Eco-Design of Digital Services

Methodology for the assessment of the environmental Impact of a Node in a Blockchain

Scoping Note

Version V1.3 – 24/02/2023

Study conducted for	Study conducted by	Critical review by
CACIB 12, Place des Etats-Unis - CS 70052 - 92547 Montrouge Cedex, France. **SEB** Kungsträdgårdsgatan 8, 111 47, Stockholm, Sweden	**APL DATA CENTER** 106 avenue Marx Dormoy 92120 Montrouge	**SGS** Rda. de Narcís Monturiol, 8, 46980 Paterna, Valencia, Spain

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3 Acronyms

Acronym	Definition
ADEME	French Agency for the Environment and Energy Management Renamed "Agency for the Environmental Transition”
LCA	Life cycle assessment
IEA	International Energy Agency
CMDB	Configuration Management DataBase
CRAC	Computer Room Air Conditioning
CRAH	Computer Room Air Handler
AHU	Air handling units
DC	Data center
LS	LifeSpan
LCI	Life Cycle Inventory
EF	Emission Factor
kWe	Electrical power
kWc	Cold power
LAN	Local Area Network
PUE	Power Usage Effectiveness
WAN	Wide Area Network

Table 1: List of acronyms

4 CONTEXT AND OBJECTIVES

Crédit Agricole CIB (CACIB) and Skandinaviska Enskilda Banken AB (SEB) (together the « Initiators ») proposed to add an environmental criterion to a blockchain consensus: for each node, its environmental footprint is measured, and the more virtuous it is, the more it will be rewarded by crypto tokens. This will create competition between nodes based on their environmental footprint.

As such the Initiators mandated APL datacenter to evaluate the environmental impacts of blockchain services under different "on premises" and "cloud computing" hosting scenarios. General objectives for the mission are:

- Definition and publication of a node environmental footprint assessment methodology (following ISO 14040/44 Life cycle assessment).
- Definition of rule and methodology to evaluate the environmental footprint of the nodes.
- Creating a token, native to the blockchain to reward the virtuous nodes.

The method used to assess environmental impacts is the life cycle assessment method as described in ISO 14040 and ISO 14044. The output of this assessment is the footprint of the nodes collaborating on this blockchain. All environmental assessment results will be presented using four indicators:

- **Greenhouse gas emissions or climate change kg CO eq,**
- **Depletion of abiotic resources depletion kg Sb eq,**
- **Primary energy consumption MJ.**
- **Water resource depletion m3 eq,**

A single indicator aggregating all these indicators will be used.

5 PROJECT MANAGEMENT

5.1 Schedule

The assignment lasted 2 months and was carried out according to the following schedule.

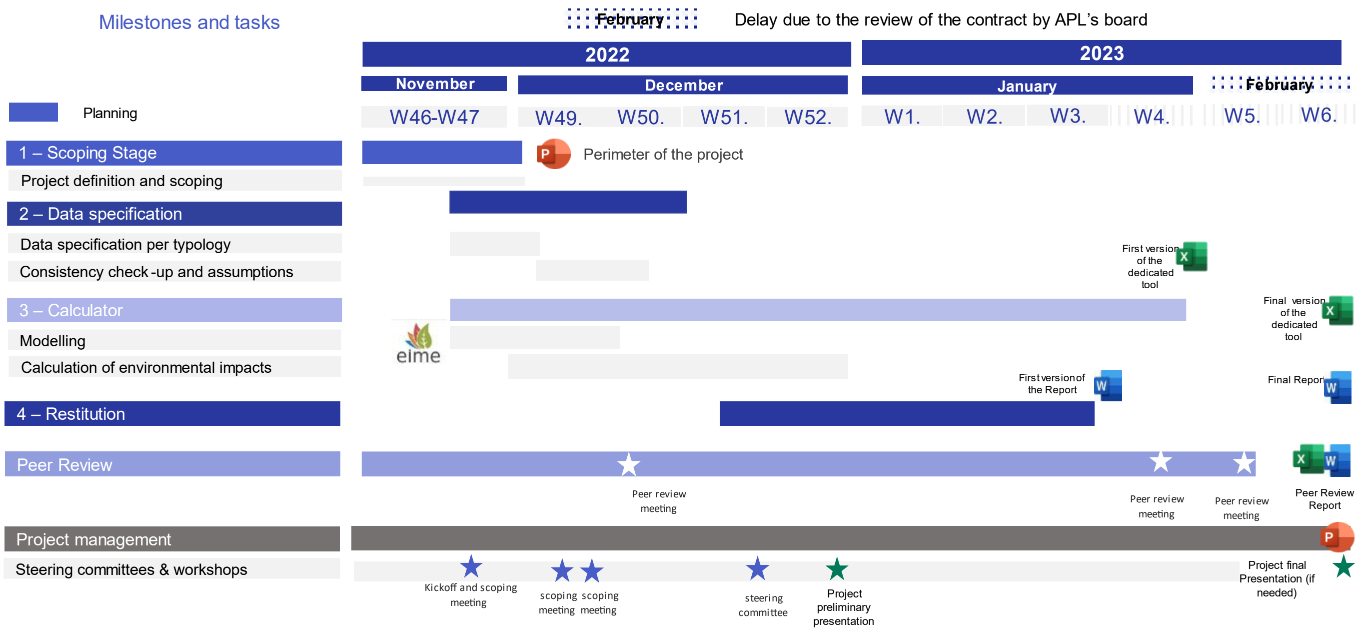

Figure 1: Project schedule

5.2 Study report

This report is a first report of the study conducted, presenting the scoping of the full life cycle assessment and will be completed to include:

- **Comments and requests for additional critical review,**
- **Comments and requests for additional information from CACIB AND SEB teams,**

5.3 Validity of results and critical review

Validity of results

The results are valid only for the situation defined by the assumptions described in this report. The findings are subject to change if these conditions differ. APL DATA CENTER cannot guarantee their relevance or reliability if used by third parties or for other purposes than those mentioned in this report. The sponsor is therefore solely responsible.

Critical review

Critical review is a procedure to certify the compliance of the Life Cycle Assessment (LCA) with international standards and national supplements to meet the objectives of the study. This is performed primarily when the results are intended to be communicated to the public or when it involves comparative statements.

Its purpose is to limit the risks in terms of:

- Inconsistency between purpose, collection data and study results
- Misunderstanding of the results
- Communication of unsupported conclusions

The critical review will be conducted in a step-by-step process:

- Review of the selected models (function, functional units, scopes),
- Review of the life cycle inventory and assumptions,
- Review of the life cycle assessment process.

The peer review report will be provided as an appendix to this study report.

6 METHODOLOGY

The environmental impacts evaluation is conducted according to the standardized method of life cycle assessment defined in the ISO 14040 and ISO 14044 standards and based on data from the NegaOctet project (database of environmental impacts of digital equipment, infrastructures, systems, and services).

6.1 Life cycle assessment

6.1.1 Fundamentals

Life cycle assessment is an environmental assessment method like carbon footprint or impact assessments, but it has specificities that make its holistic approach unique. This method has been used since the end of the 90s and standardized in the ISO 14040:2006 and ISO 14044:2006 series; it is used to determine a product or service's ecological baggage, using an approach that is:

- **Multicriteria:** Several environmental indicators are to be considered systematically, including global warming potential, depletion of abiotic resources, photochemical ozone creation, water, air and soil pollution, human ecotoxicity and biodiversity. The list of indicators is not fixed but depends on the sector of activity.
- **Life cycle:** to integrate the impacts generated during the stages of the equipment's life cycle, from the extraction of hard-to-reach natural resources to waste production, including the energy consumption during use.
- **Quantitative:** each indicator is quantified to put all the externalities of a product or service on the same scale and help make objective decisions.
- **Functional:** the object of the study is defined by the function it fulfills to compare different technical solutions.
- **Attributional or consequential:** Life cycle assessment helps to characterize the direct environmental impacts of a solution in a traditional way, through the attributional life cycle assessment as well as the indirect or systemic environmental impacts through the consequential life cycle assessment. For the LCAs conducted for NegaOctet, we use attributional LCAs.

While LCAs were initially more often applied to the field of products, their scope of action has widened in recent years. This was initially driven by the ETSI 203 199 standard and has continued thanks to the numerous works carried out by professional telecommunications organizations such as the ITU, the NegaOctet consortium for digital services and Pôle Ecoconception for services in general. This work is now feeding into French regulations and the implementation of Article 13 of the anti-waste and circular economy law (AGEC law) in particular, which aims to force telecommunication network operators to communicate on the greenhouse gas emissions of data transmission to the public.

Moving from a product to a service means keeping the multi-criteria and functional philosophy but moving from a circular approach (from cradle to grave) to a matrix approach that includes the life cycle of all the equipment that make up the three thirds (devices, networks, data centers) that allow the digital service to function.

Such an environmental diagnosis makes it impossible to transfer pollution from one phase to another but also from one third of the service to another.

The database NegaOctet will be updated at least once per year by the consortium NegaOctet. This methodology will use the last version available of NEGAOCTET database as of the end of the previous year. Yearly (in January), the consultant will use the last version available as of the previous year, and this version will be used for any audit from January 1st to December 31st of the current year.

6.1.1.1 Purpose of the LCA

Performing a Life Cycle Assessment of a digital service means acknowledging its material qualities and environmental externalities. This method is relevant to:

- establish a quantitative diagnosis of the direct environmental impacts of a digital solution
- identify the most significant drivers to improve an eco-design project
- compare digital and non-digital technical solutions and make recommendations based on technical choices and behaviors
- communicate objectively on performance and service improvements
- manage a green IT strategy and integrate the footprint of digital services into corporate reporting

The assessment is a powerful tool to support decision making at both the government and corporate levels.

6.1.1.2 The method in short

Because of its iterative nature, the life cycle assessment method can be adapted to all levels of project team maturity. You could decide to apply just the philosophy, do a screening assessment, or develop a complete life cycle assessment according to ISO 14040.

Approach	Life cycle phases	Indicators	Collection data	Modeling data
Single-criteria or single-step approach	Incomplete	Incomplete	Impact data not covering all indicators	N/A
Screening approach	Complete	Complete	Impact data and/or non-homogenous sources (manufacturers' environmental statements, studies, etc.)	Broad granularity (third party, or broad system)
Simplified approach	Complete	Complete	Secondary homogeneous LCI data	Intermediate level of granularity (finer systems, equipment)
Comprehensive approach	Complete	Complete	Primary homogeneous LCI data	Fine granularity (specific equipment)

Table 2 : Presentation of the diverse types of LCA

The important thing is to respect the four steps of the process:

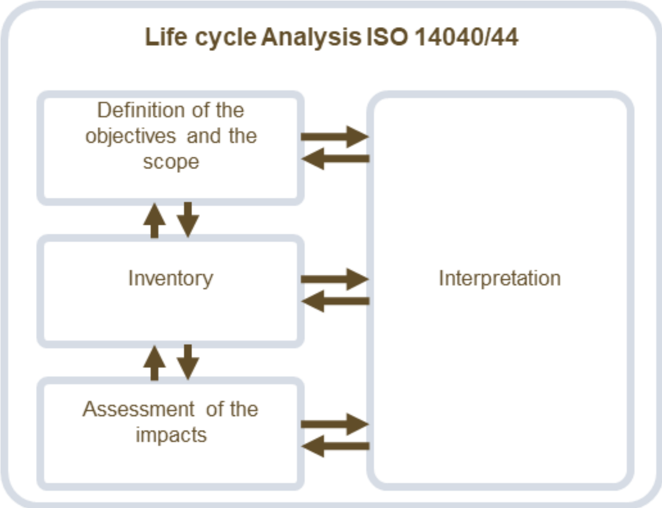

Figure 2: LCA steps as described in ISO 14040/44

The process of reflection at the origin of the production of the results is itself a vector of awareness for the sponsors and producers of digital services, allowing them to become aware of their impacts and their dependence on other actors.

