a product with a high connectivity capability would generally require a medium to high processing capability.

The heuristic developed in the core of this report revolves around the key pillar of connectivity. It leads the practitioner, through several tests, to challenge the role of connectivity and to understands how much the connected product is reliant on connectivity.

A possible extension could be to mimic the current heuristic around the two others key pillars defining ICT (i.e. processing and display). Any of the tests (except the preliminary ones on IoT, ICT or E&M classification) developed in the heuristic can be oriented towards the notion of "processing" or the notion of "display" instead of the notion of "connectivity". For instance:

- "*Is [connectivity] essential for fulfilling the functionalities of the device?*" can be mimicked by "*Is [processing] / [display] essential for fulfilling the functionalities of the device?*"
- "*Does the [connectivity] takes a substantial share of the carbon footprint of the device?*" can be mimicked by "*Does the [processing] / [display] takes a substantial share of the carbon footprint of the device?*"
- Etc.

Consequently, one could take any product and use the heuristic according to its three different versions (based on each key pillar defining ICT). Following the approach for connected products categorization developed in **Appendix II** and adapting it to this extended and generalized heuristic, one could represent any product by a vector whose coordinates are the outcomes of the heuristics (on connectivity, on processing and on display). Each of the coordinates of such vector can either be Tier 1 (i.e. belonging to Information Economy), Tier 2 (i.e. the analyzed product is reliant on [connectivity] or [processing] or [display]), Tier 3 (i.e. the analyzed product is reliant on [connectivity] or [processing] or [display]) or Beyond the digital economy (i.e. using marginally or not using [connectivity] or [processing] or [display]). Because ICT is multi-pillar, its influence on a given product is driven by the most influencing pillar. Thus, such three-dimensional vector can be factored by taking the minimum of its coordinates (i.e. the smaller Tier reflecting the most influencing pillar) as depicted in Figure 45[79]:

