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Materials-based inconsistencies in a life cycle assessment database on digital services

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Abstract

The NégaOctet consortium developed the very first database to assess the environmental impacts of digital services through life cycle assessment (LCA). A digital service regroups three third: the data centres, the networks and the end-user terminals. Around 1 500 data, specific to France and Europe, were created during the project.

In a digital service, the extraction and manufacturing of end-user terminals and data centres are the most polluting life cycle steps. The wafers are responsible for these impacts, requiring highly pure materials and power-consuming processes. Therefore, this thesis aims to identify the most critical material-based inconsistencies and correct them before the publication of the NegaOctet database.

An LCA on a cloud service was done to manipulate the database and investigate inconsistencies. The indicators from the PEF methodology have been selected. The LCA was carried out on EIME software. As a result, the data centre is the most impacting third. It impacts from 12% to 77%, depending on the indicators. In addition, nine issues were found in the database.

The most critical one concerned allocating the digital services' equipment. An experiment has shown that using the wrong allocation can double the impacts of a specific equipment. This thesis determined allocation equations for the terminal's equipment, the network, and the data centre equipment. In the end, three equations were found for the servers depending on the data available by the user. A ratio of equipment per server was selected, for the firewall and switch. The non-IT equipment and architecture allocation was determined from the ratio of IT room m^2 per server. Equations were also determined for the terminals, network and storage bay.

Keywords LCA, cloud, digital services, allocation, NégaOctet, EIME

Contents

Symbols and abbreviations

Abbreviations

ADEME	French Agency for the Environment and the control of energy
AGEC	Anti-waste for a circular economy
GHG	greenhouse gases
HDD	Hard Disk Driver
HPC	high-performance computing
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
ISO	Organisation for Standardization
IT	Information Technology
LCA	Life cycle assessment
MIPS	Material input per services
NO	NégaOctet
Nbr	Number
PEF	Product environmental footprint
PCR	Products categories rules
PUE	Power usage effectiveness
RAM	Random-Access Memory

1 Introduction

According to the sixth assessment report of the IPCC published in 2022, countries have 3 years left to reduce their greenhouse gas emissions to limit global warming to +1.5°C [1]. Digital services represent 4.2% of the greenhouse gas emissions of Europe in 2019 [2]. With the increasing demand for connected objects and data centres, the impacts of digital services will grow in the following years. Therefore, organisations are being driven to consider the environmental impacts of their digital services by European and French regulations.

The life cycle assessment (LCA) is a standardised methodology globally recognised to evaluate the environmental impacts of a product and decrease them through eco-conception. An LCA is conducted with an LCA software using a database. However, there is only one database on the different equipment constituting a digital service owned by the NegaOctet consortium. This database is not published yet.

In late 2018, three private companies and an association created the NegaOctet project funds by the ADEME, the French agency for the environment and energy control. The project aimed to develop the very first database to assess the environmental impacts of digital services. A digital service regroups the datacentres, the networks and the end-user terminals. Around 1 500 data, specific to France and Europe, were created during the project. Moreover, the NegaOctet project led to the creation of two product category rules (PCR). They are national methodologies describing how to do an LCA on digital services. Moreover, by 2024, the PCR will partly be used by the French network operators obliged by the AGEC law (anti-waste for a circular economy French law) to communicate to their consumers the carbon impact of their connexion to the internet.

This project required the full-time work of 10 persons for 3 years and the cooperation of important entities such as network operators and datacentres companies. Indeed, APL, an expert in the data centres company, is a part of the NegaOctet consortium. The other consortium members are CODDE LCIE Bureau Veritas, an expert in life cycle assessment company; GreenIT, an association specialised in responsible digital and DDemain, an expert consultant in LCA and eco-conception.

The NegaOctet project also led to a study on the global impacts of digital services in France and Europe. They fund the extraction of raw materials, and the manufacturing of end-user terminals and datacentres are the most polluting stages of digital services [2]. Indeed, end users' terminals and datacentres are composed of wafers which require highly pure materials and power-consuming processes.

Currently, at the beginning of February 2022, the work done by the experts is over on the database. However, after 3 years of work by 10 persons and the creation of 1 500 data, some errors and inconsistencies may persist in the database. Therefore, this thesis aims to identify the most critical ones and correct them before the publication of the database. However, 6 months' work might not be sufficient to find and fix all the inconsistencies, so a method will be created to sort the issues by criticality. Therefore, the criticality of an inconsistency will be higher if it concerns raw materials, as their production and extraction represent the major impacts of digital services.

To focus the thesis, certain potential research zones have already been identified. Due to the creation of 1 500 data, some might not be correctly modelled or uploaded into the database. Those errors can only be found using the database on a concrete study case. This study will be made with the LCA software EIME. Then, it is admitted that the modelling of digital services is complex and a source of issues for most users. The last potential zone of research is the electricity mixes of some European countries that have not been updated. Indeed, as they date from 2008, those mixes are no longer representatives of the current situation.

This thesis is divided into 7 chapters and focuses on France as it is a French project driven by the AGEC law and the ADEME. Chapter 2 presents the LCA methodology recommended by the standard ISO 14040 and 14044. Chapter 3 reviews the historical context of the LCA methodology creation as well as the European and French regulations governing the public and private entities. Chapter 4 synthesises the literature reviews on the LCA assessment of digital services. Chapter 5 contains the research and identification of critical inconsistencies in the NegaOctet database. Chapter 6 resolves the allocations to use for an LCA on digital services, while chapter 9 concludes and summarises the main results of the thesis.

2 Life Cycle Assessment

The general methodology of the life cycle assessment (LCA) is presented to allow a better understanding of the following chapters. Firstly, the main principle of the LCA is presented, followed by the reason LCA is used and its difference from other environmental analyses. Then, the methodology of the LCA is described. This one must be compliant with certain norms and regulations to be valid.

2.1 The main principle of the life cycle assessment

Several environmental analysis methodologies are different from LCA. These methodologies can be differenced by the number of environmental criteria they analysed and the type of data used (quantitative or qualitative). The most famous environmental analyses are shown in F*igure 1*.

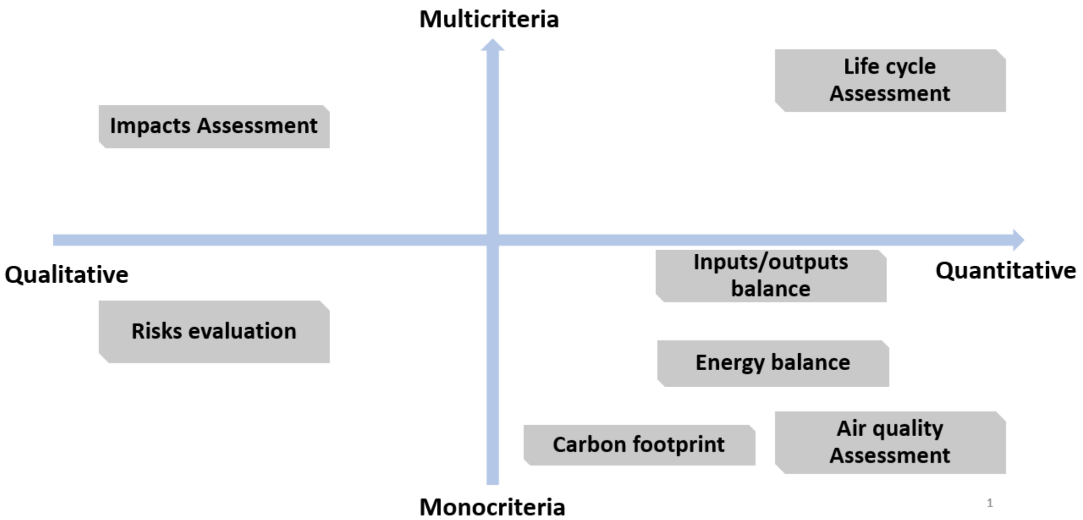

Figure 1: Different main environmental assessments

The two most known environmental analyses are carbon footprint and energy balance assessment. They both are mono-criterion and quantitative methodologies. On the other side, the LCA is a quantitative methodology which analysed several environmental criteria [4], [5] (including carbon footprint and energy balance). The environmental indicators chosen for an LCA depend on the study's goal and the type of product studied. Indeed, they are dozens of environmental indicators, but not all of them are relevant for a study. The next chapter will explained how the indicators analysed should be chosen. Moreover, the most common indicators are presented in *Table 1*.

Table 1: Main environmental indicators used in LCA and their definition

Impact indicators	**Definition**
Climate Change	Indicator that measures the emission of greenhouse gases (GHGs) in the atmosphere. The increase in their concentration contributes to global warming.[6], [7]
Ozone depletion	Indicator that measures the thinning of the ozone layer in the stratosphere. [7]
Particulate matter	Indicator measuring the presence of small particles in the atmosphere (diameter < 10µm). Such particles can harm human health through their inhalation. [6], [7]
Acidification	Indicator measuring air acidification (release of certain pollutants in the atmosphere). Through rain, they can damage ecosystems and buildings.[6]
Eutrophication	Indicator measuring the number of nutrients present in a habitat (aquatic or terrestrial). Too many nutrients provoke a depletion followed by the death of the ecosystem. [6], [7]
Ionising radiation	Indicator measuring the release of ionising radiations by the radionuclides emitted by some human activities. Ionising radiations can cause DNA damage. [6], [7]

Photochemical ozone formation	Indicator measuring the quantity of ozone formed at the ground level by volatile organic compounds and nitrogen-oxygen. At such a lower altitude, ozone can harm human health when penetrating the respiratory system. [6], [7]
Resource use, fossils	Indicator measuring the primary energy consumption from non-renewable sources (oil, natural gas, etc.). [6], [7]
Resource use, minerals, and metals	Indicator measuring the number of minerals and metals resources extracted from the earth as if they were antimony. [6], [7]
Water pollution	Indicator measuring the quantity of water necessary to dilute toxic elements rejected in water during the product's life cycle. [7]

Furthermore, the LCA is a methodology considering the whole lifecycle of a product. Consequently, the impacts of the extraction of raw materials, the manufacturing, the transport, the use and the end of life are analysed [4], [5], [7], [8]. Through this life cycle analysis, the LCA promotes the circular economy, which is a system that aims to decrease the consumption and the number of waste thrown by recycling and reusing materials.

Finally, with the lifecycle and multiple indicators considered, the LCA prevents the transfer of impacts when comparing two products. A speaking example of this phenomenon is shown in *Figures 2* and *3*, comparing electric and thermal cars. Electric cars pollute less during their utilisation stage than thermal ones because the production of electricity impacts less than the production of oil. However, they are more pollutants during fabrication, requiring more electrical components. In addition, the transfer of impacts implies a transfer between different stages of life of the cars and between various indicators. Indeed, an electric car has more impact on the acidity or human toxicity indicators while a thermal car has more impact on the contribution to climate change (CO2 emissions) [9]. Such a phenomenon can only be identified with the LCA. Indeed, a carbon footprint assessment won't show it as it only focuses on one indicator (climate change).

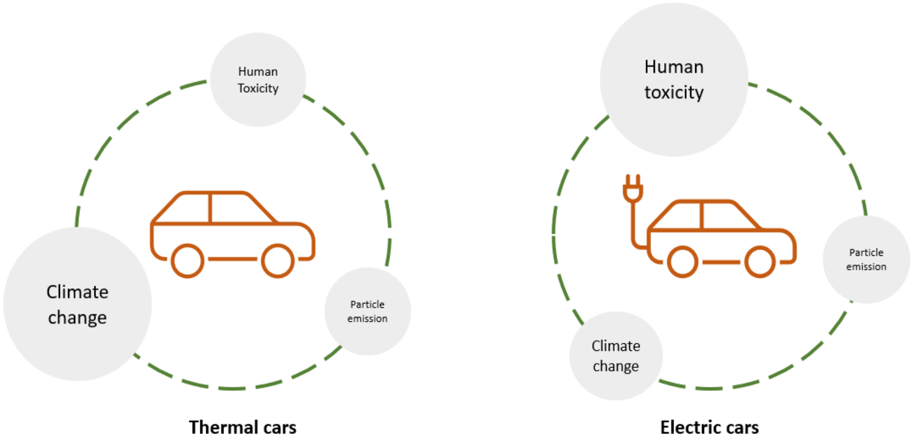

Figure 2: Impacts transfer between thermal and electric cars on different indicators

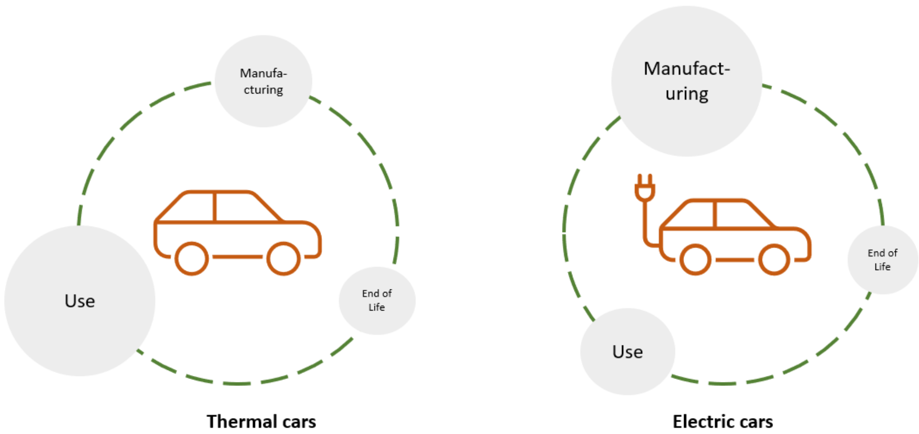

Figure 3: Impacts transfer between thermal and electric cars on their stages of life

2.2 The four steps of the life cycle assessment methodology

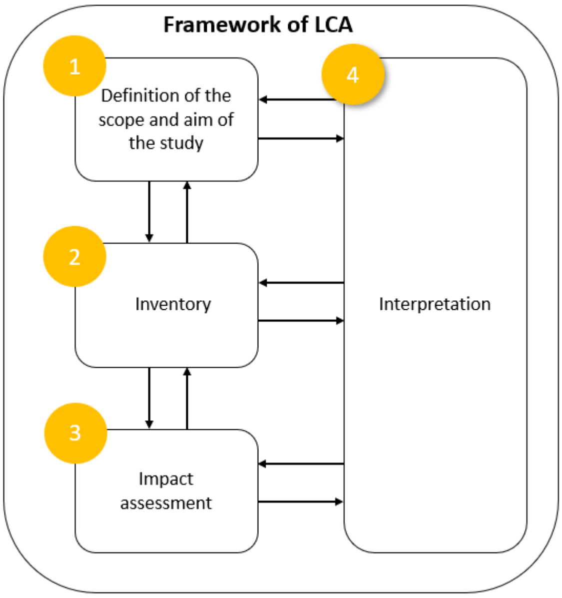

Figure 4: The four steps of the LCA methodology as defined in the ISO 14 040 and 14 044 [5] *NF EN ISO 14044:2006.* [5] *NF EN ISO 14044:2006.*

The LCA methodology is constituted of four steps shown in *Figure* 4 [4], [5]. The first one aims to define the goal of the study as well as its scope. Therefore, the goal has to state the application of the study, the reasons for carrying it out, the target audience, and if the results will be published and publicly available [5], [7], [8]. Meanwhile, the scope defines and describes the product, the function of the system, the functional unit, the allocations rules, the boundaries of the system, the impact indicators are chosen, the assumptions and limitations of the study, etc. [5], [7], [8]

Once the goal and scope of the study are stated, the functional unit must be chosen. It is the reference unit used to assess the impacts of the product's function. It should contain the function of the product studied, the lifetime of the product's function and how much it is used (it can be the frequency, the length, or the number of utilisations) [4], [5], [7], [8]. This functional unit must be coherent with the goal and scope defined previously in the study [8].