6.1.2 NegaOctet' s contributions

The implementation of the NegaOctet project is based on a simple observation: while new digital products and services are driving companies' growth and are transforming all sectors of activity (public services, retail, agriculture, energy management, risk prevention, etc.), the proliferation of connected services is not without environmental impacts (greenhouse gas emissions, waste production, resource depletion, etc.) at all life cycle stages of the various equipment needed to run the applications (devices, communicating objects, telecommunication networks, data centers).

However, there are few data and methods to quantify these direct environmental impacts, while many publications refer to the reduction potential offered by digital technology, for example GeSI's Smarter2030 report.

Thus, APL DATA CENTER, LCIE Bureau Veritas, DDemain, and GreenIT.fr, four experts about sustainable digital technology and eco-design, have joined forces to set up the NegaOctet research and development project to help meet the challenge of quantifying digital services' direct environmental impacts.

Started in 2018, NegaOctet is an R&D project that won the Perfecto call for projects launched by ADEME on the topic of ecodesign of digital software and services. Lasting 36 years, its aim is to build and test a reference framework for assessing the environmental impact of digital services.

By reference framework, we mean:

- Participate in the development and sharing of common and relevant rules for the sector: Work in progress with ADEME in the framework of the implementation of the AGEC law,
- Develop and make available an ISO 14040-compliant life cycle inventory database that allows us to calculate the impact of digital services at four levels:
    - → Components
    - → Equipment
    - → Infrastructures and systems
    - → Digital services
- Develop a standardized implementation of the database within the consortium.

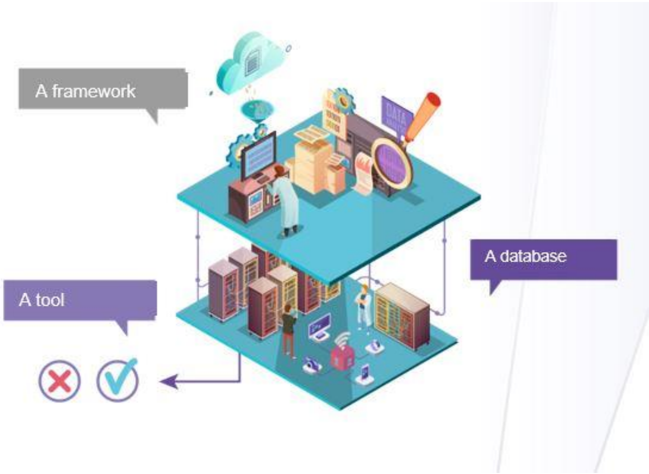

Figure 3: The NegaOctet project and its main deliverables

Built with a view to standardization, the reference framework developed within NegaOctet is in line with the standards that apply to life cycle assessment, in particular:

- ISO 14040:2006 standard – Environmental management — Life cycle assessment — Principles and framework
- ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines

Where possible and relevant, we supplement our compliance reference framework with:

- The requirements of French environmental labeling projects such as the one carried out by ADEME under the AGEC law
- The requirements of the European environmental labeling projects: PEF - Product environmental footprint
- The recommendations of the ITU L.1410 industry standard

7 DEFINING THE STUDY'S OBJECTIVES AND SCOPE

7.1 Definitions

7.1.1 Blockchain

Developed since 2008, blockchain is, in the first place, a technology for storing and transmitting information. This technology offers high standards of transparency and security because it operates without a central control body.

More concretely, blockchain allows its users - connected in a network - to share data without intermediary. In practice, a blockchain is a database that contains the history of all exchanges made between its users since its creation. The Bank of France explains the key features:

- the identification of each party is carried out by a cryptographic process.
- The transaction is sent to a network (or storage node) of computers located around the world.
- Each "node" hosts a copy of the database in which the history of transactions is recorded. All stakeholders can access it simultaneously.
- The security system is based on a consensus mechanism of all "nodes" each time information is added. Data is decrypted and authenticated by "data centers" or "miners". The transaction thus validated is added to the database in the form of a block of encrypted data (this is the "block" in blockchain)
- Decentralizing security management prevents transaction tampering. Each new block added to the blockchain is linked to the previous one and a copy is transmitted to all "nodes" in the network. Integration is chronological, indelible and tamper-proof.

7.1.2 Node, node operator and node auditor

Nodes are an essential component of blockchains. Nodes are the moderators of the blockchains: they are the ones who verify and validate the transactions of the network, and who, consequently, ensure its operation and its security.

Node Operators or node owners are the entities that operate the infrastructures of the nodes (hardware and software).

As it is important to maintain, as much as possible, a distribution of roles and avoid unique actors and centralization, such parties must be multiple and remain independent and in competition. These parties will be referred to as **node auditors or environmental footprint node agencies** with a role like rating agencies in the financial sector.

7.1.3 Gas

Gas is the fee required to successfully conduct a transaction or execute a contract on the Ethereum blockchain platform. Fees are priced in tiny fractions of the native cryptocurrency (₡ - Climate awaReness Coin) . Gas is used to pay validators for the resources needed to conduct transactions.

The exact price of the gas is determined by supply, demand, and network capacity at the time of the transaction.

The concept of gas was introduced to compensate nodes for their work done on maintaining and securing the blockchain. After the proof of stake algorithm was rolled out in September 2022, gas fees became the reward for staking ETH and participating in validation—the more a user has staked, the more they can earn.

"Gas limit" is the maximum amount of work you're expecting a validator will do on a particular transaction. A higher gas limit usually means the user believes the transaction will require more work. "Gas price" is the price per unit of work done. So, a transaction cost is the gas limit multiplied by the gas price. Many transactions also include tips, which are added to the gas price (the more you pay, the faster your transaction is completed). The lower a user estimates their gas price, the lower the priority in the queue they will be.

A blockchain node can run on a physical server or a virtual server, or virtual machine (VM), is a fully virtualized environment that runs on a physical server. It runs its own operating system (OS) and benefits from the same equipment as a physical server: CPU, RAM, hard disk, and network board.

7.1.4 Specificity of the blockchain Calculating the environmental footprint of a node

The consortium proposes a design for a new consensus that intends to incentivize the operators of nodes to select the best possible setup to run their system and enter into a competition for continuous improvement of their hardware, not only for the energy consumption but also in the ecological impact of the full lifecycle of the infrastructure they choose to use while producing the same service as an Ethereum public blockchain.

This consensus is called the **Proof of Climate awaReness (PoCR)**. Nodes will make efforts in improving the environmental footprint of their IT infrastructure if they are given a financial incentive to do so.

The Proof of Climate awaReness consensus therefore aims at aligning the crypto token earning of a node operator with the quality of the environmental footprint of its infrastructure.

This implies that the nodes can prove the level of environmental emission of their infrastructure to the rest of the network in a trustable and public way.

The PoCR consensus intends to put the nodes in competition for a better environmental footprint since the lower the footprint, the higher the earning, and the absence of progress on the environmental footprint would progressively reduce the earning as others becomes better. The earning of a node will be higher if the node can demonstrate to be running with a better setup than other nodes.

Note that carbon compensation scheme is excluded in the measurement of the node without preventing actors to compensate if they wish to do so.

Node auditors will be mandated by the node owner to assess their IT infrastructure and must follow the defined methodology and be in a position to demonstrate that the methodology has been followed. Once an assessment is done on a node, they will record in the Blockchain the environmental footprint of the node under their signature (i.e., making a blockchain transaction with their representative private key).

Only conformant auditors will be authorized to record the result of an audit in the chain. Node owners' identity will have to be publicly known and be transparent to the community. They cannot be also auditors as it would possibly create a conflict of interests.

The identity of the node owners should be known because the auditors will need to collect documentation and data and ensure that these are the actual figures of the nodes. The identity of the node owners are also expected to be public to enable public diAsplay of the node's activities and the origin of the crypto token created. Finally, as we will see in the next section the identity of the nodes will be important to decide allowing a new member in the group of block builders.

7.2 Objective of the study

As presented above, the objective of the study is to create a new criteria selection for blockchain node by its environmental footprint. In details:

- **To define a rule and a methodology to evaluate the environmental footprint of the nodes.**
- **To use the rules to calculate the environmental footprint of any Proof of Climate awaReness node and**
- **To feed the result in the Proof of Climate awaReness consensus algorithm**

7.3 Fields of the study

The study does not focus on the evaluation of products *per se*, but on the services rendered by complex systems that are comprised of a multitude of elements.

Therefore, the study includes, for each service and scenario considered, a quantification of each basic brick of products/equipment/flows needed to deliver the service studied.

A digital service meets a specific need; it has one or more functionalities and users. It is considered as the combination of:

- equipment to create, collect, store, analyze data (bytes),
- infrastructure that hosts and connects equipment (operator networks and data centers, in particular),
- software that runs on the equipment.

These digital service components are grouped in "tiers" such as:

- Users
- Networks
- Computer centers or data centers
- Other services

There may be multiple instances of each tier. For example, multiple data centers may be required to deliver the expected functional unit.

This definition is based on :

- the white paper "L'écoconception des services numériques", AGIT, 2017,
- the lexicon of reference terms "Du Green IT au numérique responsable", Club Green IT, 2018,
- the book "Sobriété numérique, les clés pour agir", Buchet-Chastel, 2019,
- the work undertaken within NegaOctet.

7.4 Description of the system

At the most comprehensive scale, a digital service incorporates the following elements categorized into "tiers":

- "Data center": as the centralized part of the information system, the data center encompasses several types of components
  - The structure itself, consisting of roads and concrete works, networks and utilities, plastering, carpentry and computer room layout (raised floor)
  - The "technical" facilities housing equipment known as the technical environment, which allows for the secure operation of the hosted computer equipment
  - The "computer rooms" housing the computer equipment
- If nodes are not provided in datacenter, they may leverage Cloud computing trough virtualization. Virtualization uses a hypervisor to allow a physical server to host several virtual servers. Thus, these virtual machines have the following characteristics:
  - vCPU: Just like physical machines, virtual machines need computing and information processing capabilities (processor or CPU) to function. Thus, the vCPU (Virtual CPU) parameter refers to their computing power capacity (virtual processor).
  - vRAM: Similarly, virtual machines need random access memory (RAM). Thus, the vRAM (Virtual RAM) parameter is the capacity of this virtual machine in terms of random-access memory.
  - Storage: this is the total storage capacity, expressed in GB, available for this virtual machine.

- The "networks" tier represents the networks used to transport data between the various data centers or between the data centers and users. The "networks" tier includes fixed and mobile network infrastructures such as WAN, MAN and LAN

- The "user" tier: the equipment on the user's side used to access the digital service; this can be a workstation, public equipment or another device

Figure 4: The various tiers of a digital service

A blockchain service is then a digital service but, in this study, the tier “user” will not be taken into account because the number of users and their type of devices may vary significantly and because the methodology defined in this document aims at qualifying the nodes and not the end users.

7.5 Function and functional unit

The functional unit is the unit of measurement used to assess the service provided by the service. It allows us to compare the environmental impacts of two services based on a common unit. This unit reflects the function that the service provides to the end user. The functional unit (FU) chosen depends on the service studied and the client's objective and must be defined during the life cycle assessment.