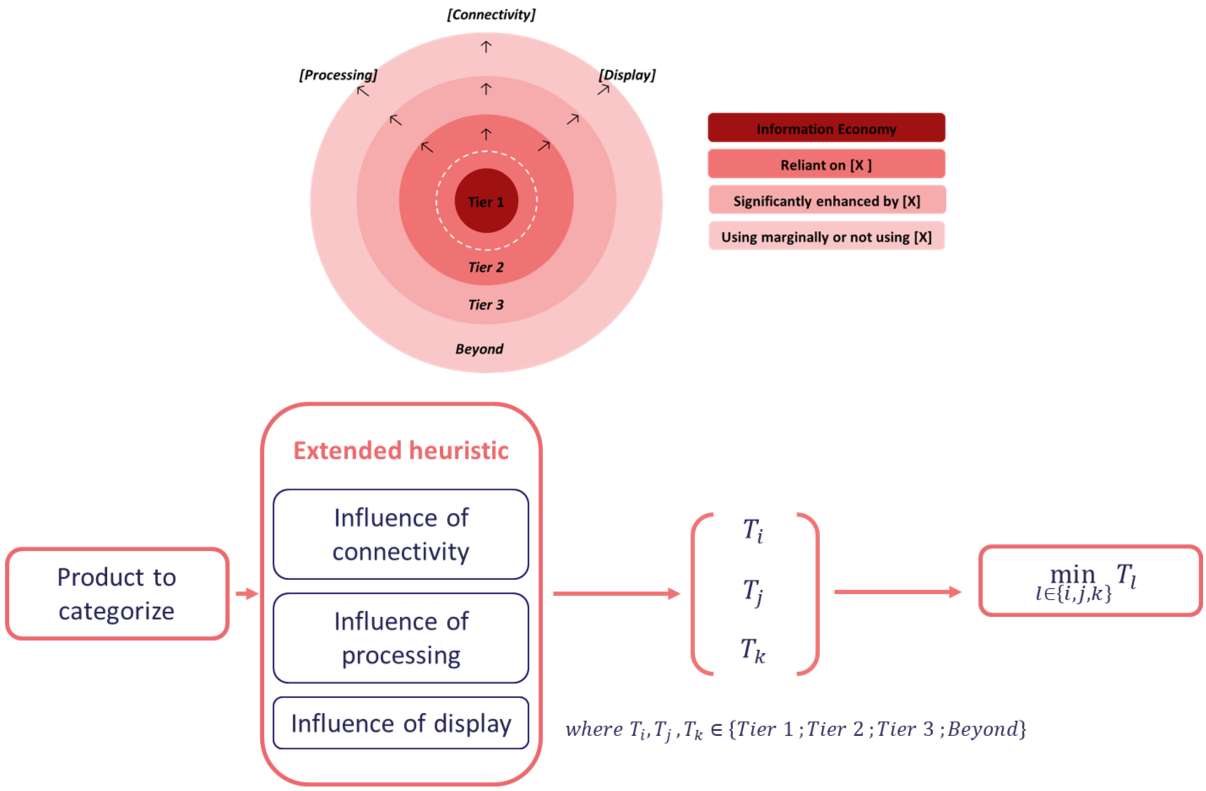

Figure 45- Deriving an extended heuristic to consider the influence of "processing" and "display" on a product

Considering the aforementioned adaptations, the revisited tiered framework of the Digital Economy introduced in **Appendix II** for the case of connected products could be generalized to address the categorization of any product with respect to ICT by taking the single coordinate vector depicting the most influencing pillar of ICT on a product and its degree of influence as illustrated in Figure 45.

One may acknowledge that for effective implementation of such revisited approach, there is a need for more extensive definitions of "processing" and "display" concepts in the guiding principle defining ICT. For instance, one can wonder if any product embedded with a micro-controller can be seen as an equipment with processing capabilities.

[79] The reader may notice that the notion of Tier 1+ developed in **Appendix II** is not considered here. Indeed, as explained in **Appendix II** this subspace lying between, while trying to use the OECD framework for the digital economy, is the equivalent of "ICT-enabled" among the possible outcomes of the heuristic. This is specific to the core heuristic regarding the influence of connectivity on an IoT product (i.e. passing positively the first test). In this general case which is not only focused on connected and IoT products, the more relevant concepts are the one on Tiers already developed in the OECD framework from which **Appendix II** is inspired. The white dashed circle corresponds to the Tier 1+ developed in **Appendix II**.

VII.2 Adapting the paradigm of the heuristic for carbon allocation rules

Based on the approach developed in **Appendix II** on carbon allocation rules, one could then, propose the same approach and derive a set of rules not only related to "connectivity" but also to the two other key pillars of the ICT sector.

Using the factorized singled coordinate vector categorizing an object which positions a given product in a particular Tier (cf. Figure 45), the rules proposed in **Appendix II** would be adapted to any product as in Table 20:

Table 20 – Rules for Carbon footprint allocation with respect to ICT

Tier which the product belongs to	Product carbon footprint allocation (with respect to ICT)
ICT products (Tier 1)	Attribute to the Information Economy the whole carbon footprint of the product
Product reliant on ICT (Tier 2)	Depending on some cluster of indicators to appreciate the influence of ICT organizations in the concerned market, either attribute to the Information Economy the whole carbon footprint of the product or the carbon footprint attributable to the connectivity, processing and display components
Product significantly enhanced through ICT (Tier 3)	Only the carbon footprint attributable to the connectivity, processing and display components is allocated to Information Economy
Products non or marginally enhanced through ICT (Beyond Tier 3)	No part of the carbon footprint's product to allocate to Information Economy

While one may acknowledge that these allocation rules may overestimate the carbon footprint share allocated to the Information Economy, the bias introduced seems not unreasonable. Further work could be conducted on the topic.

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The Regulatory Authority for Electronic Communications, Postal Affairs and Print Media Distribution (Arcep), a neutral and expert arbitrator with the status of independent administrative authority (IAA), is the architect and guardian of internet, fixed and mobile telecoms and postal networks in France.

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At ADEME – France's National Agency for the Ecological Transition – we are firmly committed to fighting global warming and resource depletion. ADEME is a public establishment, under the joint authority of the Ministry for the Ecological Transition and the Ministry for Higher Education, Research and Innovation.

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