Moreover, it allowed a meaningful and valid comparison with other products [8].

For instance, the LCA of bags used in grocery shops will compare single-use plastic bags with single-use biodegradable bags and tote bags. The functional unit that makes possible the comparison between each bag might be determined as follows:

Carrying fruits and vegetables once a week for one year.

This functional unit will also be determined for digital services. As an example, the functional unit of a website can be defined as follows:

Website operation for a year.

The second step of LCA is inventory analysis. All the data must be collected to be analysed. However, there are two types of data: primary and secondary data. The primary data are collected directly at the factory [5], [7], [8]. Therefore, all the input and output flows, materials, mass, volume, and energy are listed to be exploited later. This data type is longer to collect as it can take more than a year. To have representative data, they must be collected for a long time to get average data and not be influenced by seasonal data. The secondary data are the data available in every environmental database. The data of a specific process or matter is an average of the primary data collected in different factories or is issued from the literature [5], [7], [8]. When using a database, the user only needs to know the components, materials, and processes used during the lifecycle of his product. The data are less precise, but the inventory analysis step is faster as it requires a couple of weeks.

Then, the impacts are assessed. All the input and output flows collected during the inventory analysis are translated into environmental indicators during this step. It is worth noting that one flow can cause different impacts and different flows cause an impact. For example, in *Figure 5*, gold, carbon, sand, and copper contribute to the indicator "Resources depletion". On the other hand, lead contributes to the indicators "Eutrophication", "Ionising radiation", "Photochemical ozone creation", "Ozone depletion", and "Global warming". Furthermore, a characterisation factor is associated with each link between a flow and an indicator. It translates the flow as if it was in the unit of the indicator [4], [5], [7], [8]. Indeed, each indicator has a unit called equivalent. For instance, the global warming unit is in kg equivalent of CO2 (kg eq CO2). *Figure 5* shows that 1 kg of methane is 25 times more important than the impact of 1 kg of CO2; otherwise, the release of 1kg of methane is equivalent to the release of 25 kg of CO2. Finally, there are two types of indicators: midpoint and endpoint indicators. Midpoint indicators focused on the effects of the flows (global warming, ozone depletion, eutrophication, etc.), while endpoint indicators focused on damages caused by these flows (on human health, natural environment, natural resources, etc.) [8]. However, several different methods exist to evaluate an indicator's impacts (CML, IPCC, etc.). Consequently, the calculation method must be specified as different indicators can have the same name but not the same unit or evaluation method.

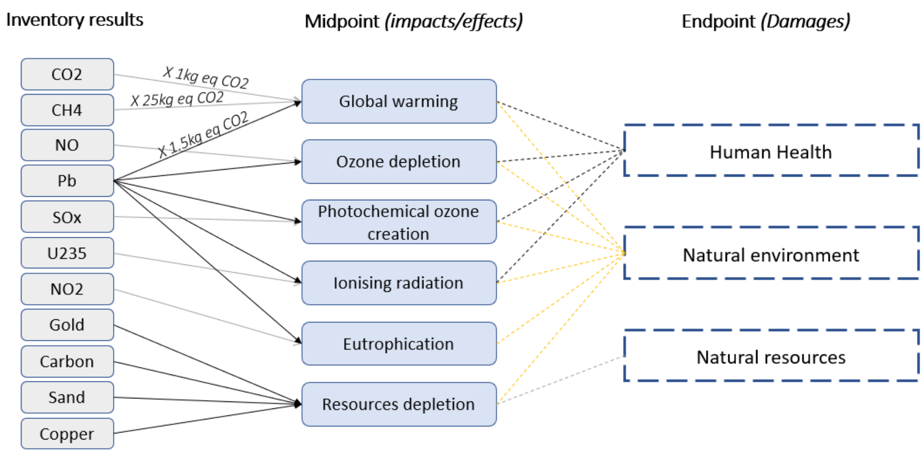

Figure 5: Impacts assessment methodology for an LCA analysis *(the list of indicators is not exhaustive)*

The final step concerns the results and the interpretation. Most of the time, results are shown in a graphic similar to *Figure 6*. The graphic shows which lifecycle step of the product is the most impacting (manufacturing, transport, use or end of life) for each indicator. The results can be even more precise by knowing which element or process of the product has the most impact. This step aims to, first, check the coherence, then validate the compliance with the goal stated, and finally conclude by explaining the limits of the study and giving some recommendations to decrease the impacts [4], [5], [7], [8].

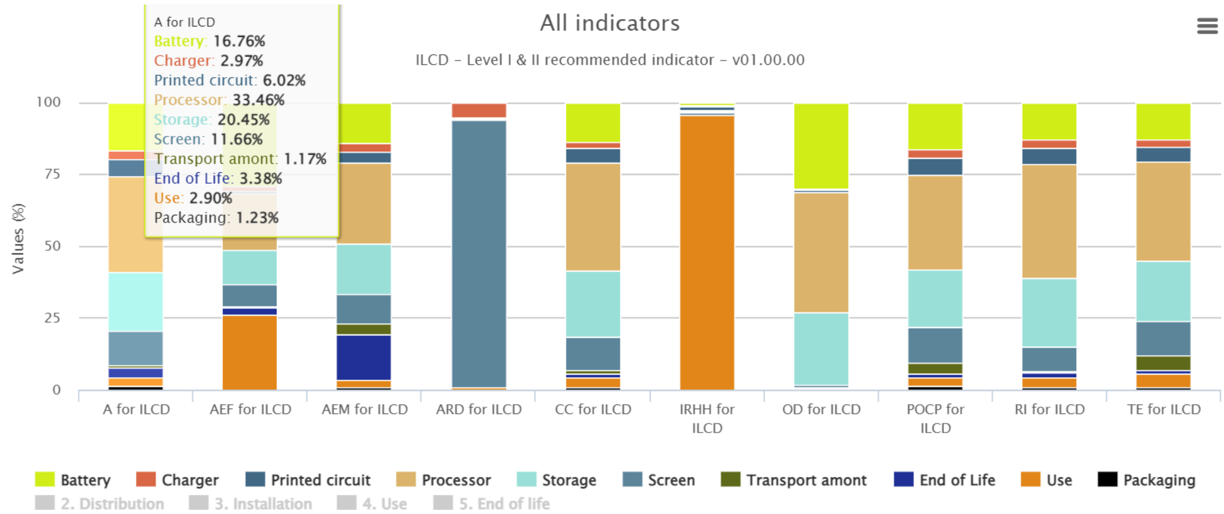

Figure 6: Example of an LCA result with EIME software

However, even if there is a standard method to do an LCA, there are also a lot of different norms and regulations to apply. Furthermore, those ones depend on the category of the product analysed. In the next chapter, the most used norms will be detailed and the historical context in which they have been created.

3 Norms and regulations governing the life cycle assessment

This chapter presents the historical context in which the LCA methodology was created and, more precisely, how the different norms and regulations were established. Then, the actual research in the LCA methodology is presented before the overview of the context of the French rules. Indeed, the work of this thesis focuses on France as the database studied was established to be used mainly in this country.

3.1 The historical context of the life cycle assessment methodology creation

Coca-Cola made the first environmental analysis in 1969 to identify which type of beverage container was less polluting [10], [11]. The report is still private, so it cannot be analysed. At that time, it was done by the Resources and Environmental Profile Analysis, now called the Midwest Research Institute. Then, from the 1960s to the 1970s, environmental analyses were mainly used comparatively. It already considered all the stages of life of a product: from manufacturing to end-of-life treatment, also called "cradle to grave" [7].

The period covering the seventies to the nineties was the period of conception [10]. At first, only the energy consumption was analysed before the scope broadened to the use of resources, the number of emissions and the wastes generated. In 1976, the first peer-reviewed publication on beverage alternatives was released [11]. The eighties registered an increase in the interest in LCA, and the first impact assessment method was created during this decade by the Swiss Federal Laboratories for Materials Testing and Research [10]. However, several countries made the environmental analysis of the same product but with different methods, leading to very different results and conclusions [11]. These diverging approaches to the LCA method came from a lack of international discussions between scientists [10]. This decade also saw the development of the first LCA software widely used: GaBi (1989). It was rapidly followed by Simapro software in 1990, while EIME software was created in 1998.

The following decade (1990 – 2000) was dedicated to the standardisation and the harmonisation of the LCA method by the worldwide coordination of scientists. That's when the name LCA became official. Before, it was named the life-cycle-orientate method [11]. This work was followed by the creation of LCA guides and a handbook. The International Organization for Standardisation (ISO) has been involved in this group work of scientists since 1994 and produced two norms:

- ISO 14 040: principles and framework [4]
- ISO 14 044: requirements and guidelines [5]

These ISO norms, updated in 2006, present only the general guidelines for an LCA; they are not specific to a product category. The ISO 14 040 widely describes the aim of an LCA, its principle, the different stages of life, and the different steps to follow [4]. The ISO 14 044 is more detailed on the methodology to follow, the rules, which elements to consider, and which ones to leave apart [5].

During that time, LCA became part of several country legislation. However, it mainly focused on the product's packaging and not the whole product itself [10]. At that time, scientists started to think about allocation methods [10], [11]. An allocation is used when an input or output of the life cycle assessment inventory is divided between different products or uses [5]. Therefore, the environmental impacts of the input/output must be divided among these products and uses. For instance, a computer can stream videos, search the internet, work, etc. When evaluating the streaming of videos, the impacts of the life-cycle of the laptop must be divided relative to the time passed watching videos.

Since the beginning of the millennial, the LCA research has focused on its elaboration through the creation of the European Platform on LCA in 2005 and the creation of the U.S Environmental Protection Agency and similar entities in other countries [10]. As shown in *Figure 7*, it did have a significant impact on the number of LCA realised. There was a significant increase in LCA reports starting from 2006.

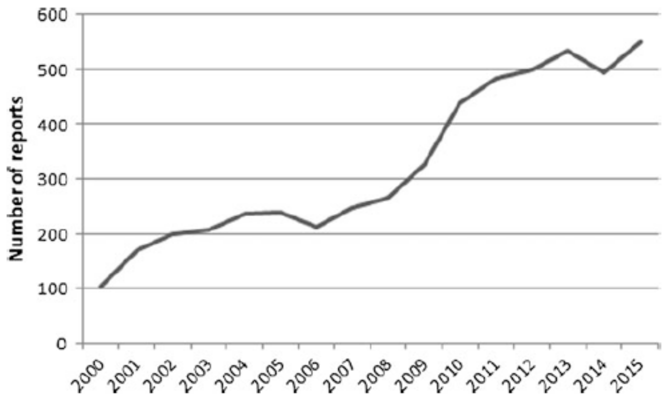

Figure 7: Development in the number of published corporate responsibility reports mentioning LCA per year from 2000 to 2015 [10] L.

However, most governmental policies linger only on the carbon footprint [10]. That brings several problems because of the limited scope of such environmental analyses. Indeed, there are other types of emissions to consider to avoid impact transfer [10]: a lower carbon footprint might be compensated by the increase of another polluting indicator (energy or water consumption, for instance). Furthermore, regular LCA has their limitations. It cannot evaluate the impacts of the rebound effect or market mechanisms [10]. Moore's law rules the most common rebound effect: the size of capacitors is divided by two every 18 months. According to this, the impacts of the production of a computer should decrease years after years as they contain fewer materials [9], [12]. However, it increases because computers have more and more capacitors, so they are more powerful. Ultimately, the environmental impact is much higher than before: this is a rebound effect. Finally, this type of environmental analysis doesn't evaluate the social and economic impacts of the product, which are a part of sustainability [10]. The social side can be evaluated through a social life cycle assessment (SLCA) that needs social experts to be done [10], [11].

Due to the exploding demand for LCA around 2010, the LCA method showed a divergence of methods [10]. These still respect the ISO norms and LCA guidelines, but there was a need to know which method applies.

In 2013, the European Commission released the Product Environmental Footprint (PEF) methodology [7]. It aims to create a standard method for LCA in Europe, allowing the presentation of transparent and traceable data and improving communication between manufacturers and consumers. Every LCA reports publicly communicated must follow the PEF methodology that indicates which indicators to use, with which methodology, etc [7]. Moreover, an LCA must also follow the product category rules (PCR or PEFCR) methodology. This methodology is even more detailed than PEF and corresponds only to a product type (beer, decorative paints, intermediate paper, IT equipment, metal sheet, etc.). It indicates the functional unit to use, the system's boundaries, the indicators and methodology assessment, etc. When doing an LCA, both PEF and PEFCR methodologies must be followed. If they are contradictory, PEFCR is dominant.

However, some environmental impacts cannot be considered with the current LCA methodology (such as the impacts on biodiversity). In addition, recent LCA results give quantities of impacts so they can be compared with another solution. Nevertheless, it doesn't give indications if the planet can support such impacts or not. Researchers are working on a new methodology called the planetary boundaries, which will be an absolute LCA [13], [14] without this limitation.

3.2 The planetary boundaries

The planetary boundaries are the systems regulating the planet. They are at the number of nine [13]. Each boundary has a threshold, a quantity beyond which the planet's stability is triggered. There are two thresholds: the dangerous tipping point beyond which the planet's limits risk being over crossed and the end tipping point beyond which, surely, the planet can't survive such impacts [13]–[15]. The planetary boundaries and their actual progress are shown in *Figure 8*. Moreover, each system of boundaries is linked to each other.