Each service studied is associated with a functional unit that will allow us to evaluate the two scenarios, on premises and cloud, according to a common unit. The functional unit studied is:

FU: Evaluation of the environmental footprint of a node with maximum 119 M gas per block (a block every 4s) and over a year.

119Mgas and 4 seconds per block are the configuration parameters of the proof of climate awareness consensus.

The functional unit considers the availability of the service provided to a user and its maintenance in usable condition for a duration of one year. The period of one year for the functional unit was chosen in order to take into account the variations of workload over 12 months and to have a complete vision of the impacts. Another reason is to consider the sobriety efforts that node operators may implement from year to year.

The definition of this functional unit is based on the following questioning:

the function(s) provided/service(s) rendered: "what",	Creation of blockchain node
the scope of the function or service: "how much",	119 M of Gas per block (a block every 4 s)
the desired level of quality: "how",	Environmental footprint
the (life)span of the service: "how long",	A year

Table 1: Definition of the functional unit

7.6 Scope by scenario studied

Within the framework of the study, several facilities and infrastructures are considered depending on the scenario.

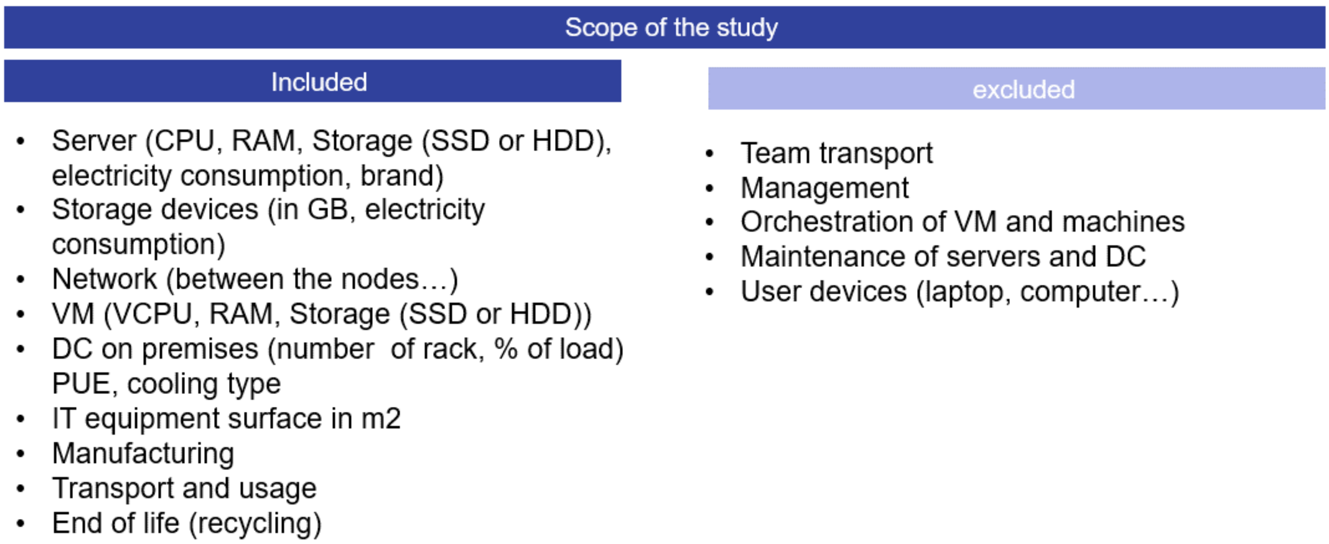

Figure 5: Overall scope of the study

The term "IT" refers to all the IT equipment hosted in the data center and used to deliver the service, namely:

- The server equipment (blade and rack) which are computing and information processing equipment.

- The storage equipment or racks that store the data. A storage rack contains a certain number of drives and a storage capacity expressed in GB.
- The network equipment is the equipment such as routers and switches that allow information (data) to be exchanged between data center equipment.

The term "DC technical infrastructure" or "infra" or "technical and building environment equipment" refers to the data center building itself (building structure) and all the technical equipment that allows for the following processes:

- Securing and distributing electricity,
- Air conditioning and treatment of computer rooms,
- Electrical backup,
- Security, safety, and monitoring

The scope considered by functional unit and by scenario is detailed below.

For our FU

TIER	"On Premises" scenario	"Cloud" scenario
Data center	Pool of computer equipment combined with the virtual server service hosted in data centers Equipment of the technical and building environment data centers.	Pool of IT equipment associated with the service under consideration hosted in a datacenter of a cloud service provider.
Networks	Network between nodes	
User	Out of scope	Out of scope

Table 3: Scope retained for FU1 to 4

7.7 Life cycle phases considered

To assess the environmental impact of providing the functional unit, we considered the following life cycle phases. This breakdown is aligned with the one defined in the ADEME " Methodological standard for the environmental assessment of digital services" PEFCR (Product Environmental Footprint Category Rules)[1] published as well as the ITU L.1410 standard.

[11] https://base-impacts.ademe.fr/gestdoclist

The drafting of this PEFCR for digital services and, particularly, for consumer telecom networks is part of the implementation of Article 13[2] of the AGEC law (French Anti-Waste Law for a Circular Economy) enacted on February 10, 2020.

This article requires internet service providers to inform their subscribers of the amount of data consumed while providing internet access and to detail the equivalent of the corresponding greenhouse gas emissions, as of January 2022.

The life cycle phases considered are presented in the table below.

	ITU L.1410		**Integration into the study**
Life cycle phase	**Tag**	**Life cycle phase**	
Manufacturing, distribution & installation	A	Acquisition of raw materials	
	A1	Extraction of raw materials	Included
	A2	Raw material processing	Included
	B	Production	
	B1	IT equipment production	
	B1.1	Production of components	Included
	B1.2	Assembly	Included
	B1.3	Support activities of IT equipment manufacturers	Excluded
	B2	Production of support equipment	
	B2.1	Production of support equipment	Included
	B3	Construction of a specific IT site	
	B3.1	Construction of a specific IT site	Included
Use	C	Use	
	C1	Use of IT equipment	Included
	C2	Use of support equipment	Included
	C3	Support activities of the operator	Excluded
	C4	Service provider support activities	Excluded
End of life	D	Processing of end-of-life equipment	
	D1	Preparing IT equipment for reuse	Included
	D2	End of life of IT equipment End of life of support equipment	Included
	D2.1	Storage/disassembly/dismantling/crushing	Included

[2] Article 13 Anti-Waste Law for a Circular Economy (AGEC) https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000041553759/ "*III. - A new 1 bis is inserted after 1 of I of Article 6 of Law No. 2004-575 of June 21, 2004 on Confidence in the Digital Economy*, as follows: '1 bis. As of January 1, 2022, and in compliance with Law No. 78-17 of January 6, 1978 on Data Processing, Data Files and Individual Liberties, the persons mentioned in 1 shall also inform their subscribers of the quantity of data consumed in the context of the provision of access to the network and shall indicate the corresponding greenhouse gas emission equivalent.*

Table 4: Life cycle phases considered

Category	Correspondence	Data used
Manufacturing and distribution of IT equipment and networks	Environmental impacts generated during the manufacturing and distribution phase of IT equipment (for the period considered in the study, i.e., 1 year)	NegaOctet
Use of IT and network equipment	Environmental impacts related to the use phase of IT equipment (electricity consumption for 1 year).	NegaOctet
End of life IT and network equipment	Environmental impacts generated during the end-of-life phase of IT equipment: transport and processing of electronic waste (for the period considered in the study, i.e., 1 year)	NegaOctet
Manufacturing DC Technical Infrastructure	Environmental impacts generated during the construction phase of the data centers and the technical environment equipment (based on the period considered in the study, i.e., one year and the space used in the data center)	NegaOctet
Use of the DC technical infrastructure	Environmental impacts related to the use of data center infrastructure equipment (air conditioning, electricity security, safety, etc.) used to support the operation of IT equipment within the scope of the study for the period considered in the study, i.e., one year.	NegaOctet
End of life DC technical infrastructure	Environmental impacts generated during the end-of-life phase of the infrastructure equipment: waste transport and processing (based on the period considered in the study, i.e., one year, and the space used in the data center)	NegaOctet

Note: Optional parts are in green

We have excluded the design and maintenance of the digital service.

For the on-premises scope, the table below presents the various phases of the life cycle and the corresponding data.

Table 5: Life cycle of the studied system and corresponding on premises data

7.8 Exclusions

In accordance with the ADEME reference document on "general principles for the environmental display of consumer products - Part 0: general principles and methodological framework", the following phases are excluded from the environmental assessment[3]:

- R&D-related flows,
- Flows related to the transport of employees from home to work and business trips,

[3]https://www.boutique.afnor.org/fr-fr/norme/bp-x303230/principes-generaux-pour-laffichage-environnemental-des-produits-de-grande-c/fa170405/37615

- Flows related to services associated with a product or system such as advertising, canvassing, and marketing,
- Flows related to administrative services,
- Sanitary facilities and cleaning of the infrastructure.

7.9 Consideration for end of life

For the purposes of the life cycle assessment in this report, we will consider material recycling and recovery at the end of their life cycle using the inventory method. This method consists in considering that the materials from waste are free for those who use them, and that the management of the materials from waste is free for those who produce the waste.

In this method, the impact of the material is therefore considered to be the sum of:

- the impacts of producing new and recycled parts in the material,
- the collection and pre-processing of the latter before it can be taken out of waste status,
- the impact of disposing of the portion of the material that will not be recycled or recovered at the end of its life.

With the inventory method, the impacts decrease sharply as the recycled content increases. They also decrease when the recycling rate increases, but to a much lesser extent.

Note that the inventory method is a hybrid allocation approach since it attributes benefits to the product related to both the incorporation of recycled material and the orientation towards recycling in proportions.

7.10 Allocation rules

7.10.1 General

For digital services, we can imagine two levels of modeling granularity:

- Equipment approach: each piece of equipment used by the digital service constitutes primary or secondary data. The digital service is considered as a sum of the usage of each piece of equipment, each use being defined through an allocation rule with respect to the equipment's total impact.

For the devices part, a digital service "Send an email" is made of a laptop, for example. The allocation rule for the laptop is:

- For the equipment's manufacturing, distribution, and end of life: the time of use to perform the business act reduced to the time of use over the life of the equipment
- For the equipment use phase: the energy consumption of the equipment to perform the business act

- System approach: a certain number of devices can be grouped into a physical (e.g., data center) or virtual (e.g., virtual machine) system, at the level of which the environmental impacts have been determined and which constitutes primary or secondary data. The digital service is considered as a sum of uses of each system, each use being defined through an allocation rule with respect to the total impacts of the system.

The equipment approach will be more precise but more complex than the system approach to implement.

The Digital Service Product Category Rules (PCR) recommends using an equipment approach on the perimeter controlled by the digital service operator and a system approach on the uncontrolled perimeter.

The digital service model can choose either or both approaches. In the latter case, particular care must be taken to avoid double counting or missing equipment.

The choice between the two approaches must be made in relation to how accessible the data is, the time required for the study, and the desired level of detail.

In the case of our study, we have adopted an equipment approach for on premises hosting by grouping this equipment by subsets:

- Computer equipment and LAN networks (in computer rooms),
- Technical infrastructure and data center structures,

For the public cloud scope, the equipment approach has also been adopted by grouping this equipment by sub-sets:

- Computer equipment and LAN networks (in computer rooms),
- Technical infrastructure and data center structures,

As recommended by ISO 14040-44, all allocations are made through physical parameters.

7.10.2 Allocation rules

7.10.2.1 General rules

As mentioned in the previous paragraph, in both the on premises and public cloud scenarios, we have considered the system in subsystems (IT equipment and LAN networks, technical infrastructure and data center structures, device equipment, WAN networks).

To reduce the impact of these subsystems to the individual functional units, the following parameters will serve as allocation keys:

Computer equipment and LAN networks (in computer rooms)

IT equipment and LAN networks

Manufacturing and distribution:

- Lifespan of each component
- 100% attributed to the platform

Use

- Power rating x load factor x 365 x 24 if power measured during operation is not available
- Operating power x 365 x 24 if operating power is available

End of life

- Lifespan of each component
- Type of waste
- 100% attributed to the platform

Technical infrastructure and data center structures

Building and technical environment	**Manufacturing and distribution:** ▪ In proportion to the duration of the FU over the life of each component ▪ In proportion to the surface area used for the platform versus the surface area of the IT room in the data center **Use** ▪ Platform energy consumption x (PUE-1) **End of life** ▪ In proportion to the duration of the FU over the life of each component ▪ By type of waste ▪ In proportion to the surface area used for the platform versus the surface area of the IT room in the data center

These settings will apply to all functional units across the on premises and public cloud scopes. Thus, the general allocation rules considered in this study for each of the systems are described in the following sections.

7.10.2.1.1 Technical infrastructure equipment (technical and building environment if datacenter)

For the **manufacturing, distribution and end-of-life** phase of the data center and the technical environment equipment, the equipment and spaces of the data centers are not exclusively allocated to the services considered in the study (VM, storage, database, messaging services).

If we know the power consumed by IT equipment, the ratio is:

$$\frac{\textit{Power of IT Equipment dedicated to the FU}}{\textit{IT Power installed on the datacenter}}$$

Otherwise, we must make an allocation according to the IT surface area allocated to these services in relation to the total surface area of the IT rooms available in the data center. This ratio is expressed in terms of the number of computer racks (cabinets).

Thus, the ratio considered is:

$$\frac{\textit{Quantity of IT racks for the FU}}{\textit{Quantity of racks for the whole datacenter}}$$

For the manufacturing, distribution, and end-of-life phases, in addition to the allocation based on physical space, we include an additional allocation based on a factor of time. As the useful life considered for the functional units is one year, the following ratio is used for each component:

$$\frac{\mathbf{1}}{\boldsymbol{LS}}$$

With **LS**, the lifespan of the equipment.

For the usage phase, since the power consumption of the technical environment is proportional to that of the IT equipment via the PUE ratio. PUE (Power Usage Effectiveness) is the energy performance indicator used for data centers. PUE is standardized according to ISO/IEC 30134-2:2016.[4] It is calculated as follows:

$$PUE = \frac{Datacenter\ electrical\ consumptions\ (over\ 1\ year)\ in\ kWh}{\text{Electrical consumptions of IT equipment (over 1 year)}\ in\ kWh}$$

The annual electricity consumption of the technical infrastructure equipment (***consInfra***), calculated yearly, is as follows

$$\boldsymbol{consInfra}(\mathbf{1}\ \boldsymbol{year}) = \boldsymbol{consIT}(\mathbf{1}\ \boldsymbol{year}) \times (\boldsymbol{PUE} - \mathbf{1})$$

With ***consIT***, the total power consumption of IT equipment. For the ***consIT*** (in kWh) we will require from the node, the real power consumption of the node over on year. Il these values are not provided we will follow the assumptions below (see section 7.12.2.3.1). To avoid being influenced by seasonal variations, the PUE value used is the one defined over the last 12 years.

7.10.2.1.2 IT equipment

The IT equipment (on the data center side) used to deliver the service is 100% dedicated to this service.

For the manufacturing, distribution and end-of-life phases, an allocation is applied according to a factor of time. As the useful life considered for the functional units is one year, the following ratio is used for each component to reduce the impacts of manufacturing, distribution, and end of life of equipment to one year, with LS (years), the equipment's lifespan.

$$\frac{\mathbf{1}}{\boldsymbol{LS}}$$

With LS, the lifespan of each component. The nodes' operator will provide these values to the auditors with proof (extension of guaranties for example), otherwise generic values (lifespan of a server is 5 for example) will be applied.

7.10.2.1.2.1 Reference flows and specific allocations for the FU

The table below specifies the various parameters and their corresponding units or designations.

[4] https://www.iso.org/standard/63451.html

Parameters	Definitions	Units
LS_DC	**Lifespan of the DC**	Year
LS_eq	**Lifespan of the equipment**	Year
$PowerEqt$	**Total power of the IT equipment used for the service**	kW
$PowerIT\_Tot$	**Total power installed on the DC**	kW
$NracksUF$	**Number of IT racks**	Racks
$NracksTotal$	**Total number of racks in the DC**	Racks
$NbVM$	**Total number of VMs provided by the service**	VM
$NbvcPU$	**Total number of vCPUs provided by the service**	vCPU
$NbGo$	**Total storage space**	GB
EF(usage)	**Emission Factor is a coefficient that describes the rate at which a given activity releases for example greenhouse gases into the atmosphere). EF(usage_eq) refer to the emission factor linked to the usage of the equipment (Power(kW)*usage (h)* Impact (1 kWh)**	Kg CO_2 eq, MJ, kg Sb eq or m^3

Table 6: The different parameters of the reference flows

The reference flow is defined as the ratio that is applied to reduce the impacts of all the elements described in the system to the different functional units.

The main reference flows and resulting allocations are as follows:

FU: Evaluation of the footprint of a node with maximum 119 M gas per block (a block every 4s) and over a year

It is important to note that this rule is used to compare different platforms using the same unit. A blockchain platform delivers a multitude of nodes with distinctive characteristics.

In addition, the lifespans are estimated at 5 years for computer equipment.

TIER		Allocation
Data center	Manufacturing, distribution and end of life	$\frac{1}{LS\_DC} \times \frac{PowerEqt}{PowerT\_Tot}$
	Use	$\frac{PowerEqt}{PowerIT\_Tot}$
IT equipment	Manufacturing, distribution and end of life	$\frac{1}{LS\_eqt}$
	Use	$EF(usage\_eq)$

Table 7: Allocation rules and reference flows for the FU if the nodes are on premises

7.11 Life cycle impact assessment methodology and impact types

The priority environmental indicators are calculated as follows:

- **Climate change**
- **Depletion of natural resources (minerals and metals)**
- **Primary energy consumption**
- **Water consumption**

The last two indicators will be assessed as relevant, **but their maturity is still questionable with respect to possible limitations on the confidence in the databases (e.g., on blue water).**

<table>
<tr>
<td>IMPACT INDICATORS</td>
<td>Depletion of natural resources (minerals and metals)
• Type of indicator: Problem-oriented impact indicator (mid-point)
• Abbreviation: PEF-ADPe
• Unit: kg of Antimony equivalent (kg Sb-eq)
• Evaluation Method: ReCiPe 2018
• Definition: Industrial exploitation leads to a decrease in available resources, which have limited reserves. This indicator measures the amount of mineral and metal resources taken from nature, as if they were antimony. Antimony is a resource considered to be depletable on a human scale and has a value of 1 by convention. A value greater than one for a resource indicates that a scarcer resource than antimony is being consumed.</td>
<td>Climate change
• Type of indicator: Problem-oriented impact indicator (mid-point)
• Abbreviation: GWP
• Unit: kg CO_2 equivalent (kg CO_2-eq)
• Evaluation Method: IPCC 2017 methodology
• Definition: Greenhouse gases (GHGs) are gaseous compounds that absorb infrared radiation emitted by the Earth's surface. The increase in their concentration in the Earth's atmosphere contributes to global warming.</td>
</tr>
</table>

	Primary energy consumption • Type of indicator: **Flow indicator** • Unit: **Primary MJ** • **Definition**: Primary energy is the first form of energy directly available in nature before any transformation: wood, coal, natural gas, oil, wind, solar radiation, hydraulic energy, geothermal energy, etc.	**Water resource depletion** • Type of indicator: **Impact Indicator** • Unit: **m³** • Abbreviation: **PEF-WU** • Unit: **m³-world eq** • Evaluation method: **Available WAter REmaining (AWARE) as recommended by UNEP, 2016** • **Definition**: This indicator represents water consumption multiplied by a factor that takes into account the water stress of the region where the water is consumed. For example, water consumption in the Sahara will have a greater impact than in Scandinavia

Table 8: Summary table of the different environmental indicators

7.12 Data that will be considered

7.12.1.1 Energy mixes

Based on RTE data[5], IAE[6] [7] and to be in line with recent developments in terms of life cycle assessment, the energy mixes of the various geographical scopes have been reconstructed using the NegaOctet method. These energy mixes are as follows.

7.12.2 Data center and technical environment

For buildings and the technical infrastructure equipment, we considered the following parameters:

7.12.2.1 Operations and life span of the buildings and technical infrastructure equipment.

We assume a permanent operation (every day of the year) of the on premises and cloud data centers.

7.12.2.2 End of life of building and technical infrastructure equipment.

At the end of their life, 100% of the building equipment and technical infrastructure of the data centers are collected. This equipment becomes machine waste. In this study, the deconstruction of the various buildings housing the data centers is not considered.

7.12.2.3 IT equipment

7.12.2.3.1 Electrical consumption of IT equipment

During the use phase, the real power consumption will be collected.

[5] RTE https://www.rte-france.com/eco2mix/la-production-delectricite-par-filiere

[6] https://www.iea.org/data-and-statistics/data-tables?country=GERMANY&energy=Electricity&year=2018

[7] UK : https://www.iea.org/data-and-statistics/data-tables?country=UK&energy=Electricity&year=2018

7.12.2.3.2 Equipment lifespan

The project team has defined an equipment lifespan of seven years for all types of equipment (server, storage and network). The site's IT equipment operates 24 hours a day, 365 days a year, except for shutdowns for operational readiness or maintenance.

7.12.2.3.3 End of life management of IT equipment

We considered that 100% of electronic equipment waste is directed towards dismantling channels at the end of its life.

7.13 Type, Origin, Sources & Quality of Data

7.13.1 Methodological bases

7.13.1.1 Articulation between data

Primary activity data (or specific data) is a quantified value derived from direct measurement or calculation from direct measurements of an activity or process in the product life cycle. This value is multiplied by an emission or characterization factor to calculate an impact category indicator.

Secondary data (or generic data) is a quantified value of a product life cycle activity or process obtained from sources other than direct measurement or calculation from direct measurements.

Semi-specific data is:

- primary (or specific) data to be filled in by the operator but for which a default value is proposed,
- data specified by default but can be specified by the operator to improve the environmental assessment.

These semi-specific values, which are deliberately conservative, are intended to encourage stakeholders to substitute their own values to improve the results of the environmental assessment. The conservative values thus proposed are not average values and must be used only within the framework of this methodological reference.

7.13.1.2 Primary data collection method

In practice, data collection is carried out over a long period of time (at least one year) to smooth out the effects associated with seasonality and the ramp-up of services. The impacts are then scaled back to the duration defined in the functional unit.

Primary data are collected over a one-year period to avoid seasonal variations. If the digital service in question has a total duration of less than one year, the collection period must cover the entire duration of the digital service.

The impact of digital services generally depends on the service's maturity, particularly in terms of its size in relation to the number of users: a service may be oversized in certain parts of its life. Thus, you must evaluate the variations in impact related to variations in usage and service sizing.