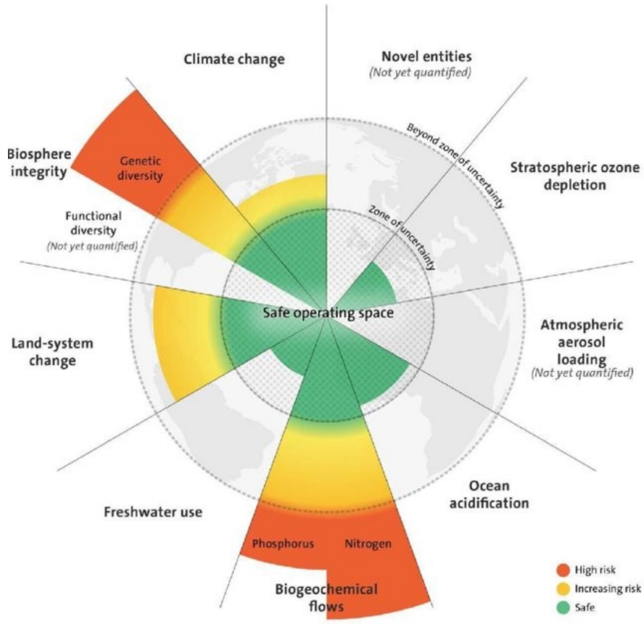

Figure 8: The nine identified planetary boundaries [14]
C.

The first boundary is climate change which is linked to the planet's ice. This one quickly changed these last decades as ice melt from the Antarctic and Arctic showed it. Its power is to cool the earth's temperature by reflecting the sun's heat, allowing the earth to stay stable year after year. And the more the ice melt, the more it melts quickly. Indeed, when melting, the ice turns black, which is a colour that absorbs the sun's heat and gets the ice warmer [15]. This can be found in every boundary: when a certain point is crossed, the earth system will turn against itself by increasing the damages done. The dangerous tipping point for this boundary has been crossed [13] since 1988 [15].

The second planet boundary is the land configuration which regroups the forests, grasslands, and wetlands. The dry season in the Amazon rain forest lasts 6 more days every decade; if it lasts 4 months, the jungle will die and be replaced by the savanna. When dying, the three will release lots of carbon dioxide into the atmosphere [15]. The dangerous tipping point is already crossed [13].

The next boundary is biodiversity. A lot of biodiversities have been lost because of deforestation and the expansion of intensive agriculture [15]. It was complex for scientists to determine the limits of this boundary, but they stated that the end tipping point had already been crossed [13], [15].

The planet's bloodstream is another critical boundary. A mean human need 3 000 L of water per day. This is mainly to do the production of food which is water consuming. This planet's bloodstream boundary determines if the quantity of water is enough to support the living of all humans [15]. For now, the answer is yes, but the dangerous tipping point is close [13], [15].

The following boundary concerns nutrients which are nitrogen and phosphorus. They are essential components of life and are present in fertilisers. When using too many fertilisers, the ground can't absorb them and release them into the rivers, which get fertilised. They developed green algae, which reduce the quantity of oxygen in the water[15]. It creates dead zones: there are hundreds of them in the oceans. The end tipping point has been crossed [13].

The ocean acidity is the next boundary. The ocean can absorb a third of our CO_2 emissions, depending on its acidity. In the last decades, the ocean has become 26% more acidic. It affects molluscs and other life, leading to a mass extinction [15]. No tipping points have been crossed yet [13].

An entire boundary is dedicated to the novel pollutant entities such as nuclear waste, microplastics, heavy metals, etc. Humankind has created more than 100 new materials, of which the long-term impacts are unknown [13], [15].

Aerosols are another boundary which produces particles making the sky darker. It also reduces the circling of sunlight, so they are cooling the planet. However, aerosols only mask up to 40% of global warming. Moreover, the particles released into the atmosphere cause the death of millions each year and reduce the average lifetime [15].

The last boundary is the ozone layer. This is the only one which moves away from the tipping points. The ozone layer is a barrier between the skin and UV, impacting DNA. There was a hole in the Antarctic ozone layer in the 1980s. It raised a global panic, and politics acted [15]. The dangerous tipping point was crossed, but now, the boundary is back to the green zone [13].

However, for now, they are no scientific consensus on the methodology to translate the planetary boundaries in LCA indicators [13]. At the national level, some regulations have been created to fit some planetary boundaries, especially the climate change boundary.

3.3 The national regulations

The Paris agreement was signed in 2015 by 196 parts. It is an international treaty which states obligations concerning climate change. Moreover, developed countries can help less developed ones by giving them funding, based on voluntary. The treaty’s main goal is to maintain the earth's temperature below +1.5 °C, at a maximum below +2 °C [16]. For this, states must reduce their Green House Gases (GHG) by at least 55% by 2040 compared to 1990. An intermediate goal is to reach -40% of GHG in 2030 [16]. The national (French) Green Deal fits the Paris agreement and aims to have zero net emissions of GHG in 2050 [16]. It means the emissions of GHG will be compensated by the carbon sink that caught and retained it. It can be done through threes, ocean, or ground.

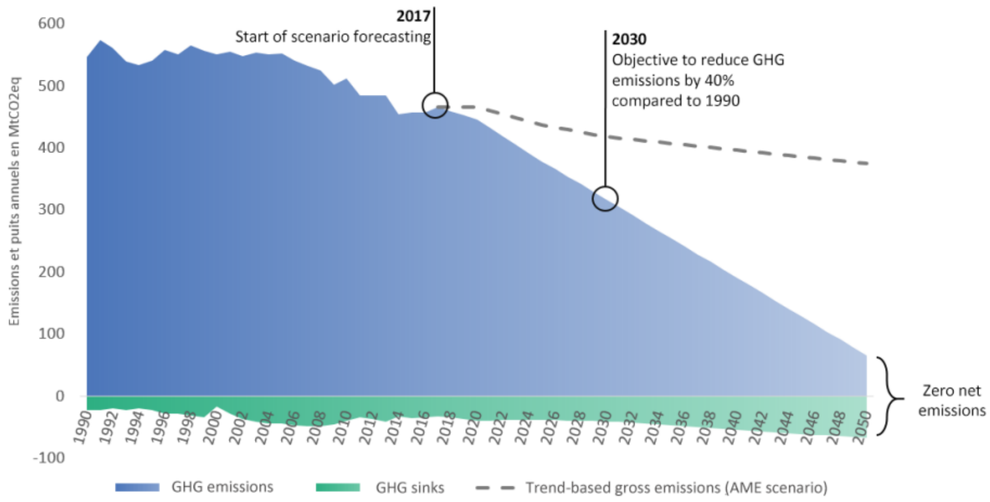

Figure 9: Changes in greenhouse gas emissions and sinks in the national territory between 2005 and 2050 [16]

The trend to follow to reach the goal of zero net emissions in 2050 is represented in blue in *Figure 9*. The zero net emissions in 2050 correspond to 80 MtCO2 eq per year emitted and absorbed. Reduce to the French population (68 million habitants [17]) represents 1.2 tCO2 eq per person per year. In 2018, the carbon footprint of a French was 11 tCO2 eq per year [18].

Moreover, the national strategy is to reduce by 40% the primary energy consumption by 2050 relatively to the 2012 consumption. This would limit primary energy consumption to 156 Mtoe per year [19] (millions of tonnes of oil equivalent).

3.4 Digital services and service provider product category rules

The ADEME (French Agency for the Environment and the control of energy) asked for the creation of PCR on digital services. Two came out in 2021: digital services [20] and service providers [21]. The digital services PCR is the mother PCR: it concerns every type of digital service. Then, daughters, PCR will be created for every kind of digital service and published at the end of 2022.

The mother PCR describes the methodology to respect environmental labelling, which will become mandatory for certain types of digital services [22]. The environmental labelling aims to inform the consumers of their impacts, help them to choose a less impacting product and encourage manufacturers to reduce the impacts of their products [20]. The digital services PCR describes the types of functional units to use, the boundaries of the systems, the exclusions, the different kinds of allocations possible, and the environmental indicators to use.

The service provider PCR is more precise than the mother PCR: it states the exact functional unit to use "Access to the internet with fixed or mobile network for a user, with a consumption of X GB for a month" [21]. The PCR also adds exclusions, specific allocations for each piece of equipment, etc.

However, both PCRs are still being written and are not finalised. There were made by the NégaOctet consortium, which created the first database on digital services.

4 Literature review of digital services' life cycle assessment

This chapter reviews the existing literature on the life cycle assessment of digital services. Therefore, it begins with the description of the NegaOctet project as they created the first database on digital services and is at the origin of the LCA on digital services. Then, the three third of composing a digital service are described before the presentation of the results of the NegaOctet project on the impacts of digital services in France. Finally, the other papers treating the LCA on digital services are presented, followed by the limits of the NegaOctet project.

4.1 Creation of the NegaOctet project

The worldwide impacts of digital services are 2 to 3 times the impacts of France. Moreover, everyone has, on average, 8 digital pieces of equipment [2]. It explains why it represents 4.2% of the GHG emissions and 9.3% of the electricity consumption in Europe [2]. To better comprehend, the impacts have been compared to the planetary limits at the level of Europe. It equals up to 40% of two limitations: global warming and using natural resources (metals and minerals) [6]. On the one hand, the impacts of digital services are consequent, but, on the other hand, there was no method nor database to evaluate them quickly through an LCA [23]. Indeed, it was impossible to get the data on some equipment such as ICT [24]. That's why the NégaOctet (NO) Project has been created. This project allowed the collaboration of datacentre and network companies to create the database. Digital services are constituted of terminals, transmission networks and datacentres [3], [25], [26] (those elements will be detailed later), and only data for terminals existed.

This issue was partially solved when a new law was passed in France in 2020: section 13 of the law named AGEC (Anti-waste for a circular economy). By the beginning of 2022, network companies must communicate to their clients the carbon footprint of their internet consumption [22]. Until 2024, they can use the average data created by the ADEME (French Agency for the Environment and the energy control) through the NO project. However, in 2024, they must be able to furnish their networks' accurate data; for this, they want an already created database [22]. That's why the biggest network companies collaborated with the NO project.

The NO Project was a 3-year project to develop a database on digital services that started in 2019 [27]. The conclusion was that digital services can be modelled in three-thirds, as shown in *Figure 10*. The three parts of a digital service are the terminal, the network, and the datacentre [6], [9], [20].

Figure 10: Three third composing a digital service

4.2 Description of the third composing a digital service

The terminals represent the first third of digital services. They are composed of end-users terminals such as smartphones, computers, screens, the Internet of Things (IoT) and connected objects (GPS, connected watch, etc.). The IoT are objects related to others virtually or physically to exchange data. They are partly composed of captors and are used to monitor, control, optimise, and make automatic things [9].

The second third is the transmission network. This category regroups network infrastructures which link the end-user terminals and the datacentres by exchanging data [3], [9], [26]. Networks are divided into two types: mobile networks and fixed networks. Mobile networks use wireless connexions like 2G, 3G, 4G, or 5G. Fixed networks can be ADSL or FTTX connected to the user's terminals through Wi-Fi or Ethernet cables. The network third includes an internet box [3], [26]. During the study, the impacts of a fixed network per GB transfer weren't determined because the manufacturers hadn't the data [3]. Only the data of the impact of a line (a line per customer) per year was determined. However, this data will be developed in the next few years due to the AGEC law, which requires network companies to find the data [22].

Moreover, the network's infrastructures are divided into three layers [28], represented in *Figure 11*: the access layer, the aggregation layer, and the backbone. The first layer – the access layer – links the end-user terminals to the network [6], [25]. It is composed of switches that are similar to routers. The aggregation layer connects the access layer to the backbone layer. The uplinks of all switches from the access layer are aggregated in this layer composed of routers. A router can transfer the data from one network to another, with each router only having access to its closest neighbours [25]. A message can be passed from one router to another one. To do so, every router needs to be physically interlaced together. As it would be logistically too complicated, the backbone layer was created. This layer allows the transfer of a significant quantity of data at high speed and is linked to every router from the aggregation layer [6]. Several routers in the backbone layer are connected through high-speed transfer cables to avoid all the data passing by one specific network point.

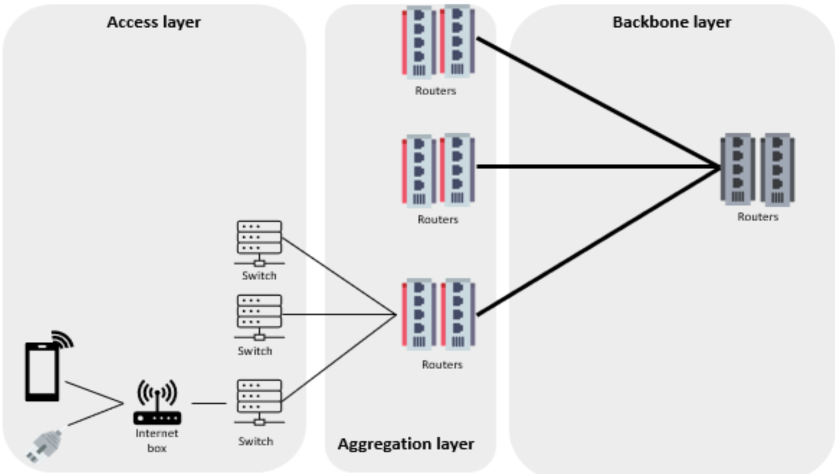

Figure 11: Architecture in three layers of the network

The last third is the Datacentres. It is a complex entity as it is not only composed of Information Technology (IT) equipment. Indeed, it also contains the non-IT equipment and the architecture of the building [3], [6], [26]. Moreover, there are several typologies of datacentres such as public (used by the state and all other public functions), private (used by companies), collocation (several users share a datacentre), or high-performance computing (HPC) [3]. The ratio of servers, routers, storage bays and non-IT equipment won't be the same for each typology of datacentres. The different elements of a data centre are in *Figure 12*. In addition, the IT equipment that composes the data centres is not the only one consuming energy; this is also the case with non-IT equipment [3], [9]. And the impacts of the data centre's structure are significant partly because of clients' high expectations regarding security[9]. Here are the description of IT and non-IT equipment of a datacentre:

- *Servers*: it is a computer that answers the requests sent by the network. It can answer several requests at the same time. They comprise processors, memories, hard disks, and a network interface. There are three types of servers in a data centre [25]. The entry server is here to control the data that comes into the data centre and to dispatch them to the firewall and the anti-spam. It has a high Random-Access Memory (RAM), a small amount of storage and low power [25]. Then, there is the data processing server. It does the calculations asked, so it is composed of a high RAM, significant storage capacity, and important power [25]. The last server is the controlled server. It is used in disk arrays: it links the hard disks together and sends the data to the right place at the right time. It has a small amount of RAM, medium power, and medium storage capacity [25].

- *Firewall:* it controls the traffic between the data centre and the external network to protect the data [25].

- *Switch:* it looks like a router and links several networks. The difference with a router is the use of MAC (Media Access Control) address instead of IP (Internet Protocol) address [25].

- *Disks array:* a large cabinet in which several servers or hard disks can be put inside. A disk array can contain up to 12 or 15 hard disks, so they stock a large amount of data [25].