The following approaches were chosen for this:

- **Real approach:** the usage rate is determined based on the data collection performed. It should be specified,
- **Assumption approach:** the usage rate is determined by assumption. In this case, it must be specified, and several usage rate assumptions must be calculated through a sensitivity assessment in order to present the change in impact related to this assumption. In particular:
- **Optimized hypothesis, "the best theoretical case ":** the equipment implemented is used in such a way that the impacts reduced to the functional unit are minimized,
- **"By design" assumption:** this corresponds to the forecast made when the service was designed.

In the context of our study, the real approach is the preferred approach. In the absence of data, we will use an assumption-based approach.

7.13.2 Data quality

The quality of the study is linked in particular to the quality of the primary data collected - i.e., the input parameters: consumption, number of users, number of transaction hours, statistical breakdowns of the devices used, statistical breakdowns of the connection modes used, etc. - and the quality of the life cycle inventory data.

7.13.2.1 Data quality assessment

To characterize data quality, Data Quality Assessment (DQA) is used. The DQA method used by Ecoinvent was originally developed by Weidema and Wesnaus [25] and has evolved alongside the growth of the Ecoinvent database (Wernet et al. 2016 [26], Weidema et al. 2013 [27]). It consists of evaluating the quality of the data according to the following criteria:

7.13.2.1.1 Data reliability and verification

Verification focuses on how the collected data is verified. Verification can take place in several ways, such as on-site verification, recalculation, remeasurement or verification with other sources.

7.13.2.1.2 Data completeness

Completeness is defined as the percentage of available data in relation to the existing data set.

The adequate period is defined as a period of time large enough to account for periodic fluctuations (summer, winter). For digital technologies, one year can be considered as a good length of time.

7.13.2.1.3 Temporal correlation

Temporal correlation measures the difference in years between the date the data was created and the date it was collected.

7.13.2.1.4 Geographic correlation

Geographic correlation allows us to compare the data's origin to the geographic area of the scope considered in the study and to evaluate any discrepancies.

7.13.2.1.5 Technological correlation

Technological correlation specifies whether the data used covers the technology of the process studied.

The table below summarizes the various parameters and evaluation criteria.

Table 9: Data Quality Assessment (DQA)

Indicator	1 Excellent	2 Very good	3 Good	4 Fair	5 Poor
Reliability	Verified data based on accurate measurements or qualitative data	Verified data partially based on assumptions **or** Unverified data based on measurements	Verified data partially based on assumptions	Estimated and documented data (e.g., field data)	Undocumented estimated data
Completeness	Data representative of the market or field under consideration (more than 80%) or a significant sample size of companies and over an adequate period of time	Data representative (60-79%) of the market or field under consideration and over an adequate period of time **Or** Data representative (more than 80%) of the market or field under consideration and over a relatively short period	Data representative (40-59 %) of the market or field under consideration and over an adequate period of time **Or** Data representative (60-79%) of the market or field under consideration and over a relatively short period of time	Representative data (less than 40%) of the market or field considered and over an adequate period of time **Or** Data representative (40-59 %) of the market or field under consideration and over a relatively short period of time	Data of unknown representativeness
Temporal correlation	Less than 3 years between the data's date of collection and the date of creation	Less than 6 years between the data's date of collection and the date of creation	Less than 10 years between the data's date of collection and the date of creation	Less than 15 years between the data's date of collection and the date of creation	Data with unknown creation dates or older than 15 years
Geographic correlation	Data from the geographical areas of study	Average data from broader geographic areas that cover the areas considered in the study	Data from geographical areas with the same production conditions	Data from geographical areas with slightly similar production conditions	Data from unspecified geographic areas or from geographic areas that are completely different from the study areas
Technological correlation	Data from the companies, processes and materials under study	Data from the processes and materials under study but from different companies	Data from the processes and materials under study but from different technologies	Data on related processes or materials but identical technologies	Data on related processes or materials but different technologies

Based on this framework, we assessed the quality of the study data in the table below.

Scenario	Component	Life cycle phase	Sources	Reliability	Completeness	Correlation		
						Temporal	Geographical	Technological
NegaOctet Database	IT and network equipment	Manufacturing	Research and development, Equipment disassembly, manufacturer's data sheets, Experience on building over 1000 DC	**1 – 2**	**1**	**1**	**1 – 2**	**1 – 2**
		Distribution		**2**	**2**	**2**	**2**	**2**
		Use		**1 – 2**	**1 – 2**	**1**	**1**	**1**
		End of life		**1 – 2**	**1**	**1**	**1**	**1**
	Technical and building infrastructure equipment	Manufacturing		**1**	**1**	**1**	**1**	**1**
		Distribution		**2**	**2**	**1**	**1**	**1**
		Use		**1**	**1**	**1**	**1**	**1**
		End of life		**2**	**1-2**	**1**	**1**	**1**
Cloud services and datacenter	IT and network equipment	Manufacturing	Bibliography, cloud services Web sites, Experience on building DC, Experience on building over 1000 DC	**4**	**4**	**2**	**3**	**3**
		Distribution		**4**	**2**	**2**	**2**	**3**
		Use		**4**	**4**	**2**	**1**	**3**
		End of life		**4**	**4**	**2**	**2**	**3**
	Technical and building infrastructure equipment	Manufacturing		**4**	**3**	**3**	**4**	**4**
		Distribution		**4**	**3**	**3**	**4**	**4**
		Use		**4**	**3**	**1**	**4**	**4**
		End of life		**4**	**3**	**3**	**4**	**4**

Table 10: Summary table of study data quality

The hierarchy of the data used is as follows

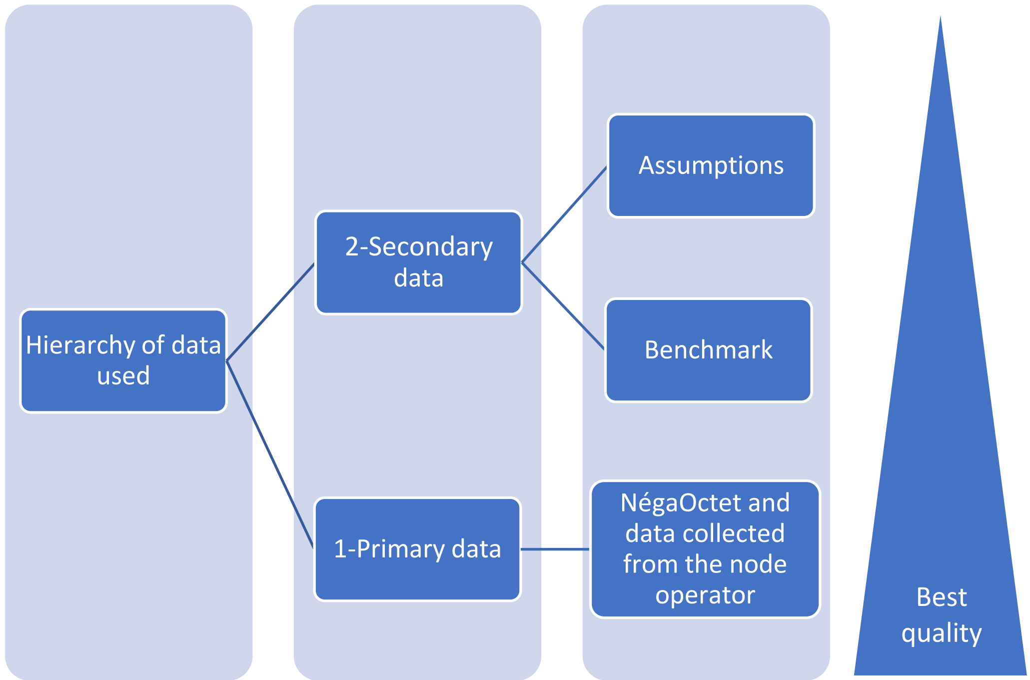

Figure 6: Data hierarchy

7.13.2.1.6 Methodology in the absence of primary data

When a primary data item was not available but was essential to quantify an impact in accordance with the lifecycle assessment methodology, by default we used the most penalizing data item from either the literature or from the sample of data available for this study.

Furthermore, the data related to cloud scenarios comes from various sources (websites, blog articles, scientific publications etc.). This data was submitted to the cloud providers for confirmation or correction. They did not wish to comment explicitly on the data provided. Thus, we assessed the consistency of these data to obtain the most reliable data possible, always based on a penalizing approach.

In the context of this study, we will use the rules and assumptions below (see next section) if primary data are not available. These rules and assumptions may be reviewed every 4 years.

7.13.3 Rules and assumptions when primary data are missing

7.13.3.1 Cloud scenarios

Virtual machines

The capacity of the platforms operated by nodes, expressed in the number of "standard" VMs, will be gathered.

The total number of VMs hosted in the cloud infrastructures as well as the number of vCPUs will be also provided by nodes teams based on the consumption and billing statements delivered by cloud services providers (for example using an internal Amazon calculator for which we do not have the details on the methodology it uses).

Furthermore, generally, cloud services providers consider that a vCPU is allocated to a thread of a server core. Thus, by knowing the number of vCPUs that is used, we can determine the number of servers required for the FU (a server has 70 vCPUs by default) and, therefore, the number of racks required for the FU (NracksFU).

In addition, the lifespans are estimated at 4 years for computer equipment. If the node operator knows exactly the real values, he can provide theses values.

TIER		"Cloud" scenario
Data center	Manufacturing and end-of-life	$\frac{1}{LS\_DC} \times \frac{NrackFU}{NracksTotal}$
	Use	$EF(NrackFU)$
IT equipment	Manufacturing, distribution and end of life	$\frac{1}{LS\_eq}$
	Use	$EF(usage\_eq)$

Table 11: Allocation rules and reference flows for VM on cloud services providers platforms

Storage

The storage capacity of the platforms operated by the node, expressed in GB, will be provide by the nodes teams based on information from the management interfaces.

In the cloud, we were able to determine the impact of the storage of one GB by considering the overall storage capacity on the basis of the information gathered [6].

In this case, a storage rack has a capacity of 11,000 TB. Moreover, if one third of the computer racks hosted in cloud services providers data centers (65,000 servers for 9,217 racks) are storage racks, we can determine the total storage capacity of cloud platforms (33,796,888 TB).

Since we know the number of racks needed for storage, we can determine the ratio (NracksFU/NracksTotal) for the cloud.

TIER		"Cloud" scenario
Data center	Manufacturing and end-of-life	$\frac{1}{LS\_DC} \times \frac{NrackFU}{NracksTotal}$
	Use	$EF(NrackFU)$
IT equipment	Manufacturing and end-of-life	$\frac{1}{LS\_eq}$
	Use	$EF(usage\_eq)$

Table 12: Allocation rules and reference flows for storage on cloud services providers platforms

7.13.3.2.1 Operations and life span of the buildings and technical infrastructure equipment

We assume a permanent operation (every day of the year) of the on premises and cloud data centers.

In addition, the data centers in all scopes have an average lifespan of 25 years. Details of the lifespan for each piece of equipment are presented below.

The assumptions about the operation and lifespan of the buildings and equipment of the technical infrastructure of public cloud data centers are the same as those that are on premises.

7.13.3.2 IT equipment

7.13.3.2.1 Constitution of the IT equipment

The work carried out within the framework of the NegaOctet project allows us to evaluate the environmental impacts of IT equipment, starting from the basic components (motherboard, processor, RAM, power supply, etc.). Therefore, it was necessary to have data on the IT equipment configurations used in all functional units.

However, for a given equipment model, the environmental impacts can vary considerably depending on the configurations chosen. This is especially true for storage equipment where the type (SSD, HDD, flash), technology (SLC, MLC, etc.) and the amount of storage (GB) are parameters that considerably influence the results of environmental analyses.

If the exact configurations are missing, the values provided below will be used to configure typical servers.

		Motherboard surface area (cm_2)	Number of CPUs	No. of cores	No. of SSDs	Storage per SSD (TB)	No. of HDDs	Storage per HDD (TB)	No. of RAM	GB per RAM
Servers	1 U rack server	3086	2	7	6	0.5	2	1	11	41
	Server blade 1 U	283	2	8	4	0.6	1	1	4	47
Storage	Storage rack	2802	3	14	80	7	166	0.7	4	4
	4U NAS storage equipment	2802	3	14	1	0.8	35	2	4	32

Table 13: Summary table of IT equipment compositions (average when data are not available)

These data were collected making a weighted average based on the number of occurrences of our benchmark database.

7.13.3.2.2 Electrical consumption of IT equipment

During the use phase, if the metrology system in place does not allow the energy consumption of all the equipment pools used to deliver the service to be reported, electricity consumption is evaluated according to the following formula:

$$\boldsymbol{IT\ equipement\ consumption\ over\ one\ year\ (kWh) = P \times 0{,}7 \times 24 \times 365 \times \frac{1}{1000}}$$

with **P** being the power rating of the equipment (expressed in watts) as defined in the manufacturers' data sheets and sometimes reported in the CMDB.

The factor **0.7** represents the average electrical load rate of IT equipment, which is estimated at **70%** in practice. This value is derived from APL's experience. It is also a ratio that is often used in the data center field.

The parameter 0.7 is not added is not used where the operating power is available. The factor $\mathbf{24 \times 365}$ represents the use in hours of the IT equipment over a year of use.

The factor **1/1000** represents the conversion of equipment power from W to kW.

7.13.3.2.3 Equipment lifespan

The project team has defined an equipment lifespan of seven years for all types of equipment (server, storage and network). The site's IT equipment operates 24 hours a day, 365 days a year, except for shutdowns for operational readiness or maintenance.

The lifespan of IT cloud equipment has been set at 4 years ([6]).

7.13.3.2.4 IT equipment power and electrical load rate

Where these data are not available, for WAN network equipment, we consider the nominal power available in the suppliers' data sheets, and we consider that the power in use phase is equal to the power ratings of this equipment multiplied by the load rate of 70%.

The power of the IT equipment hosted in the data centers of cloud service providers was estimated by referring to the article [1] published in the journal Sciences, which is a reference article on the energy performance of data centers.

Masanet, E., Shehabi, A., Lei, N., Smith, S., and J.G. Koomey (2020). ""Recalibrating global data center energy use estimates."" Science, Vol 367, Iss 6481."	
Average power of Hyperscale servers (W)	249
Average power of cloud provider servers (W)	236
Average power consumption per SSD (W)	5.3
Average power consumption per HDD (W)	6.2
Power consumption per network port (W)	1.6

Table 14: Operating power of the servers (source [7])

7.13.3.2.5 End of life management of IT equipment

We considered that 100% of electronic equipment waste is directed towards dismantling channels at the end of its life.

7.13.3.3 Server virtualization

When determining the number of virtual machines (and VDIs) for both internal hosting and cloud hosting, we have assumed that a virtual CPU uses one core of the physical processor.

$$\mathbf{1\ vCPU = 1\ core\ Thread}$$ [8][9]

This allocation is generally a consensus in the cloud computing field. Amazon corroborates this allocation on its site.

7.13.3.4 Cloud services

Since the cloud providers did not disclose specific information about their physical and virtual infrastructures, none of the data about cloud infrastructures comes from these providers directly but from various other sources (websites, blog articles, scientific publications etc.). A consistency analysis was performed on these

[8] https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/instance-optimize-cpu.html

[9] https://www.credera.com/insights/whats-in-a-vcpu-state-of-amazon-ec2-in-2018

data in order to have the most reliable data possible with a penalizing approach. The tables above summarize the main assumptions made.

Cloud services providers

The assumptions made regarding the scope of these data centers are presented in the table below.

Services	Data	Values	Sources
Data center	Average surface area of a data center	20,739	[2] [3]
	Average number of servers per DC	65,000	[2]
	PUE	< 1.12	[2]
	Technical and building infrastructure equipment	The IT equipment model is based on the collected information, and the technical infrastructure equipment model is based on Facebook's OpenCompute data center in Prineville, USA.	[4] [5] [6] [7]
	Number of data centers per zone	3 (but only one data center is assumed to host the services at a time.	[2] [3]
Compute	Number of TB per server	7.5 SSD and 7.5 HDD	[2]
	Number of VMs used by nodes on cloud infrastructures	1,294	Nodes
	Number of physical cores per Bare Metal	36	[2]
	Number of servers per switch	64	[2]
	Processor type for Bare Metal machines	Intel Xeon E5-2686 v4 (Broadwell)	[8]
	Lifespan of computer equipment	4 years	[9]
	Composition of the servers		[2] and [9]
Storage	Amount of storage for a storage array (TB)	1,100	[2]

Table 15: Cloud services providers (case of Amazon).

Below is a sample of data from the technical specifications of Facebook's OpenCompute data center in Prineville, USA.

Data	Values, numbers, and characteristics
Average data center surface area (m^2)	27,870
LVMB	4
Generator sets	As many 3,750 kVA units as there are LVMBs
Number of servers per OpenCompute Triplets	90. An OpenCompute triplet corresponds to a set of three computer racks
Batteries	The batteries have a life span of 10 years. They have a storage capacity of over 70 AH. There are 20 batteries per OpenCompute triplet. So, we have 20/3 batteries allocated to the racks.
Air conditioning	No need for chillers and other air-conditioning equipment because there is direct-air free cooling

Table 16: Data for the Facebook Prineville data center.

7.13.4 Database and tools

Thus, the model of the environmental impacts of this specific equipment was carried out by APL DATACENTER and by LCIE Bureau Veritas in the EIME v 5.8.1 LCA software combined with the 2018-11 database, either from the dismantling of the equipment and visual recognition of the components after identification and weighing, or from the detailed bill of materials.

7.13.5 Validity of results

The results are valid only for the situation defined by the assumptions described in this report. The findings are subject to change if these conditions differ. APL cannot guarantee their relevance or reliability if used by third parties or for other purposes than those mentioned in this report.

8 LIFE CYCLE INVENTORY

The node operators will be responsible of the data collection and the auditors will be responsible of the data validation (Figure 7).

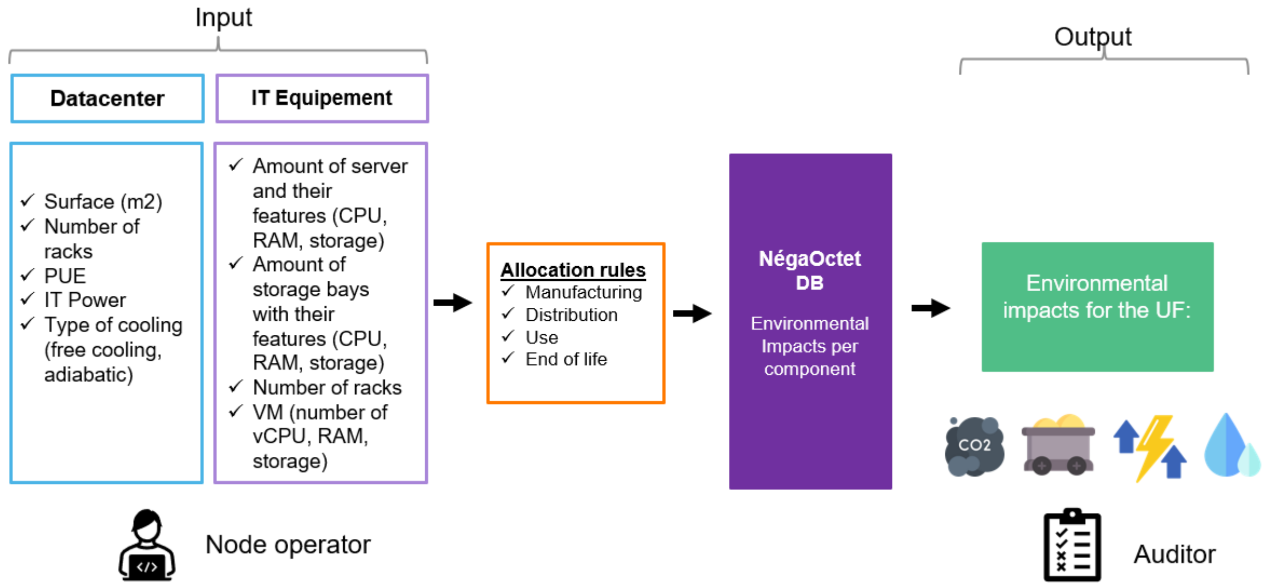

Figure 7: Workflow of the assessment

For datacenter and IT equipment, sample data required from the node operators are the following:

Building and technical environment (if necessary)

- Surface (m2)
- Amount of racks and IT rooms
- PUE
- IT Power consumption
- Type of cooling (free cooling, adiabatic)
- Location of the DC
- Electrical mix

IT equipment

- Amount of server and their features (CPU, RAM, storage)
- Amount of storage bays with their features (CPU, RAM, storage)
- Number of racks
- VM (number of vCPU, RAM, storage)
- Etc.

Full data required from the node operators will be found on the Excel sheet following this methodological node. The following information was obtained from these workshops.

9 IMPACT ASSESSMENT

All environmental assessment results will be presented using four indicators presented above:

- Greenhouse gas emissions **kg CO eq**,
- Abiotic resources depletion **kg Sb eq**,
- Water resource depletion **m^3 eq**,
- Primary energy consumption **MJ**.

After these results will be normalized and weighted in order to have a unique indicator.

8.1 Normalization of LCA results

The normalization in the LCA framework is the division of the impact computed for the system under study, by the impact of a reference value named the normalization reference[10][11]. LCA normalization has been identified as a leading driver in the aggregation process.

$$\boldsymbol{Normalized\ results} = \frac{\boldsymbol{Value\ of\ the\ environmental\ Indicator}}{\boldsymbol{Reference\ value}}$$

According to LCA standards, normalization can be used for 5 objectives:

- identifying incoherence during the iterative way of LCA. This means pointing out some aberrations in the LCA or LCI by comparing them to other references (order of magnitude).
- helping to select impact category indicators. The normalisation highlights the impact category indicators for which the studied product contributes the most compared with reference values.
- studying relative contribution of impact category indicators to a referent system: By reporting to a reference scenario (e.g., historical or sectorial reference), normalisation can help for decision making or communication of performance results.
- facilitating communication of LCA results:
    - by giving order of magnitude
    - by comparing with a product reference to help comparison,
- a calculation step toward weighting.

[10] https://eplca.jrc.ec.europa.eu/EnvironmentalFootprint.html

For this study, normalization will be used for the last two bullet points. Furthermore, one aspect particularly important in normalization is the selection or calculation of references values. We considered then the following reference values[12][13]:

Impact category	Unit	Normalization reference values
Climate change	kg CO2 eq./person	7,55E+03
Abiotic resources depletion	kg Sb eq./person	6,36E-02
Water use	m3 water eq of deprived water/person	1,15E+04
Primary energy consumption	MJ/person	6,50E+04

Table 17: Normalization reference values

Normalisation elements are in “unit / person” which means that the normalized indicator is the share of climate impact of one person.

8.2 Weighting of impact categories

This step aims to determine the significance of each category and how important it is relative to the others. It allows studies to aggregate impact scores into a single indicator. Weighting is a mandatory step in several framework (Product Environmental Footprint (PEF)). Weighting supports the interpretation and communication of the results of the analysis.