- *Non-IT equipment:* in average, they represent 50% of the electric consumption of a data centre. It contains the cooling system, all the electrical systems with the lights, presence detector, the generator set, emergency alimentation, or the fire alarm [27]. Nowadays, datacentres are evaluated on their power usage effectiveness (PUE) which is the ratio of the total energy consumed by the datacentre to the energy consumed by the IT equipment [9], [24], [25], [29], [30]. The ratio is always bigger than 1.

- *The architecture:* it contains the building, the public utilities leading to this building, the sanitation system, the isolation, the tilted floor, the painting, the elevator, carpentry, etc [27].

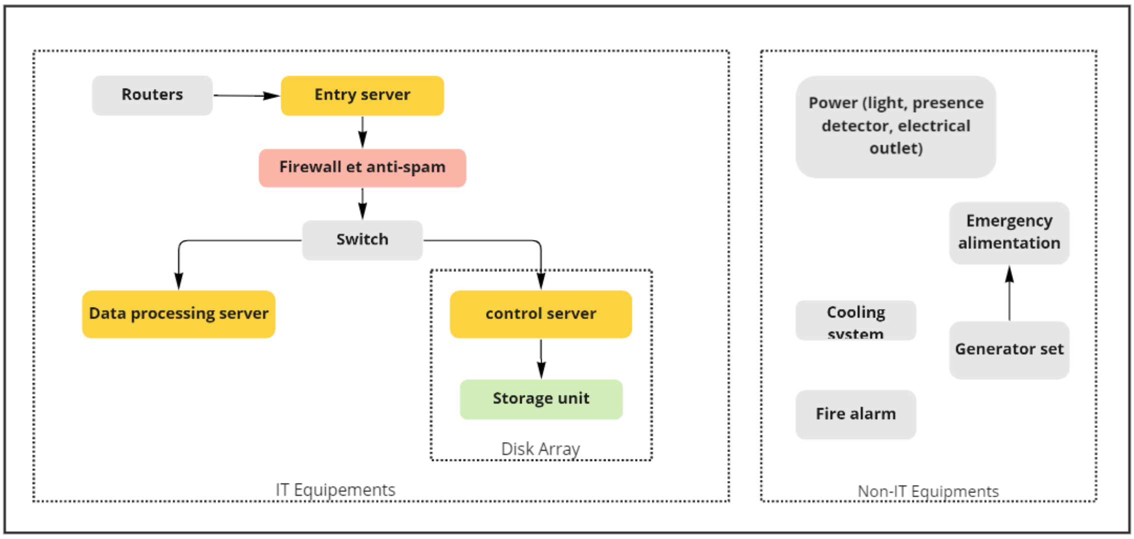

Figure 12: Datacenter organisation (IT and non-IT equipment only)

During the project, indicators set has been chosen to match the digital services needs [6]. All indicators have been analysed to do so, and the indicators representing more than 80% of the impacts have been selected. The height indicators presented in *Table* 3 have been chosen as well as four additional flows presented in *Table 2* [6]. Those flows were proposed for a better comprehension of the impacts of digital services. The material input per service (MIPS) flow counts the resources used or moved from the extraction of materials until the end of the product's manufacturing [31]. The primary energy flow considers the energy which was not transformed or converted, such as natural gas, oil, coal, sun, wind, or geothermal energy [6]. On the other hand, the final energy considers the energy at its final stage of transformation, when the consumer can use it.

Table 2: Flows selected to increase the comprehension of the digital services impact [6] S. [6] S.

Impact category	Model	Unit
Material input per services	MIPS, Schmidt-Bleek, 1994 and Ritthoff and al, 2002	Kg
Waste production (not limited to e-waste)	A compilation of 3 types of waste (non-hazardous waste, hazardous waste, and radioactive). The non-hazardous waste category represents most of the mass of wastes product for ICT.	Kg
Primary energy	Cumulative energy	MJ
Final energy		MJ

Table 3: Indicators representing more than 80% of the impacts of digital services [6] S. [6] S.

Impact category	Model	Unit
Climate change	IPCC 2013, GWP 100	Kg CO2 eq
Particulate matter	Fantke and al, 2016	Disease incidence
Acidification	Posch and al., 2008	Mol H+ eq
Ionising radiation, human health	Frischknecht and al., 2000	kBq U235 eq
Photochemical ozone formation, human health	Van Zelm and al., 2008, as applied in ReCiPe, 2008	Kg NMVOC eq
Resource use, fossils	ADP for energy carriers, based on van Oers and al. 2002 as implemented in CML, V 4.8 (2016)	MJ
Resource use, minerals, and metals	ADP for mineral and metal resources, based on van Oers and al. 2002 as implemented in CML, V 4. (2016)	Kg Sb eq
Ecotoxicity, freshwater	USEtox (Rosenbaum and al., 2008)	CTUe

Then, the database was constructed in 5 levels. Each level uses the lower levels to be created [27]. The first level is composed of wafers and semiconductors. The second level regroups the digital components such as SSD, HDD, RAM, touchscreen slab, motherboard, graphic card, or fan. The third level is for specific equipment like TV, computer, servers, disk array, cooling system, etc. The fourth level comprises mobile and fixed networks, cloud service, datacentre by typology, etc. The last level concerns digital services. There is the sending of an email, streaming video, downloading a file, stock data in a cloud, using a connected watch, etc.

This database is available in three different versions. One of them is for the ADEME and will be published on their open-source software. Particular data have been created for them. First, the database comprises only 150 data in which all the stages of life except the use phase are aggregated [27]. It means that parameters can’t be modified. An example is that the manufacturing or transport country can't be chosen. However, the impacts can significantly vary from one country to the other, especially concerning the power mix. For instance, a power mix mainly constituted of nuclear energy will have fewer impacts than a power mix constituted of coal energy. Moreover, the end-of-life calculation is different from the regular one. Indeed, the ADEME wants to use a method that considers the benefits of recycling for the studied product [27]. The impact of end-of-life for the studied product is the impacts of recycling processes minus the avoided impacts of the production of the virgin materials. Most of the time, it gives a negative result as the production of virgin material has a more significant impact than recycling the same material. For the following product system studied, using recycled materials in the production stage is counted as the production of virgin materials.

The second version of the NO database has more than 1500 data and is composed of calculators in excel format [27]. Each calculator is about a specific digital service such as the sending of an email, the use of a cloud service, streaming video, making a web request, doing a web conference, downloading a file, etc. In total, there are 21 calculators. In each calculator, all the calculations are already done, and the user modifies the parameters to have the impacts corresponding to their situation. This is used to rapidly get an idea of a service's impacts and where the major impacts are. However, the results are not very precise, and the other parameters than the one already created can't be modified.

The last version of the database is composed of the five layers set of data presented earlier. They are also at the number of 1500 and can be downloaded under ILCD node 3.0 version [27]. This version allows the user to download and import the whole database into any LCA software. This version calculates the end of life as the European method recommends it [7]. For the current studied product, the impacts of the recycling processes are counted. For the following studied product system, the impacts of manufacturing of the recycled materials used are null.

4.3 Main impacts of the digital services

The NO project presented the main impacts of digital services in France [3]. As shown in *Figure 13*, the first third represents 62% of the impacts on every indicator, followed by the datacentres (5 to 22% of the impacts). Another study states that end-users terminals contribute to 78% of the impacts [23] but does not precise the methodology used nor the pieces of equipment taken into account. In both terminals and data centres third, the manufacturing stage has the most impact, followed by the use stage. Indeed, manufacturing end-user terminals and datacentres pollute much because of the processes of transformation and extraction of materials [3]. IT equipment is partly composed of rare-earth elements, materials present in a small concentration on the earth. The amount of rare-earth elements on earth is important but is diluted in deposits of other minerals, some of which are radioactive [9]. Moreover, due to the small concentration of rare-earth elements in a deposit, it needs a lot of energy to extract them, creating a massive quantity of waste (the main minerals of the deposit). These wastes might be radioactive and are put in consistent amounts in one place; it causes human health problems in the surrounding cities [6]. Then, it requires a large quantity of water and chemical products to isolate rare-earth elements from other minerals. Rare-earth elements are essential to producing semi-conductors which are critical to manufacturing computers, smartphones, or datacentres [9], [32]. That's why the first and second third of the digital services are the most impacting.

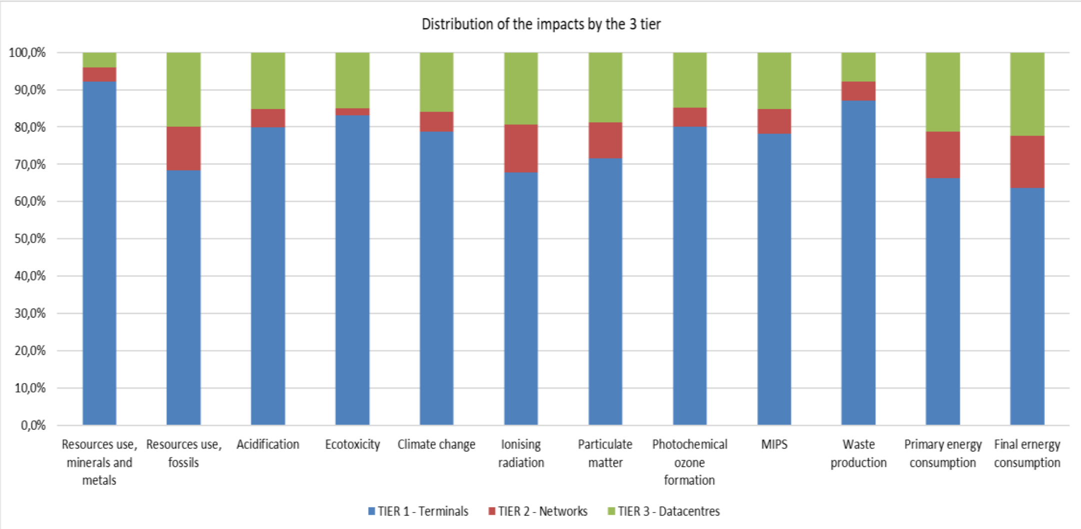

Figure 13: Repartition of the impacts of a cloud service by third [3] E.

All the impacts are more detailed, third by a third. *Figure 14* shows that computers and screens represent at least 50% of the impacts per indicator for the first third [3]. The computer category regroups laptops, computers, and tablets, while the screen category contains the computer screen, television (TV), video projector, TV box, and other screens [3]. It is worth noting that those results are based on the number of pieces of equipment currently owned by the French population. It doesn't compare the manufacture of one smartphone to the manufacture of one computer, for instance. The television is the equipment that has the most impact (between 11% to 30% depending on the indicators). This is explained by their number in France, associated with the high impacts of manufacturing and the high power consumption [3]. Moreover, the impacts of IoT objects might be highlighted even if they are currently relatively low. Those impacts are elevated compared to the number of IoT objects in France, but if the trends continue, the number of IoT objects will explode in the upcoming years [3].

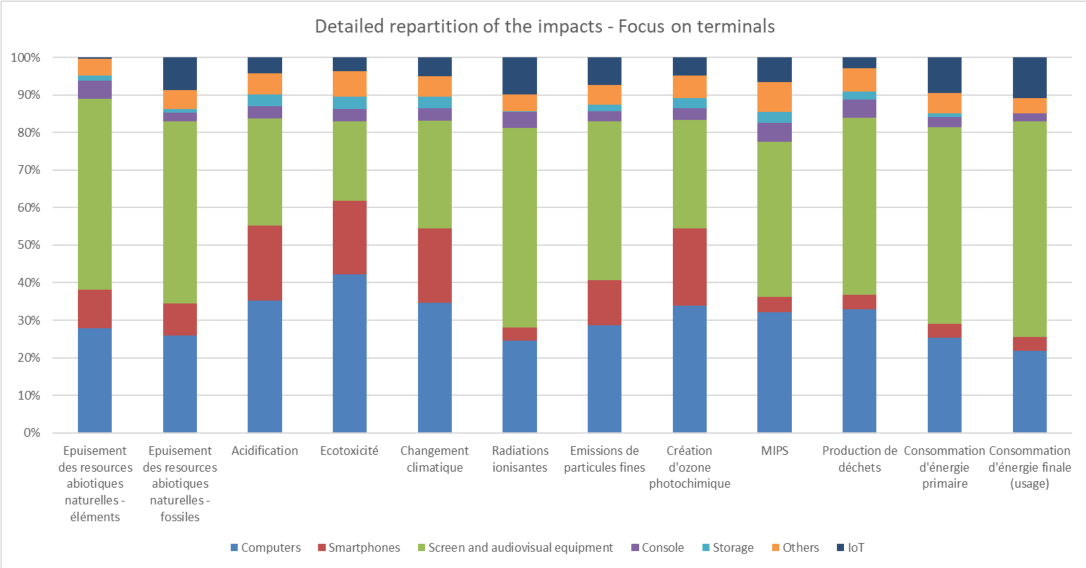

Figure 14: Detailed impacts of a cloud service - Focus on terminals [3] E.

The second third results in *Figure 15* show that the fixed-line network has more impact than the mobile network. It represents 76.2% to 90% of the impacts [3]. In the impacts of the fixed-line network, 27.4% to 73.8% are attributable to the internet box. Most of the time, it is never off so it has an important power consumption. So, a fixed-line network requires more equipment and consumes more electricity than a mobile network. However, if the impacts are reduced per GB transfer, the fixed-line network has 25% to 75% fewer impacts than the mobile network [3]. The fixed network has better energetical efficiency.

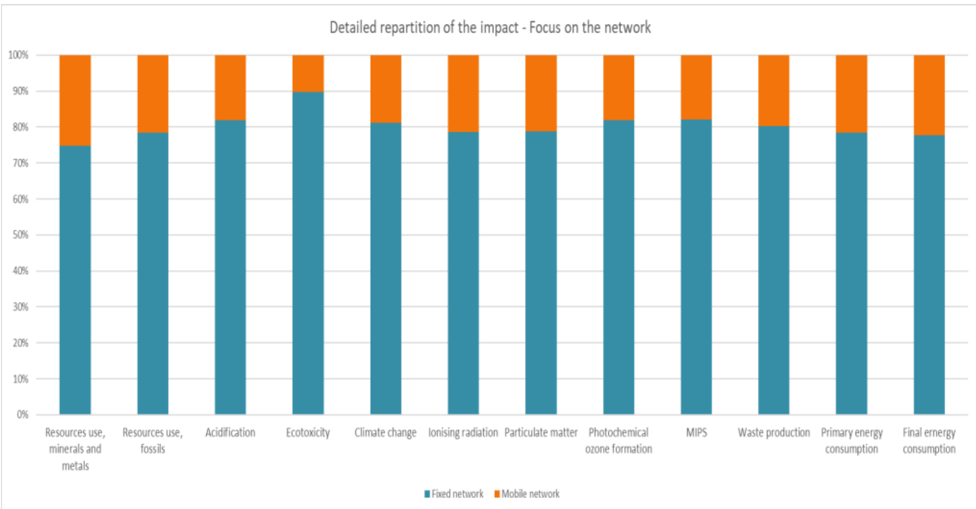

Figure 15: Detailed repartition of the impacts of a cloud service - Focus on the network [3] E.

The last first third results in *Figure 16* show the impacts of the components of a data centre. The main impacts came from the IT equipment (more precisely, servers and storage) and the energy consumption [3]. The results are coherent with R. Rauta, who analysed the data centre's carbon footprint [24]. It is shown that servers are responsible for 54% of the impacts (60.2% in *Figure* 16). This slight difference might be due to the data centre analysis made in Finland by R. Rauta. The impacts of the non-IT equipment are evident through their electricity consumption. However, the impacts linked to the fabrication, distribution, and end-of-life of the non-IT equipment and the architecture are low. This can be explained by the fact that there are simpler and have a greater lifetime than IT equipment.

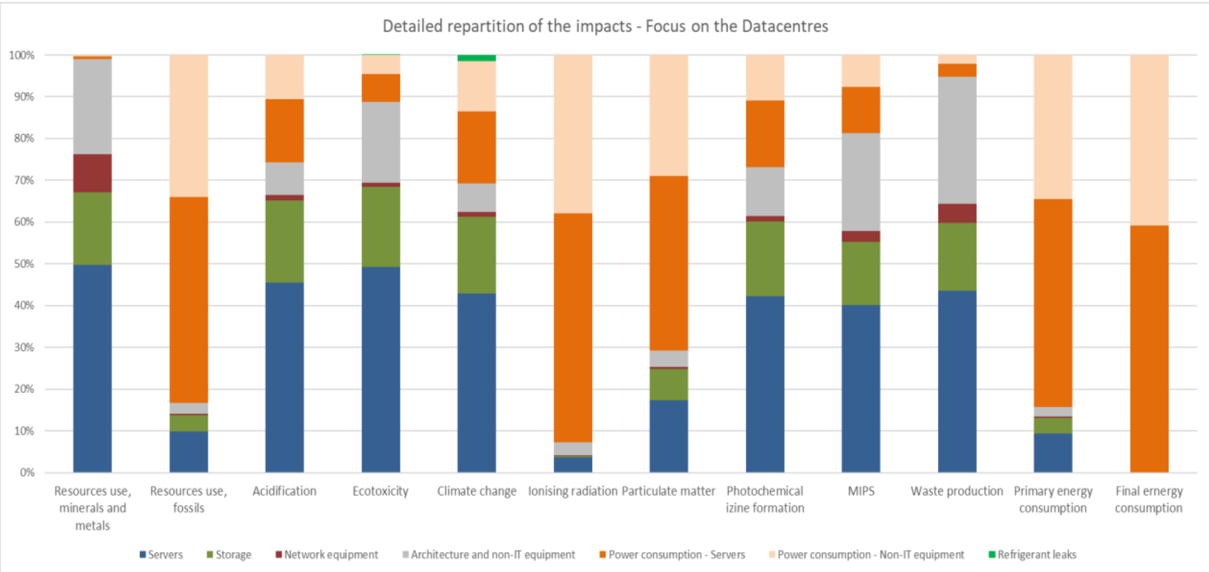

Figure 16: Detailed impacts of a cloud service - focus on Datacentres [3] E.

4.4 Other studies reviewed

Other scientific articles were reviewed for this thesis and are regrouped in *Table 4*. However, none of them is concerned by the LCA of digital services. Indeed, most of the articles studied the carbon footprint or the energy efficiency of the different third of the digital services but not all of them simultaneously. Some of them analysed the LCA of a specific terminal. Furthermore, most of these studies don't offer a comparison point as they are concerned with only one or two indicators or a particular terminal. At the same time, this thesis focuses on the impacts of digital services for a country and the European level.

Table 4: Studies reviewed for this thesis and the topic they are dealing with

Studies	**Third concerned**			**Indicators analysed**		
	Terminal	Network	Datacenter	Carbon	Energy	LCA
[29]			X	X	X	
[33]	ICT			X	X	
[30]			X	X	X	
[34]		Internet energy			X	
[24]			For a cloud service	X	X	
[35]			Datacenter and cloud computing	X	X	
[36]			Cloud-based services			X
[37]	LED					X
[38]	ICT					X
[32]	DRAM					X
[39]	HDD					X
[40]		Wireless ICT		X		
[41]			X		X	
[28]		Wireless network			X	
[42]	IoT				X	

4.5 Limits of the NégaOctet studies reviewed

However, there are some limits to this study. Indeed, some points need a more profound analysis to be correctly evaluated:

- Some pieces of equipment have not been considered because of the lack of data (DVD reader, security cameras, payment devices, etc.) [3]. It leads to an underestimation of the impacts of digital services.

- Moreover, the study considers only the pieces of equipment inside the UE. Still, a European user can be linked to a data centre somewhere else in the world to network connexion beyond the European continent [3].

- In addition, the digital services' technologies are constantly evolving, so the data created during the NO project must be regularly updated to fit the current technology.

- Finally, the power effectiveness is measured by the PUE, which doesn't consider the speed of data treatment of the data centres. For instance, a datacentre that treats 1 problem per second with a PUE of 1.2 will be less efficient than a datacentre that treats 0.5 problems per second with a PUE of 1.1 [9].

5 Research of inconsistencies in the NégaOctet database

This part of the thesis presents the inconsistencies found in the database on digital services. First, the method used to investigate and validate the inconsistencies is described. Then, the results of the investigations are explained, and finally, the validation of those is discussed.

5.1 The methodological process to investigate the database

This part presents the method used to investigate the NégaOctet database. This has been done in three different steps. First, a study has been realised with the database. The possible inconsistencies have been checked before being added to the table of criticality to determine which elements are more worthy of working on.

5.1.1 Life cycle assessment of a Cloud service

To manipulate the NégaOctet database, a cloud service has been modelled with the EIME software. Indeed, the more efficient way to identify issues in 1 500 data is to use the database on a real case: the life cycle assessment of a digital service. The NégaOctet database is not published yet. Consequently, it is only available in the development part of the software EIME owned by CODDE LCIE Bureau Veritas, one of the members of the NégaOctet consortium. And hence, the EIME software has been chosen for this study.

This LCA study identifies a cloud service's environmental impacts and investigates the database's inconsistencies. The cloud service is mainly used to upload, stock, and download pictures. As it is a digital service, the three third and their entire life cycle must be considered when modelling: terminals, networks, and datacentre. The functional unit determined for this service is "using a cloud service by an average person for one year". This person uploads 100 pictures per week on the cloud and stores them for a year. Twice a year, he uploaded 500 photos a week. He views its photos for 30min each week and downloads 300 pictures annually.

The exclusions of the scope of the study as stated in the digital services PCR are:

- The lightning, heating, sanitary and cleaning of the infrastructure
- Transport and meals of the employees
- Manufacturing and maintenance of the manufacturing tool
- Flows of administrative, management and R&D departments
- Flows linked to the marketing and advising of the service
- Flows linked to the sale service

The exclusions of the scope specific to this study are:

- The pictures uploaded previously to the cloud
- The pictures deleted during the year
- All the pictures are supposed to be uploaded from France

Those hypotheses have been taken because of a lack of data.

As there is no specific PCR to a cloud, the modelling of the service respects the general PCR "digital services". It indicates which indicators to use for the analysis [20]: climate change, depletion of natural resources (minerals and metals), depletion of natural resources (fossils), depletion of water resources, acidification, freshwater eutrophication, marine eutrophication, terrestrial eutrophication, photochemical pollution, human toxicity – cancer, human toxicity – non-cancer, aquatic ecotoxicity, ozone layer depletion, fine particle emissions, land use and ionising radiation. Those are directly regrouped under the indicator set of EIME named "digital services". Furthermore, the allocation types of each piece of equipment have been determined to fit the requirements of the PCR digital services and are presented in *Table 5*.

Table 5: Type of allocation for each third for the Cloud LCA

Third	**Type of allocation**
Terminals	Usage time
Network	Volume of data transported
Datacentre	Amount of storage

However, each third is composed of different equipment and stages of life, which might imply several allocation equations for the same third. For the manufacturing and end-of-life stages of the terminals, the allocations are the same for each type of terminal. It depends on the repartition between them and the time passed to surf on the cloud. The allocation of the network depends on the volume of data consumed. The use stage of the network and terminals depends on the allocation determined for the manufacturing as well as on the consumption of the equipment. The datacentre comprises a server, switch, firewall, storage, non-IT equipment, and the architecture of the building. The allocation of the server depends on the amount of data transported, while the allocations of the switch and the firewall rely on the allocation of the server. The allocation of the non-IT equipment and the architecture depends on the allocation of the server and the duration of storage of the pictures. Finally, the storage allocation depends on the amount and duration of storage. The use phase of the data centre depends on its PUE.

All the equations of allocation used are listed in *Table 6,* and more characteristics of the cloud service modelled are presented in *Appendix 1*. The choice of these equations of allocation is discussed in *Chapter 6*.

Table 6: Equation of the allocations of every equipment composing the cloud service

Third	Equipment	Equation of allocation
Terminals	Smartphone	$Repartition * \frac{Time\ of\ use\ for\ the\ service}{Time\ of\ use\ per\ day * 365 * lifetime}$
	Laptop	
	Desktop	
	Computer Monitor	
	Energy Consumption of one terminal	$Allocation\ of\ terminal * Consumption\ for\ a\ year * lifetime$
Network	Mobile network	$Repartition\ fixed/mobile * Amount\ of\ data\ consumed$
	Fixed-line	$Repartition * \frac{Amount\ of\ data\ consumed}{12 * average\ data\ consumed\ per\ month}$
	Energy consumption	$Consumption\ for\ a\ year * allocation$
Datacentre	Server	$\frac{Amount\ of\ data\ consumed}{time\ of\ use * lifetime * utilisation\ rate * flow\ rate}$
	Firewall	$\frac{Allocation\ of\ the\ server}{12}$
	Switch	$\frac{Allocation\ of\ the\ server}{7}$
	IT and non-IT pieces of equipment	$\frac{Allocation\ of\ server * \frac{m^2}{server} * storage\ time}{lifetime}$
	Storage	$\frac{Amount\ of\ storage * storage\ time * reduncancy}{Total\ amount\ of\ storage * lifetime * filling\ ratio}$
	Energy consumption for an equipment	$PUE * consumption\ for\ a\ year * lifetime * allocation$

After modelling the Cloud service in EIME software, the results will be compared with the literature review to check their coherency and, therefore, the coherency of the database.

5.1.2 Checking the inconsistencies

Once inconsistencies have been identified, they have been verified. Indeed, this work is done after a project of 3 years realised by 10 experts in LCA; therefore, the comprehension of the project, data created, and method used are complex. That is why an information document has been created for every data in the database. This document regroups the description of the data, its content, its method of creation, usage, impact on a set of environmental indicators, etc. Moreover, this document is based on the ILCD requirements, a European regulation to facilitate data integration on different LCA software [8]. With this document filled, the data can be added to any software. The information document is presented in *Appendix 2*.

Each potential inconsistency related to the creation or content of the data was analysed with the help of its information file. This step led to the suppression of half of the inconsistencies, which were finally difficult points of the LCA methodology for digital services.

5.1.3 Table of criticality

The table of criticality has been created to order the inconsistencies discovered by importance. Indeed, nine issues were found, but not all were solvable during this thesis or interesting for this work. The table comprises three criteria: subject of concern, time to solve, and user importance.

Firstly, the subject of concern is necessary as this thesis focus on materials-based inconsistencies. The inconsistencies directly linked to materials will be prioritised over the others. Nevertheless, they may also concern the datacentre, the network, the modelling of specific third or data, or the content of a data. In fact, in the EIME software, each data is linked to its description and comments that are also available in its information file.

Then, the time needed is declined into three categories: less than a day (-), between a day and a month (+), and more than a month (++). The issues needing more than a month can't be treated during the thesis due to a lack of time, while the elements needing less than a day will not be interesting enough for this work.

As the database will be released and sold to clients, the importance for the users is an essential criterion of the table. Depending on the issue found, the users might either not be able to use the database without solving the problem (high importance), or it will be difficult to model a digital service (medium importance), or it will still be possible to use the database without the solving of the issue (low importance).

An example of the table of criticality filled is presented in *Table 7*. The inconsistencies concerning materials with high importance for users and more than a day needed to be solved will be chosen for this thesis.

Table 7: Example of the criticality table filled

Name of the inconsistency	Subject of concern	Time to solve it	Importance for the users
Inconsistency 1	Materials	-	High
Inconsistency 2	Database	+	Medium
Inconsistency 3	Datacentre	++	Low

5.2 Results

This part presents the results of the LCA of the cloud service. The LCA results involved the service's environmental impacts, their comparison with the literature, and the discovery of inconsistencies in the database. Then, the table of criticality is filled with the issues found during the realisation of the LCA.

5.2.1 Results of the cloud LCA

The LCA results will be detailed, compared to the literature, and analysed in this part of the study. Moreover, an investigation will be made to determine the origin of the main impacts.

First, the study's results on a cloud service are compared to the literature and, more precisely, to the ADEME-ARCEP report, which is the latest to analyse digital services in France [3]. As the functional unit of a cloud study is for an average user, the results are compared with the digital services impacts for an average person in France in *Figure 17*. The results show that the cloud service represents a maximum of 10% of the impacts stated by the ADEME-ARCEP report. Those results seem coherent and accordingly do not show any inconsistencies. However, the distribution of the impacts between the different third has still to be studied to determine the consistency of the data.

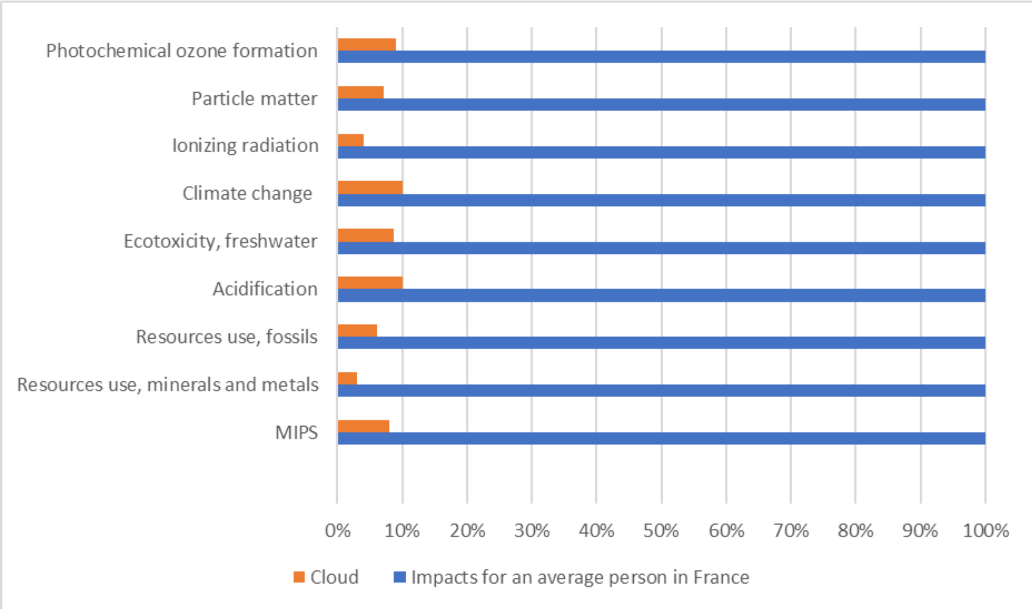

Figure 17: Comparison of the impacts of the cloud service for an average person with the digital services impacts of an average person in France find in the ADEME-ARCEP report.