For doing it, normalised results are multiplied by a set of weighting factors (in %) which reflect the perceived relative importance of the life cycle impact categories considered. Weighted results of different impact categories may then be compared to assess their relative importance. They may also be aggregated across life cycle impact categories to obtain a single overall score.

The weighting factors[14] that will be used here are provided below:

[12] https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml

[13] https://eplca.jrc.ec.europa.eu/permalink/EF3_1/EF-v3.1.zip

Impact category	Weighting factor (%)
Climate change	21%
Abiotic resources depletion	8%
Water use	9%
Primary energy consumption	8%

Table 18: Weighting factors

Since we only consider 4 indicators, we could also add a second weighting factor as follows:

Impact category	Weighting factor (%)	Second Weighting factor (%)
Climate change	21%	$21/46=\mathbf{46\%}$
Abiotic resources depletion	8%	$8/46=\mathbf{17\%}$
Water use	9%	$9/46=\mathbf{20\%}$
Primary energy consumption	8%	$8/46=\mathbf{17\%}$

Table 19: Weighting factors updated

We will consider the second weighting factor for the calculation.

8.3 Single indicator

Once the impacts have been normalized and weighted, they are thus aggregated to form a single indicator which will constitute the environmental rating of the node. It is this note that will ultimately allow the remuneration of the nodes to be calculated.

$$\boldsymbol{SingleIndicator} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} \boldsymbol{Weighted\_indicator_i}$$

This single indicator is not expressed in any unit. In order to present the result in a more meaningful indicator, the ***SingleIndicator***, will be converted to the equivalent in each indicator as if the total is only made of this indicator.

$$CorrespondingImpact_i = \frac{SingleIndicator}{NormalizationReferenceValue_i}$$

The image below gives an idea of the result.

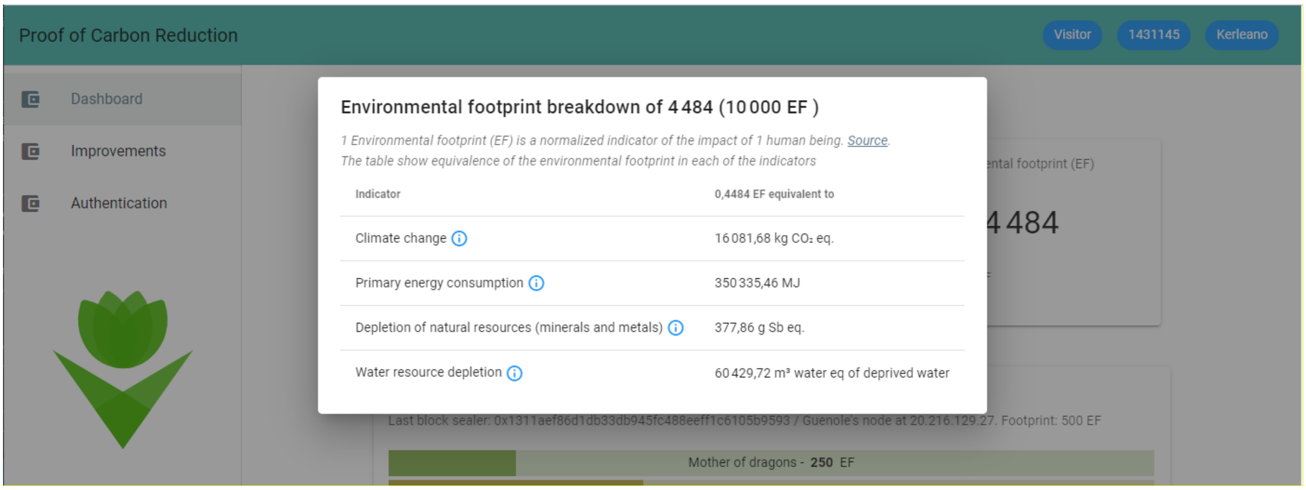

Figure 8: Idea of the conversion of the single indicator into the four environmental indicators

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11 Detailed characterization of data quality

11.1 On premises

11.1.1 IT equipment and networks and services

	Data	Features	Sources
Manufacturing	Inventory of fleet equipment mobilized	Pieces of equipment (*) Servers (*), Switches (*) Routers (*) Storage racks (*) Number of racks (*) Mass of the equipment (*)	NegaOctet
	Composition of the equipment	Motherboard surface area (*) CPU (**), RAM (**), SSD (**), Power supply (**)	NegaOctet
Distribution	Transport scenario	Transport scenario (*)	NegaOctet
Use	Power consumption	Operating power (*m) Nominal power (**) Calculated operating power (Power rating * 0.7) (c)	NegaOctet
	Service data inventories	Number of VMs (*c) Number of vCPUs (**c) Number of RAM (**c) Amount of GB for data storage (**c) Amount of GB for databases (**c) Number of VDIs (**c) Number of accounts (**c) Number of emails (*)	NegaOctet
End of life	Lifespan data	Lifespan (*) End-of-life scenario (*)	NegaOctet

Table 17: Type of data used for on premises IT equipment.

Similarly, the corresponding data quality assessment is presented in the table below

Indicator	Life cycle phases	1 Excellent	2 Very good	3 Good	4 Fair	5 Poor
Reliability	Manufacturing	Pieces of equipment (*) Servers (*), Switches (*) Routers (*) Storage racks (*) Number of racks (*) Motherboard surface area (*) CPU (**), RAM (**), SSD (**), Power supply (**)				
	Distribution		Transport scenario (*)			
	Use	Operating power (*m)		Calculated operating power (Nominal power*0.7) (c)		
	End of life	Mass of the equipment (*)	Lifespan (*) End-of-life scenario (*)			
Completeness	Manufacturing	Pieces of equipment (*) Servers (*), Switches (*) Routers (*) Storage racks (*) Number of racks (*) Mass of the equipment (*) Motherboard surface area (*) CPU (**), RAM (**), SSD (**), Power supply (**)				
	Distribution		Transport scenario (*)			
	Use	Operating power (*m) Nominal power (**) Calculated operating power (Nominal power*0.7) (c)				
	End of life	Lifespan (*) End-of-life scenario (*)				

Temporal correlation	Manufacturing	Pieces of equipment (*) Servers (*), Switches (*) Routers (*) Storage racks (*) Number of racks (*) Mass of the equipment (*) Motherboard surface area (*) CPU (**), RAM (**), SSD (**), Power supply (**)				
	Distribution		Transport scenario (*)			
	Use	Operating power (*m) Nominal power (**) Calculated operating power (Power rating * 0.7) (c) Number of VMs (*c) Number of vCPUs (**c) Number of RAM (**c) Amount of GB for data storage (**c) Amount of GB for databases (**c) Number of VDIs (**c) Number of accounts (**c) Number of emails (*)				
	End of life	Lifespan (*) End-of-life scenario (*)				

Geographic correlation	Manufacturing	Pieces of equipment (*) Servers (*), Switches (*) Routers (*) Storage racks (*) Number of racks (*) Mass of the equipment (*)	Motherboard surface area (*) CPU (**), RAM (**), SSD (**), Power supply (**)			
	Distribution		Transport scenario (*)			
	Use	Operating power (*m) Nominal power (**) Calculated operating power (Power rating * 0.7) (c) Number of VMs (*c) Number of vCPUs (**c) Number of RAM (**c) Amount of GB for data storage (**c) Amount of GB for databases (**c) Number of VDIs (**c) Number of accounts (**c) Number of emails (*)				
	End of life	Lifespan (*) End-of-life scenario (*)				
Technological correlation	Manufacturing	Pieces of equipment (*) Servers (*), Switches (*) Routers (*) Storage racks (*) Number of racks (*) Mass of the equipment (*)	Motherboard surface area (*) CPU (**), RAM (**), SSD (**), Power supply (**)			

	Distribution		Transport scenario (*)			
	Use	Operating power (*m) Nominal power (**) Calculated operating power (Power rating * 0.7) (c) Number of VMs (*c) Number of vCPUs (**c) Number of RAM (**c) Amount of GB for data storage (**c) Amount of GB for databases (**c) Number of VDIs (**c) Number of accounts (**c) Number of emails (*)				
	End of life	Lifespan (*) End-of-life scenario (*)				

11.1.2 Structure and equipment of the building infrastructure

Life cycle	Data	Features	Sources
Manufacturing	DC data	Data center surface area (*) IT room surface area (*) Surface area for offices (excluding data centers) (*) Power installed (*m) Power used (*m/c) Copper wiring (**) Fiber optic wiring (**)	NegaOctet
	DC equipment inventory	Pieces of equipment (*) Air conditioning (CRAH/CRAC) (*) Refrigeration units (*) Chilled water pumps (*) Air handling units (AHU) (*) Cooling tower Dry cooler (*) LVMB (*) LVDP (*) Transformers (*) Oil tanks (*) Generators (*) Inverters (*) Batteries (*)	NegaOctet
	Equipment weight data	Mass of equipment (**)	NegaOctet
Distribution	Transport scenario	Transport scenario (*)	NegaOctet
Use	Electrical consumption and consumables	Electricity: Total consumption (*m) Electricity: IT consumption (*m) Electricity: Infrastructure consumption (*m) PUE (*c) Mains water (*m) Refrigerant leaks (*m/c)	NegaOctet
End of life	Lifespan data	Lifespan (*) End-of-life scenario (*)	NegaOctet

Table 18: Type of data used for the equipment of the technical infrastructure.

Indicator	Life cycle phases	1 Excellent	2 Very good	3 Good	4 Fair	5 Poor
Reliability	Manufacturing	Data center surface area (*) IT room surface area (*) Surface area for offices (excluding data centers) (*) Power installed (*m) Power used (*m/c) Pieces of equipment (*) Air conditioning (CRAH/CRAC) (*) Refrigeration units (*) Chilled water pumps (*) Air handling units (AHU) (*) Cooling tower Dry cooler (*) LVMB (*) LVDP (*) Transformers (*) Oil tanks (*) Generators (*) Inverters (*) Batteries (*)			Mass of equipment (**)	
	Distribution		Transport scenario (*)			
	Use	Electricity: Total consumption (*m) Electricity: IT consumption (*m) Electricity: Infrastructure consumption (*m) PUE (*c) Mains water (*m) Refrigerant leaks (*m/c)				
	End of life		Lifespan (*) End-of-life scenario (*)			
Completeness	Manufacturing	Data center surface area (*) IT room surface area (*) Surface area for offices (excluding data centers) (*) Power installed (*m) Power used (*m/c)		Mass of equipment (**)		

		Pieces of equipment (*) Air conditioning (CRAH/CRAC) (*) Refrigeration units (*) Chilled water pumps (*) Air handling units (AHU) (*) Cooling tower Dry cooler (*) LVMB (*) LVDP (*) Transformers (*) Oil tanks (*) Generators (*) Inverters (*) Batteries (*)				
	Distribution		Transport scenario (*)			
	Use	Electricity: Total consumption (*m) Electricity: IT consumption (*m) Electricity: Infrastructure consumption (*m) PUE (*c) Mains water (*m) Refrigerant leaks (*m/c)				
	End of life	Lifespan (*) End-of-life scenario (*)	Lifespan (*) End-of-life scenario (*)			
Geographical, temporal and technological correlation	Manufacturing	Data center surface area (*) IT room surface area (*) Surface area for offices (excluding data centers) (*) Power installed (*m) Power used (*m/c) Pieces of equipment (*)				