Figure 18 shows the relative impacts of the three third. The datacentres represent the main impacts of the cloud service: 12% to 77%, depending on the impacts. Except for the resources used, fossils, the eutrophication of freshwater, the ionising radiation and the particle matters indicators, the terminals are the second most impacting third. The four indicators previously listed are impacted by power consumption. Indeed, during the uploading and downloading of pictures, the networks are highly solicited through electricity consumption. Moreover, the electricity mix in France mainly comprises nuclear power (70.2% in 2018). This type of electricity has few impacts on global warming, but it produces ionising radiation and particle matter hence the non-negligible impact of the network third on specific indicators.

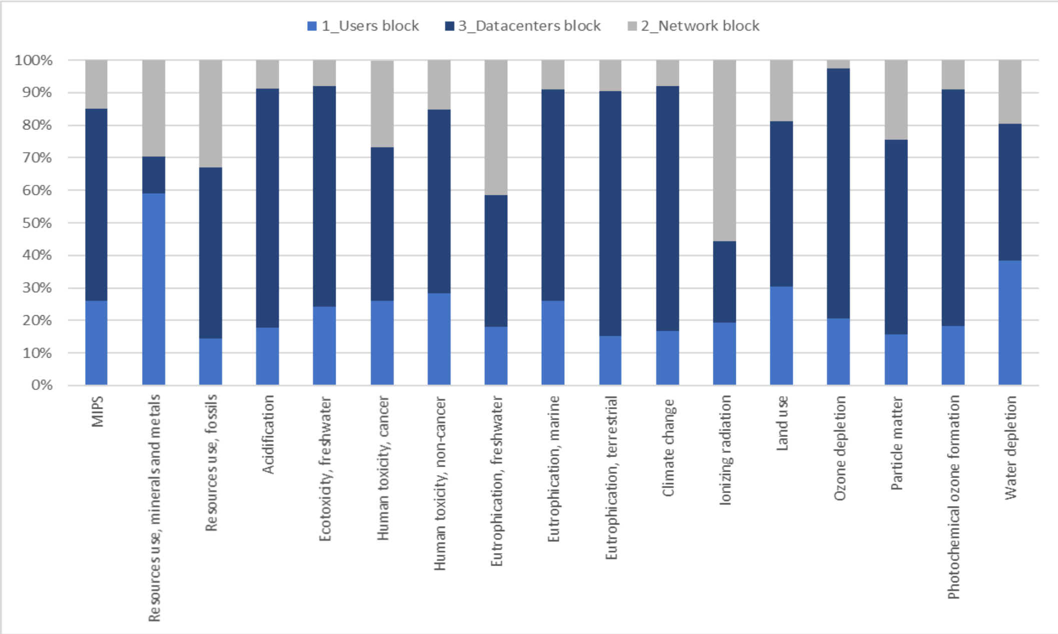

Figure 18: Relative results of the LCA of the cloud service. In deep blue is the data centre block; in light blue is the users' block; in grey is the network block.

However, the main conclusion of this study doesn't perfectly fit the literature as the main impacts of digital services in France are due to the terminals (64% to 92% [3]). The datacentres represent only 4% to 23% of the impacts. This divergence from the literature can be explained by the type of digital service evaluated. The report of the ADEME-ARCEP estimates the global digital services in France, while this study focuses on a specific cloud service and its use by an average person. This cloud is used to store pictures for years in a data centre and punctually consult them on a terminal. As datacentres are never off, it seems coherent that they represent the main impacts.

Finally, a third focus is made on the data centre to determine which element contributes most to the impacts. *Figure 19* shows the different elements of a data centre and their contribution to the environmental impacts. Overall, the impacts of the data centre come from the storage elements. Indeed, the cloud service, as defined for this life cycle assessment, is used to store pictures, so the servers, which usually regroups the main impacts, are almost not used. The results are coherent with the scope and definition of the LCA and don't show inconsistencies. However, several have been discovered during the use of the database and are discussed in the next chapter.

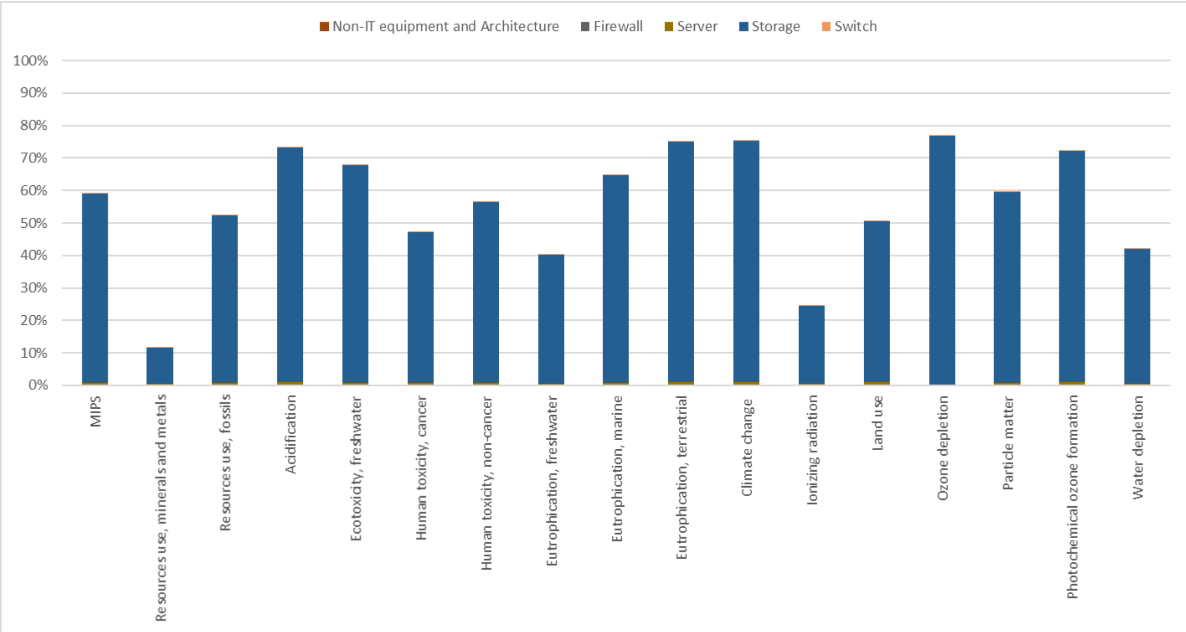

Figure 19: Relative results of the LCA of a cloud service. In red, the non-IT equipment and architecture, in grey, the firewall, in ochre, the server, in blue, the storage, and in orange, the switch.

A point of interest is to go deeper into the results to determine what is so much impacting in the storage system of a data centre. *Figure 20* details the manufacturing impacts of disk arrays constituted of 48 SSD disks. Each disk is a TLC (triple-level cell) of 2048 GB of storage. There are four existing technologies of SSD: single-level cell (SLC), multi-level cell (MLC), triple-level cell (TLC), and quad-level cell (QLC), which have different properties (*Table 8*) depending on the bits per cell, the writing speed, the lifetime, and the price.

The data of the SSD is composed of the upstream transport, the graphic card, and the dies (which are produced from wafers). The results show that the dies are responsible for at least 85% of the impacts except for two indicators: ionising radiation and resources use, minerals and metals. For these two indicators, the graphic card is responsible for the impacts. Moreover, the die losses also have a significant impact (approximately 40%). Indeed, the dies are composed of wafers that are etched by photolithography. The photolithography process is a light beam passing through a mask to deposit several layers. This operation is repeated several times with different masks to obtain the die. A wafer can contain thousands of dies. A study made by the NegaOctet consortium showed that the dies' environmental impacts are proportional to the number of masks and the size of the die. Indeed, when the die surface increases, the loss proportion also increases.

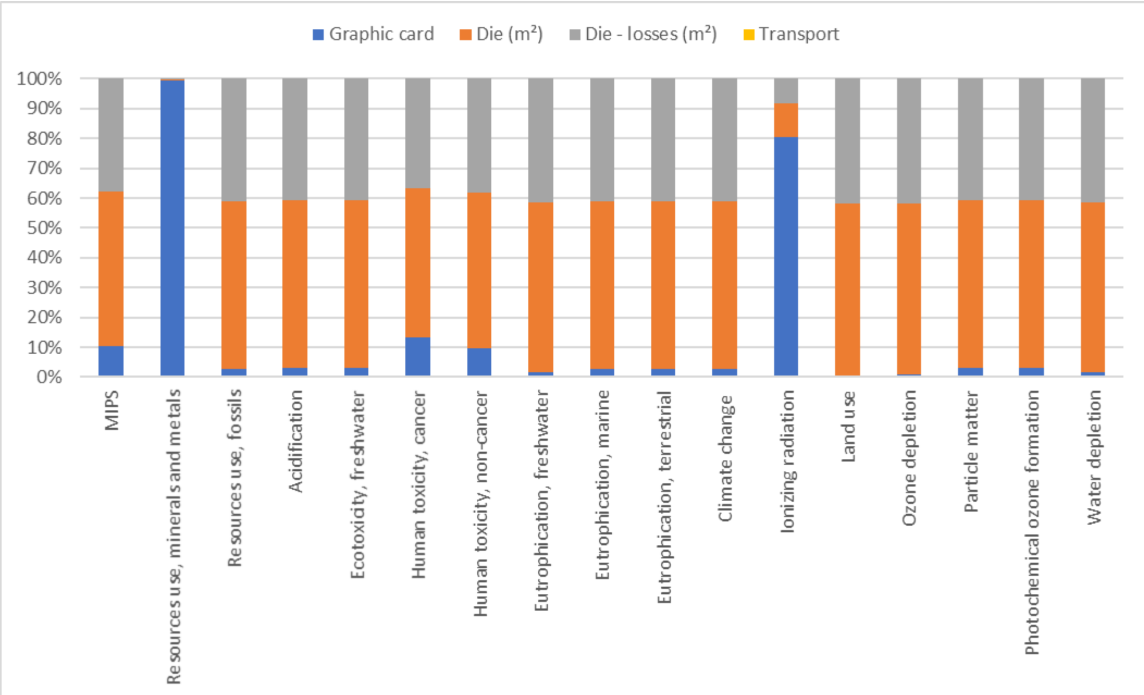

Figure 20: Environmental impacts of a 2048 GB, TLC (triple-level cell) SSD.

Table 8: Properties of the different SSD technologies

	Bit per cell	Writing speed	Lifetime	Price
SLC	1	++++	++++	++++
MLC	2	+++	+++	+++
TLC	3	++	++	++
QLC	4	++	++	+

To conclude, the die represents the main impacts of this LCA study on a cloud service. These impacts are due to the wafers' and dies' extraction and production. Consequently, it is coherent to look for materials-based inconsistencies in the NegaOctet database as they represent the main impacts of a digital service.

5.2.2 Results of the criticality table

The LCA study of a cloud service allowed the identification of nine inconsistencies in the database NégaOctet. This part aims to determine which problems will be solved in this thesis and to present the issues found. For this, the table of the criticality of the *Table 9* lists all the inconsistencies.

The first major inconsistency of the database concerns the allocation of the different equipment. As seen in the previous subchapter, the manufacturing of materials is the main impact of digital services; thus, it is essential to choose wisely the allocation of equipment. As equipment may be used for different services such as using a cloud, streaming video or doing internet research, the allocation is used to determine the percentage of the equipment used for the service analysed. This percentage can be determined based on the use time of the equipment, the amount of data transferred through the equipment, or the mass of the equipment. The impacts difference between two allocation equations will be analysed in *Chapter 6*. This inconsistency requires more than a day to be solved and has high importance [23] for users. They can't use the database without the different possible allocations.

The second issue concerns ten countries' electric mix that was not updated since 2008. The countries involved are Algeria, Argentina, Chile, Bangladesh, Colombia, Egypt, New Zealand, Peru, Pakistan, and Syria. As data for an electric mix is valid for 10 years, the mixes have been outdated since 2018. Nevertheless, this issue has medium importance for users as they can use the old mix even if it does not represent the current impacts. Those mixes might influence the impacts of manufacturing materials composed of energy-consuming processes. However, these countries are not the main producers of semiconductors. Therefore, the influence of the electricity mixes on the impacts of a digital service will be negligible.

The following inconsistency concerns the evaluation method of a data centre. Currently, the PUE of a data centre states if it has good energy efficiency. The PUE is the ratio of the electric consumption of the overall building over the electric consumption of the IT equipment. However, it doesn't consider the amount of data treated by the IT equipment. It means a datacentre with a PUE of 1.1 will be considered better than a datacentre with a PUE of 1.2, even if it can treat only half of the data treated by the second datacentre. Yet, this issue will require a tremendous amount of work to be solved and has low importance for users. Indeed, as every LCA expert is using the PUE to evaluate a data centre, it will be coherent for the users of the NégaOctet database to use it as well.

Then, two minor inconsistencies concerning the data description were found. The description of the data of the typical architecture of a datacentre has been exchanged with the data of the typical non-IT pieces of equipment of a datacentre. The second problem is that the database contains 20 processors with different configurations, but the exact weight is referenced in the data description. Both issues might annoy some users but are not necessary to lead an LCA on digital service.

The two following inconsistencies both concern the modelling of a digital service. They have high importance as it is complicated to do an LCA without their solving. The first one will require less than a day to be solved and concerns the modelling of a fixed network. The data created contain the impacts of the fixed-line for one subscriber for a year. So, the users must know the average data consumption through a fixed-line network for one year, which is currently not included in the data description. The second issue concerns modelling an HDD storage as the amount of data storable is not indicated. This element is needed to model digital service and, more precisely, to determine the allocation.

The two last issues have medium importance for the users as they might be able to find the solution. The first one concerns the modelling of a data centre. Users not specialising in datacentres might not know the different equipment and configurations of the datacentre used by their digital service. However, it is possible to determine the elements composing a data centre by the name of its configuration, which is present on the customer's bill. The last inconsistencies concern the data of the equipment already available in the database, such as a laptop, processor, server, tablet, etc. Indeed, the database lack details concerning the lifetime, the electrical consumption, and the usage time of those equipment. Without these elements, users will have difficulties calculating the allocations of the pieces of equipment composing their digital service.