		Air conditioning (CRAH/CRAC) (*) Refrigeration units (*) Chilled water pumps (*) Air handling units (AHU) (*) Cooling tower Dry cooler (*) LVMB (*) LVDP (*) Transformers (*) Oil tanks (*) Generators (*) Inverters (*) Batteries (*) Mass of equipment (**)				
	Distribution	Transport scenario (*)				
	Use	Electricity: Total consumption (*m) Electricity: IT consumption (*m) Electricity: Infrastructure consumption (*m) PUE (*c) Mains water (*m) Refrigerant leaks (*m/c)				
	End of life	Lifespan (*) End-of-life scenario (*)				

Indicator	Life cycle phases	1 Excellent	2 Very good	3 Good	4 Fair	5 Poor
Reliability	Manufacturing	Data center surface area (*) IT room surface area (*) Surface area for offices (excluding data centers) (*) Power installed (*m) Power used (*m/c)	Mass of equipment (**) Pieces of equipment (*) Air conditioning (CRAH/CRAC) (*) Refrigeration units (*) Chilled water pumps (*) Air handling units (AHU) (*) Cooling tower Dry cooler (*) LVMB (*) LVDP (*) Transformers (*) Oil tanks (*) Generators (*) Inverters (*) Batteries (*)			
	Distribution		Transport scenario (*)			
	Use		Electricity: Total consumption (*m) Electricity: IT consumption (*m) Electricity: Infrastructure consumption (*m) PUE (*c) Mains water (*m) Refrigerant leaks (*m/c)			
	End of life		Lifespan (*) End-of-life scenario (*)			
Completeness	Manufacturing	Data center surface area (*) IT room surface area (*) Surface area for offices (excluding data centers) (*) Power installed (*m) Power used (*m/c)	Pieces of equipment (*) Air conditioning (CRAH/CRAC) (*) Refrigeration units (*) Chilled water pumps (*) Air handling units (AHU) (*) Cooling tower	Mass of equipment (**)		

			Dry cooler (*) LVMB (*) LVDP (*) Transformers (*) Oil tanks (*) Generators (*) Inverters (*) Batteries (*)			
	Distribution		Transport scenario (*)			
	Use		Electricity: Total consumption (*m) Electricity: IT consumption (*m) Electricity: Infrastructure consumption (*m) PUE (*c) Mains water (*m) Refrigerant leaks (*m/c)			
	End of life	Lifespan (*) End-of-life scenario (*)				
Geographical, temporal and technological correlation	Manufacturing	Data center surface area (*) IT room surface area (*) Surface area for offices (excluding data centers) (*) Power installed (*m) Power used (*m/c) Pieces of equipment (*) Air conditioning (CRAH/CRAC) (*) Refrigeration units (*) Chilled water pumps (*) Air handling units (AHU) (*) Cooling tower Dry cooler (*) LVMB (*)				

		LVDP (*) Transformers (*) Oil tanks (*) Generators (*) Inverters (*) Batteries (*) Mass of equipment (**)				
	Distribution	Transport scenario (*)				
	Use	Electricity: Total consumption (*m) Electricity: IT consumption (*m) Electricity: Infrastructure consumption (*m) PUE (*c) Mains water (*m) Refrigerant leaks (*m/c)				
	End of life	Lifespan (*) End-of-life scenario (*)				

11.2 In the cloud

Similarly, for cloud services, the following tables present the quality of the data.

11.2.1 IT equipment and networks and services

Life cycle phases	Data	Features	Sources
Manufacturing	Inventory of fleet equipment mobilized	Pieces of equipment (**) Servers (**) Switches (**) Routers (**) Storage racks (**) Number of racks (**) Mass of the equipment (**)	[28] ; [4]
	Composition of the equipment	Motherboard surface area (**), CPU (**), RAM (**), SSD (**), Power supply (**)	[28] ; [4]
Distribution	Transport scenario	Transport scenario (*)	NegaOctet
Use	Power consumption	Operating power (**) Nominal power (**) Calculated operating power (Power rating * 0.7) (c)	[1], [16], [17], [18]
	Service data inventories	Number of VMs (*) Number of vCPUs (*) Number of vRAM (**c) Amount of GB for data storage (**c) Amount of GB for databases (**c) Number of accounts (**c) Number of VDIs (*) Number of emails (*)	Node operators
End of life	Lifespan data	Lifespan (**) End-of-life scenario (**)	[28] ; [4]

Table 19: Type of data used for IT equipment in the cloud

Similarly, the corresponding data quality assessment is presented in the table below

Indicator	Life cycle phases	1 Excellent	2 Very good	3 Good	4 Fair	5 Poor
Reliability	Manufacturing				Pieces of equipment (**) Servers (**) Switches (**) Routers (**) Storage racks (**) Number of racks (**) Mass of the equipment (**) CPU (**), RAM (**), SSD (**), Power supply (**)	
	Distribution				Transport scenario (*)	
	Use				Equipment power (**)	
	End of life				Lifespan (*) End-of-life scenario (*)	
Completeness	Manufacturing				CPU (**), RAM (**), SSD Pieces of equipment (**) Servers (**) Switches (**) Routers (**) Storage racks (**) Number of racks (**) Equipment weight (**), Power supply (**)	

	Distribution		Transport scenario (*)		Transport scenario (*)	
	Use				Equipment power (**) Number of VMs (*) Number of vCPUs (*) Number of vRAM (**c) Amount of GB for data storage (**c) Amount of GB for databases (**c) Number of accounts (**c) Number of VDIs (*) Number of emails (*)	
	End of life				Lifespan (*) End-of-life scenario (*)	
Temporal correlation	Manufacturing		Pieces of equipment (**) Servers (**) Switches (**) Routers (**) Storage racks (**) Number of racks (**) Mass of the equipment (**) CPU (**), RAM (**), SSD (**), Power supply (**)			
	Distribution		Transport scenario (*)			
	Use		Operating power (**) Number of VMs (*) Number of vCPUs (*) Number of vRAM (**c) Amount of GB for data storage (**c)			

			Amount of GB for databases (**c) Number of accounts (**c) Number of VDIs (*) Number of emails (*)			
	End of life		Lifespan (*) End-of-life scenario (*)			
Geographic correlation	Manufacturing			Pieces of equipment (**) Servers (**) Switches (**) Routers (**) Storage racks (**) Number of racks (**) Mass of the equipment (**)		
	Distribution		Transport scenario (*)			
	Use	Energy mix				
	End of life		End-of-life scenario (**)			
Technological correlation	Manufacturing			Pieces of equipment (**) Servers (**) Switches (**) Routers (**) Storage racks (**) Number of racks (**) Mass of the equipment (**) CPU (**), RAM (**), SSD (**), Power supply (**)		
	Distribution			Transport scenario (*)		

	Use			Equipment operating power (**) OpenCompute reference		
	End of life			Lifespan (*) End-of-life scenario (*)		

11.2.2 Structure and equipment of the building infrastructure

Life cycle phases	Data	Features	Sources
Manufacturing	DC data	Data center surface area (**) IT room surface area (**) Surface area for offices (excluding data centers) (**) Power installed (**) Power used (**) Copper wiring (**) Fiber optic wiring (**)	[28] ; [4]
	DC equipment inventory	Pieces of equipment LVMB (**) LVDP (**) Transformers (**) Oil tanks (**) Generators (**) Inverters (**) Batteries (**)	[1], [16], [17], [18]
	Equipment weight data	Mass of the equipment (**)	[28] ; [4]
Distribution	Transport scenario	Transport scenario (**)	NegaOctet
Use	Electrical consumption and consumables	Electricity: Total consumption (**c) Electricity: IT consumption (**c)	[1], [16], [17], [18]

		Electricity: Infrastructure consumption (*c) PUE (**) Mains water (**)	
End of life	Lifespan data	Lifespan (**) End-of-life scenario (**)	[28] ; [4]

Table 20: Type of data used for technical infrastructure equipment in the cloud

Similarly, the corresponding data quality assessment is presented in the table below

Indicator	Life cycle phases	1 Excellent	2 Very good	3 Good	4 Fair	5 Poor
Reliability	Manufacturing	Data center surface area (*) IT room surface area (*) Surface area for offices (excluding data centers) (*) Power installed (*m) Power used (*m/c)			Data center surface area (**) IT room surface area (**) Surface area for offices (excluding data centers) (**) Power installed (**) Power used (**) Copper wiring (**) Fiber optic wiring (**) Pieces of equipment LVMB (**) LVDP (**) Transformers (**) Oil tanks (**) Generators (**) Inverters (**) Batteries (**) Mass of the equipment (**)	
	Distribution				Transport scenario (**)	

	Use	PUE (**) Mains water (**)			Electricity: Total consumption (**c) Electricity: IT consumption (**c) Electricity: Infrastructure consumption (*c)	
	End of life				Lifespan (**) End-of-life scenario (**)	
Completeness	Manufacturing			Data center surface area (**) IT room surface area (**) Surface area for offices (excluding data centers) (**) Power installed (**) Power used (**) Copper wiring (**) Fiber optic wiring (**) Pieces of equipment LVMB (**) LVDP (**) Transformers (**) Oil tanks (**) Generators (**) Inverters (**) Batteries (**) Mass of the equipment (**)		
	Distribution			Transport scenario (**)		
	Use			Electricity: Total consumption (**c) Electricity: IT consumption (**c) Electricity: Infrastructure consumption (*c)		

	End of life			Data center surface area (**) IT room surface area (**) Surface area for offices (excluding data centers) (**) Power installed (**) Power used (**) Copper wiring (**) Fiber optic wiring (**) Pieces of equipment LVMB (**) LVDP (**) Transformers (**) Oil tanks (**) Generators (**) Inverters (**) Batteries (**) Mass of the equipment (**)		
Temporal correlation	Manufacturing			Data center surface area (**) IT room surface area (**) Surface area for offices (excluding data centers) (**) Power installed (**) Power used (**) Copper wiring (**) Fiber optic wiring (**) Pieces of equipment LVMB (**) LVDP (**) Transformers (**) Oil tanks (**) Generators (**) Inverters (**) Batteries (**)		

				Mass of the equipment (**)		
	Distribution			Transport scenario (**)		
	Use	PUE (**) Mains water (**)		Electricity: Total consumption (**c) Electricity: IT consumption (**c) Electricity: Infrastructure consumption (**c)		
	End of life			Lifespan (**) End-of-life scenario (**)		
Geographic correlation	Manufacturing				Data center surface area (**) IT room surface area (**) Surface area for offices (excluding data centers) (**) Power installed (**) Power used (**) Copper wiring (**) Fiber optic wiring (**) Pieces of equipment LVMB (**) LVDP (**) Transformers (**) Oil tanks (**) Generators (**) Inverters (**) Batteries (**) Mass of the equipment (**)	
	Distribution				Transport scenario (**)	
	Use	Energy mix (*)			Electricity: Total consumption (**c)	

					Electricity: IT consumption (**c) Electricity: Infrastructure consumption (**c)	
	End of life				Lifespan (**) End-of-life scenario (**)	
Technological correlation	Manufacturing			Data center surface area (**) IT room surface area (**) Surface area for offices (excluding data centers) (**) Power installed (**) Power used (**) Copper wiring (**) Fiber optic wiring (**) Pieces of equipment LVMB (**) LVDP (**) Transformers (**) Oil tanks (**) Generators (**) Inverters (**) Batteries (**) Mass of the equipment (**)		
	Distribution			Transport scenario (**)		
	Use			Electricity: Total consumption (**c) Electricity: IT consumption (**c) Electricity: Infrastructure consumption (**c)		
	End of life			Lifespan (**) End-of-life scenario (**)		