Table 9: Table of criticality filled with the inconsistencies found in the database

Name of the inconsistencies	**Subject of concern**	**Time to solve it**	**Importance for the users**
Allocation	Materials	+	High
Electric mix	Database	+	High
PUE	Datacentre	++	Low
Inversion of the description of two data	Database	-	Low
Incorrect weight for the processors	Database	-	Low
Modelling a fixed network	Modelling	-	High
HDD storage	Modelling	+	High
Modelling a datacentre	Modelling	+	Medium
Data for the pieces of equipment	Database	+	Medium

5.3 Discussion

The LCA assessment of the cloud service gave coherent results, even if they were unusual. The impacts of a digital service are mainly due to the manufacturing of terminals followed by the manufacturing of datacentres. However, when considering the characteristics of this specific digital service, the results don't show any incoherence, which validates the content of the data. Furthermore, the study shows that the main impacts come from manufacturing raw materials, especially from using masks for manufacturing dies through the photolithographic process. This supports the aim of this thesis to investigate materials-based inconsistencies in the NegaOctet database.

The LCA study has therefore contributed to identifying nine inconsistencies in the database. Each of them was classified in the table of criticality depending on the subject it concerns, the time required to solve it, and the importance it has for users. One inconsistency will be solved during this thesis. It involves materials, needs more than a day to be solved and has high importance for the users. This is the allocation issue. However, the PUE issue excepted, all the other inconsistencies listed were solved but are not interesting to be mentioned. Besides, the creation of the NégaOctet database required the work of ten persons for three years, so all the inconsistencies in the database might not have been found.

6 Solving the allocation's inconsistency

The present chapter discusses the resolution of the main inconsistency of the NégaOctet database: the allocation of the digital services equipment. At first of all, the method to investigate the existing allocation formulae is explained, then the research results are shown, detailed, and analysed. Finally, the findings of this chapter are discussed.

6.1 A research method to solve the allocation's inconsistency

This sub-chapter detailed the methodology used to determine which allocation equation to use with which type of equipment and in which situation. For this, different sources have been investigated to list all the allocation formulae existing and their compliance with the European norms and regulations for LCA. Then, the coherency of the investigation results will be analysed, and in certain cases, there will be case distinguishing.

Thus, three sources have been investigated to regroup all the possible equations of allocation existing for each piece of equipment composing a digital service. Those are described in the following sub-chapter, as well as their accuracy. Furthermore, the allocation formulae must be compliant with the different European and French regulations such as the ILCD handbook [8], the ISO 14 044 [5], the PEF methodology [7] and the PCR on digital services and service provision [20], [21].

Some regulations are similar, while others are more specific. Indeed, the ISO 14 044 norm, the PEF methodology and the ILC handbook all agreed that allocations should be avoided if possible [5], [7], [8]. If the analysed system can be subdivided into smaller systems, then allocations are unnecessary.

Likewise, if the boundaries of the systems can be extended to include the other production functionalities in the scope. However, when it is not possible (when having a single unit operation process, for instance), allocation depending on physical causality must be preferred [5], [7], [8]. The ILCD Handbook gives an example of physical causality: the physical flows, the mass, the volume, the length/distance, the number of pieces, etc [8]. If no allocation is determined on physical causality, another mutual relation such as the economic value can be used. On top of that, the norm ISO 14 044 precise that the choice of an allocation equation must be explained and a sensitive analysis made if there is more than a single possibility for this equation [5]. Nevertheless, the ILCD handbook [8] is more precise than the other regulations by giving the type of allocation to use in certain cases. Those cases don't concern digital services and are not interesting for this chapter. However, the table summarising them is presented in *Appendix 3*.

In addition to these constraints, the allocations must comply with the PCR on digital services and the PCR on service providers [20], [21]. The PCR on digital services explains the two possible approaches for an allocation: the equipment approach and the system approach. The first one is more precise but more complex and concerns each item or device used in the digital service. The system approach is less complicated and less precise and considers allocating systems containing several pieces of equipment, such as a data centre as a whole [20]. The PCR on digital services presents the different types of allocation possible to use, which are regrouped in *Table 10*. Yet, the PCR on service providers must specify the allocation type/formulae to use for the network. In its new version planned for the beginning of 2023, the PCR on service providers should determine the equations to use for a network.

Table 10: Type of allocations possible accordingly to the Product Category Rules (PCR) on digital services [20]

Digital service third	Type of allocation
Terminals	Usage time or memory usage, or computing power
Network	Volume of data transported/Bandwidth usage
Datacentre	Amount of data stored and/or Computing power (computation and storage)

Once the different possibilities for the allocation and their compliance with the European and French regulations are determined, each equation will be submitted for analysis. This one will check the coherence of the previous work in this field. The coherence of the formulae will also be validated thanks to the LCA knowledge gained with the literature review and dimensional study of the equation. However, several allocation equations may remain for the same equipment even after the validation step. For this reason, the cases where to use each equation will be detailed.

6.2 Results of the allocation formulas research

This chapter regroups the different equations of allocation found for each piece of equipment depending on the source. Those will be described to validate their coherence and compliance with the European and French regulations. Then, sensitivity analysis will show the variation of the impacts depending on the allocation formula chosen. Finally, each equation will be analysed, and case differentiation will be made.

6.2.1 Identification of the existing allocations in the literature

Using three different sources allowed the census of the possible allocations on all the pieces of equipment of a digital service. No issues were found for the allocations of the terminals and network third. The allocation of the terminals depends on their usage time, while the allocation of the network depends on the volume of data transported. Therefore, they are both compliant with European and French regulations. Nevertheless, the terminals studied were only the ones composing the cloud service of the LCA done previously in *chapter 5*. For the network third, the system approach used during the LCA of the cloud service was the only approach analysed in this chapter. Indeed, to model a network with the NégaOctet database, it is possible either to use the data of a fixed-line/mobile network or to reconstitute the network from the core, the aggregation, and the access layers.

The first source listing different allocations for each piece of equipment of a digital service is the NégaOctet study. Indeed, during this project, they made the LCA of several digital services such as a web conference, the downloading of a file, the stream of videos, a web request, and the sending of mail. Furthermore, each LCA study made by the NégaOctet consortium doesn't use the same allocation formulae for all the equipment. The second source for identifying the existing allocation is APL, the data centre company which is a part of the NégaOctet consortium. They were able to provide information on the firewalls and switch pieces of equipment. That information was used in several LCA made for the NégaOctet project but not for all of them.

The last source used is the report on analysing a web request made in 2011 [25]. This report made the LCA of a web request following the ISO 14 040 [4] and 14 044 [5] norms. The more significant work was on the data centre third, through which the request passes several times. Therefore, they determined an allocation formula for every piece of data centre equipment except the non-IT equipment and the architecture, which were not considered in this study.

The following part lists the allocation associated with its source and the equipment concerned. The following subchapter will analyse those equations using their label for more readability. For the same reason, the word number is abbreviated nbr.

The first piece of equipment investigated was the server which has a total of four different allocation formulae used in the literature:

1. From NégaOctet – Video streaming:

$$\frac{Nbr\ of\ servers}{Nbr\ of\ hours\ viewing\ per\ year * lifetime\ of\ a\ server} \tag{1}$$

2. From NégaOctet – Cloud service:

$$\frac{Nbr\ of\ servers}{Total\ amount\ of\ data\ transferred\ per\ year * lifetime\ of\ a\ server} \tag{2}$$

3. From NégaOctet – Conference:

$$\frac{Nbr\ of\ servers * hours\ of\ viewing}{Total\ nbr\ of\ viewing\ per\ year * lifetime\ of\ a\ server} \tag{3}$$

4. From the web request report:

$$\frac{Amount\ of\ data\ transfered}{Transfer\ rate\ of\ ethernet\ port * usage\ time * utilisation\ rate * lifetime} \tag{4}$$

With the transfer rate of ethernet port = 255 Mo/s
The usage time = 24 hours per day
And the utilisation rate = 25%, according to the report.

The next piece of equipment reviewed is the storage bay which counts two references:

1. From NégaOctet:

$$\frac{Amount\ of\ data\ store * storage\ time * redundancy}{Total\ amount\ of\ storage * lifetime * filling\ rate} \tag{5}$$

With the redundancy = 3 minimum because of security questions
And the filling rate = 50% according to the NégaOctet study

2. From the web request report:

$$2.11 * \ 10^{-11}\ per\ Mo\ stored \tag{6}$$

Then, the switch allocations are reviewed, and all three sources present different formulae. Moreover, except for the web request report, the two other sources give a ratio of switches per server. It means that to do the allocation of a switch; this ratio must be multiplied by the allocation of the server for the study considered:

1. From NégaOctet:

$$\frac{1}{7}\ switch\ per\ server \tag{7}$$

2. From APL company:

$$1.468\ switch\ per\ server \tag{8}$$

3. From the web request report:

$$7.05 * 10^{-13}\ per\ Mo\ transferred \tag{9}$$

Then, the firewall allocations are investigated. The results are the same as for the switch equipment. Therefore, all three sources give different equations and the NégaOctet source, as well as the APL company source, provide a ratio that must be multiplied by the allocation of the server to obtain the allocation of the firewall:

1. From NégaOctet:

$$\frac{1}{12}\ firewall\ per\ server \tag{10}$$

2. From APL company:

$$0.0358\ firewall\ per\ server \tag{11}$$

3. From the web request report:

$$1.69 * \ 10^{-10}\ for\ 1\ Mo\ transferred \tag{12}$$

Finally, the allocation for the non-IT and architecture pieces of equipment are presented. For these, only one source was available, and it was NégaOctet:

$$\frac{Server\ allocation * \frac{m^2}{server} * usage\ time}{Lifetime} \tag{13}$$

With m^2/server = 0.68 according to the source.

Now that all the allocations available for each piece of equipment of a data centre have been a census, they will be analysed in the next subchapter to determine which one is the most accurate in which case.

6.2.2 Analysis of the allocation's equations

Before analysing the equation associated with each piece of equipment, the importance of this choice is presented. Indeed, the allocations of each part of the equipment described in the previous subchapter were calculated for the cloud service assessment done in *chapter 5*. Then the relative difference between the maximum and minimum numbers found were calculated and represented in the graph *Figure 21* shows.

For the server, both minimum and maximum came from the NégaOctet source. More precisely, the minimum corresponds to the allocation for downloading a file, while the maximum corresponds to the allocation for a conference. The results have shown a difference of 99.6% between these two allocations formulae. The non-IT equipment and architecture allocations used by the NégaOctet project have no adversary. However, in the web request analysis report, it was mentioned that the non-IT pieces of equipment and the architecture were not assessed because they have minor impacts [25]. Therefore, the allocation given by NégaOctet was considered to have 100% more impact than in the other study. Then, the storage had two possibilities of allocation coming from the NégaOctet project and the web request. The web request allocation was minimal, ending in a difference of 66.7% between the two formulae. Knowing that the storage represents the main impact of the cloud service, the allocation formula should be chosen carefully. Finally, for both the firewall and the switch, three allocations formulae were available from the NégaOctet project, the web request report, and APL, a company specialising in datacentre which is a part of the NégaOctet consortium. The results have shown that the difference between the formulae was 93.3% for the firewall and 99.7% for the switch.

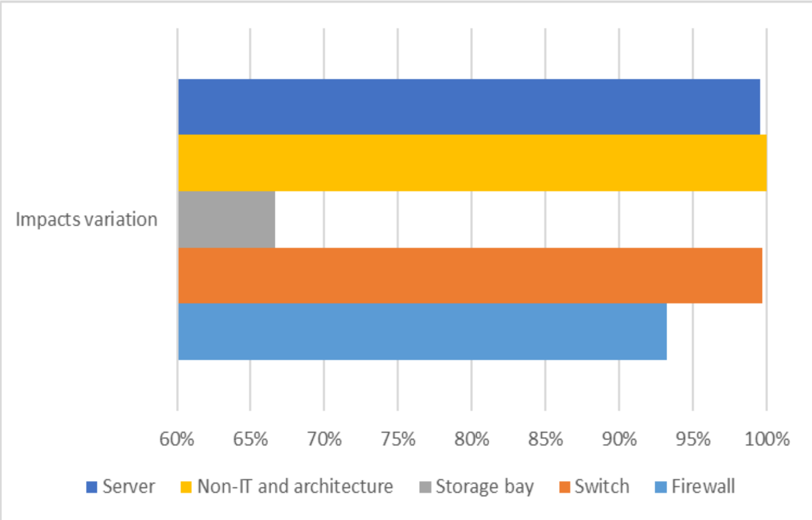

Figure 21: Variation between the different formulae of allocation available for each piece of equipment of a data centre applied to the case of a cloud service LCA

Secondly, the equations listed previously will be analysed to determine their consistency. First, the server's equations (1) to (4) are analysed. The equation (1) remains for the analysis of video streaming; therefore, it considers the total number of servers allocated to the streaming platform. The allocation is per hour of watching. For this, the impacts of all the servers used should be divided by the service's total number of watching hours per year. Moreover, the servers have a lifetime bigger than a year; consequently, the previous ratio should also be divided by the lifetime of the servers. To conclude, the allocation is coherent but only for 1 hour of watching. It should be multiplied by the hour of viewing considered in the study to be entirely correct. Consequently, equation (3) is accurate and consistent. Nevertheless, the current allocation only considers the time pass to watch a video and not the weight of the videos. Indeed, videos can have different quality and so, for the same duration of watching, different sizes and environmental impacts. Therefore, if the data is available, it is more accurate to use an allocation based on the weight of the videos, as the equation (14) is detailed in the following subchapter. It will be compliant with European and French regulations.

Equation (2) presents the same organisation as equation (1) but is based on the amount of data transferred. Hence, the conclusion is the same: the amount of data transmitted for the functional unit studied should be multiplied by the ratio, and the equation will comply with the PCR for digital services. Otherwise, it will give the impact of 1 GB transferred and so not accurate.

The last equation for the server allocation is equation (4) which comes from the web request report. This allocation is based on the fact that the number of servers dedicated to the service is unknown. Another case to use this formula is if the server is common to several digital services and/or companies. Consequently, the amount of data transferred for the service is divided by the total amount of data transmitted through the server. Therefore, this equation is compliant with European and French regulations. The total amount of data transferred through the server is not directly available; it can be calculated with the transfer rate of the server multiplied by its utilisation rate and lifetime in seconds to have the same unit as the transfer rate. Indeed, the IT equipment of a data centre is never off. Therefore, the utilisation rate allowed the calculation of the actual usage time. To conclude, this equation is consistent. The only limit is that the transfer and utilisation rates are not available for the users of the NégaOctet database. They will use the numbers determined by the web request report. These data are slightly outdated as they are from 2011.

Then, the allocations for the storage bay are reviewed. The previous subchapter listed two equations (5) and (6). The first one is from the NégaOctet project and is based on the amount of data stored, the storage duration as well as the redundancy of the data. Indeed, for security reasons such as the failure of the storage disks, the destruction of the data centre or else, the data are stored at least in 3 different places worldwide. Furthermore, this equation respects the requirements of the PCR on digital services. The multiplication of these three terms is divided by the total capacity of the storage array, its lifetime, and its filling rate. The storage bay is never full, so the total amount of storage multiplied by the filling rate gives the actual amount of data stored. This filling rate was calculated during the NégaOctet project and is 50%. In conclusion, this equation doesn't show inconsistency and can be used. Consequently, the allocation (6) given by the web request report won't be maintained as it doesn't consider redundancy.

As the allocations of the switch and the firewall present the same characteristic, they are analysed together. Indeed, both switch (equations (7) to (9)) and firewall (equations (10) to (12)) have three possibilities with one of each source. The two equations coming from the web request report are not retained. For the firewall, they didn't make any difference between a firewall and a server, and the data are outdated. For the switch, they made a calculation based on the transferred rate of a switch and the amount of data passing through it. However, it requires knowing the number of switches the digital service uses, which is not likely to happen in most cases. Therefore, only two options remain in the equation from the NégaOctet project and the one from APL. For both equations, there were no more details and explanations. However, the allocation from the NégaOctet project dates from 2021, while there is no date for the other one. Moreover, APL company is a part of the NégaOctet consortium, so they must agree on the allocation presented by the project. To conclude, the most accurate allocation is the equation (7) for the switch and the equation (10) for the firewall. As they depend on the allocation of the server, if this one is compliant with the PCR on digital services, this is also the case for the allocation of the switch and the firewall.

Finally, the last equipment reviewed is the non-IT and the architecture of the datacentre, which has only one possibility. The equation (13) depends on the allocation of the server. Indeed, the average data of the number au meter square per server has been estimated by the NégaOctet project. Multiplied by the allocation of the server, it gives the amount of equipment used by the service. Then, the lifetime of the equipment should also be considered as well as the usage time of the service. That is why there is a ratio between the usage time and the lifetime of the equipment. To conclude, this equation is coherent and accurate. As they depend on the allocation of the server, if this one is compliant with the PCR on digital services, this is also the case for the allocation of the non-IT equipment and architecture.

6.2.3 Results and case differentiation

Finally, the equations maintained are listed in this section. The server will have several possibilities detailed in the next section. Furthermore, certain equations are not perfect because of the lack of indications in the sources and some outdated data. However, the equations chosen in this case will maximise the impacts, unlike the other choices available.

The first piece of equipment reviewed was the server starting with four different formulae for its allocation. In the end, only three remained, slightly different from what was written in subchapter 6.2.1. Indeed, depending on the data available, when having the total number of servers used for the service, the allocation will be made at the time of usage or the data transiting through the servers. It should be noted that equation (3) is not compliant with the PCR for digital services. Nevertheless, it is impossible to know the number of servers allocated for certain digital services, such as with a cloud. If the database users are not directly dealing with the software, they cannot have global data, so they can't use the two first allocations. Moreover, even when dealing with the software, it is not always possible to have all the data as many companies rent a portion of a data centre. Consequently, when the number of servers is unknown, the web request report allocation must be used.

1. With the number of servers – time dependence:

$$\frac{Nbr\ of\ servers * hours\ of\ viewing}{Total\ nbr\ of\ viewing\ per\ year * lifetime\ of\ a\ server} \tag{3}$$

2. With the number of servers – data transiting dependence:

$$\frac{Nbr\ of\ servers * amount\ of\ data\ exchange}{Total\ amount\ of\ data\ transiting\ year * lifetime\ of\ a\ server} \tag{14}$$

3. Without the number of servers, from the web request report:

$$\frac{Amount\ of\ data\ transfered}{Transfer\ rate\ of\ ethernet\ port * usage\ time * utilization\ rate * lifetime} \quad (4)$$

With the transfer rate of ethernet port = 255 Mo/s
The usage time = 24 hours per day
And the utilisation rate = 25%, according to the report.

Only the allocation given by the NégaOctet project for the storage bay was maintained, as explained previously in Chapter 6.2.2.

$$\frac{Amount\ of\ data\ store * storage\ time * redundancy}{Total\ amount\ of\ storage * lifetime * filling\ rate} \quad (5)$$

With the redundancy = 3 minimum because of security questions
And the filling rate = 50% according to the NégaOctet study

For both the switch and the firewall, only the data from the NégaOctet source was selected as it is the most recent. The data from the web request report was too old, while the APL company data undermined the impacts. However, there is a lack of explanations on how these data have been calculated. Nevertheless, these two elements are not the most impacting ones in a data centre, so the determination of their allocation will have a minor impact.

$$\frac{1}{7}\ switch\ per\ server \quad (7)$$

$$\frac{1}{12}\ Firewall\ per\ server \quad (10)$$

Finally, there was only one possibility for allocating the non-IT and architecture equipment from the NégaOctet source. However, this equation is coherent and so selected.

$$\frac{Server\ allocation * \frac{m^2}{server} * usage\ time}{Lifetime} \tag{13}$$

With m²/server = 0.68 according to the source.

6.3 Discussion

The investigation of the existing allocation equations of the pieces of equipment composing a digital service gave some results. If there were no issues concerning the terminal and network third allocations, it was not the case for the datacentre third. At first sight, the allocations from the NégaOctet study seemed the most coherent as they were issued from the most recent study. However, it was not always these allocations selected.

Indeed, the different sources reviewed have some limitations. The NégaOctet source is the newest, but the work made on allocation has still not been finished to be reviewed by another LCA expert. It is highly expected to have several changes to do. The study on the web request impacts [25] gives very much details on the calculation made, but it dates from 2011, so the data such as the utilisation and flow rates might be outdated. However, as the actual data centres are more efficient, their impacts would be increased with the allocation of this source. Therefore, this is not an important issue as in LCA; it is preferable to overestimate the impacts over the contrary.

Furthermore, it must be noticed that they are still issues with some allocations selected at the end of the investigation. First, equation (3) used for allocating a server is not compliant with the PCR on digital services. It also concerns the allocation of the switch and the firewall. Both allocations selected do not depend on the lifetime of the equipment. Even worse, if the lifetime of a switch, or a firewall, increases, the environmental impacts of these pieces of equipment will also increase instead of decreasing, as the power consumption will be more significant. Indeed, the overall consumption over the product's lifetime increases, but the equipment's allocation doesn't decrease as it should. Consequently, the total environmental impact of the product is higher. As a reminder, the allocation of the power consumption is written in the equation (15).

$$\text{Allocation} = \text{power consumption for a year} * \text{lifetime} * \text{allocation of the equipment} \qquad (15)$$

Moreover, the LCA of digital services being new and the PCR associated not created, there is a high possibility that modifications will be done. Indeed, two PCR are in creation (datacentre and company network) while the existing PCR on service providers is being updated. Each one of them must indicate which type of allocations to utilise in which case.

Finally, only specific terminals and network equipment have been considered for this study. Only the terminals have been analysed for the laptop, smartphone, desktop, and screen. At the same time, there are still dozens of different pieces of equipment in the NégaOctet database, such as IoT objects, USB keys, television, barcode scanner, digital price tag, etc. For the network, a system approach was used, and no analyses were made on the pieces of equipment composing the aggregation, access, and backbone layers of the network because of a lack of time. For the same reason, a data centre's non-IT equipment and architecture have only been analysed through global data. They do not specify the allocation of each piece of equipment, such as the air conditioning group, the fire detection station, the generator, the access floor, the tiling, etc.

7 Conclusions

This thesis investigated and solved materials-based inconsistencies in the NegaOctet database. This is the first one focusing on digital services, allowing their life cycle assessment (LCA). The LCA is a standardised methodology following the norms ISO 14 040 and ISO 14 044 [4], [5] to evaluate the environmental impacts of a product. However, LCA on digital services is more complex because all the equipment – from the terminals to the data centres, including the networks – mutualised several services. Therefore, allocations must be done to allocate equipment impacts to the service considered. Furthermore, this database was created after three years of work, so this study reviewed this work. As the database was not released thesis's beginning, this work was essential.

An LCA on a cloud service was done to manipulate the database and investigate inconsistencies. As a result, the data centre is the most impacting third for a cloud service. It impacts from 12% to 77%, depending on the indicators. This thesis shows that these significant impacts come from the storage technology (SSD) manufacturing of the pictures' storage. This result confirmed the aim of the thesis to resolve material-based inconsistencies. Moreover, it was concluded the data from NégaOctet are coherent with the literature. Furthermore, this work results discovering of nine inconsistencies in the database. The criticality table evaluated the most critical to solve. Among the nine inconsistencies identified, eight were solved during the time of this thesis, with only one interesting in the scope of this thesis. The inconsistency not solved requires more significant work.

The most critical inconsistency; concerning allocation of the digital services' equipment; was solved. Indeed, the extraction and manufacturing of materials are the most impacting steps for digital services. Therefore, their allocation is essential, but the literature didn't agree on the equations to use. Furthermore, an experiment has been conducted, showing that using the wrong allocation can double the impacts of a specific equipment. As a result, allocation equations were determined for the terminals equipment and the network. The terminal allocation is reduced to the time of use, while the one for the network is reduced to the number of GB transported. A deeper work has been made for the data centres equipment allocations, as the literature provided several equations for the same equipment. They have been reviewed, corrected, and sorted to be coherent and compliant with European and French regulations. In the end, three equations were found for the servers depending on the data available by the user: one relies on the time of use, the second on the GB transferred, and the last one the computing power. A ratio of equipment per server was selected, for the firewall and switch. The equation of the storage bay is reduced to the amount of data stored, the duration, and the redundancy. Finally, the non-IT equipment and architecture allocation was determined from the ratio of IT room m^2 per server and the period of use.

However, this study has several limits that should be further investigated. Firstly, all the inconsistencies in the database might not have been found as all the 1 500 data were not analysed during this thesis. Furthermore, some of the allocations selected in the previous chapter should be improved. Indeed, for the switch and firewall, dependence on their lifetime should be added to the equation, while for the server, more actual data should be determined for the constants of the equation (4). Moreover, a system approach has been used for the terminal and networks third. It means that all the pieces of equipment were modelled by generic data. Therefore, the allocations should be investigated equipment by equipment. This work will be partially done through the update of PCR for internet service providers.

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Appendix 1: characteristics of the cloud service used to do its LCA

1. Modelling

The cloud user uploads 100 pictures per week with its laptop. Twice a year, he uploads 500 pictures. Those are in 36 MPx compressed in JPEG formation which is 15 MB. He stores the pictures for a year. Every week he views 100 pictures and downloads 300 per year.

Uploading time	*Pictures weight* nbr of pictures per year/flow/60 = 15 * 6 000/0.25/3600 = 100 h per year*
Viewing time	26h per year
Downloading time	30min per year
Total consultation time	126h and 30min per year

User's block – characteristics

Terminal		Lifetime (years)	Consumption	Usage time per day	Distribution
Laptop	564 GB SSD	5	27.98 kW/year	3.45 h/d	100%

Electric consumption	
Electric mix	French production mix
Consumption (kWh)	Consumption per year*lifetime*allocation of the terminal

Laptop allocation :

$$Repartition * \frac{Time\ of\ use\ for\ the\ service}{usage\ time\ per\ day * 365 * lifetime}$$

Network block – upload characteristics

Pictures caracteristics	
Pictures size	15 MB
Number of pictures	6 000 per year
Amount of GB transfered	87.9 GB per year

Electric consumption	
Electric mix	French production mix
Consumtpion (kWh)	181 kWh * allocation of the network

Network	
Fixed network	100%
Mobile network	0%

Network allocation :

$$\frac{Amount\ of\ GB\ transfered}{12 * Nbr\ of\ GB\ transfered\ per\ month} = 0.033$$

Network block – download characteristics

Display

Pictures caracteristics	
Pictures size	15 MB
Nbr of pictures viewed	5 200 per year
Amount of GB transfered	76.2 GB per year

Network	
Fixed network	100%
Mobile network	0%

Electric consumption	
Electric mix	French production mix
Consumtpion (kWh)	181 kWh * allocation of the network

Network allocation :

$$\frac{Amount\ of\ GB\ transfered}{12 * Nbr\ of\ GB\ transfered\ per\ month} = 0.029$$

downloading

Pictures caracteristics	
Pictures size	15 MB
Nbr of pictures viewed	300 per year
Amount of GB transfered	4.4 GB per year

Network	
Fixed network	100%
Mobile network	0%

Electric consumption	
Electric mix	French production mix
Consumtpion (kWh)	181 kWh * allocation of the network

Network allocation :

$$\frac{Amount\ of\ GB\ transfered}{12 * Nbr\ of\ GB\ transfered\ per\ month} = 0.0017$$

Data centre block – characteristics

Equipment		Lifetime (year)	Consumption	Usage time per day	Flow	Usage rate	Storage capacity
Firewall		5	876 kWh/year	24 h/d			
Switch	48 ports per U, 512 GB RAM	5	4 424 kWh/year	24 h/d			
Server	Blade, 1SSD 1024GB; 0HDD; 2 RAM 16GB, O GPU	3	3 504 kWh/year	24 h/d	897 GB/h	25%	
Storage	SSD 48 disk	5	2 523 kWh/year	24 h/d		50%	TLC – 2048 GB

	PUE	Lifetime (years)	M²/server
Non-IT equipment and architecture	1.69	25	0.68

Electric consumption	
Electric mix	French production mix
Consumption of a piece of equipment (kWh)	$PUE * consumption * lifetime * allocation$

Data centre allocations :

Equipment	Equation	Allocation
Server	$\frac{Amount\ of\ data\ consumed}{time\ of\ use * lifetime * utilisation\ rate * flow\ rate}$	2.86E-05
Switch	$\frac{Allocation\ of\ the\ server}{7}$	4.09E-06
Firewall	$\frac{Allocation\ of\ the\ server}{12}$	2.38E-06
Storage	$\frac{Amount\ of\ storage * storage\ time * reduncancy}{Total\ amount\ of\ storage * lifetime * filling\ ratio}$	2.6E-03
Non-IT architecture and equipment	$PUE * consumption\ for\ a\ year * lifetime * allocation$	7.78E-07

2. Quantitative results

	Users block	Datacenters block	Network block	Sum
MIPS (kg)	1.92E+01	4.39E+01	1.09E+01	7.40E+01
PEF-ADPe (kg SB eq.)	2.49E-04	4.89E-05	1.25E-04	4.22E-04
PEF-ADPf (MJ)	1.03E+02	3.81E+02	2.40E+02	7.24E+02
PEF-AP (mol H+ eq.)	2.62E-02	1.09E-01	1.30E-02	1.48E-01
PEF-CTUe (CTUe)	8.29E+01	2.34E+02	2.72E+01	3.44E+02
PEF-CTUh-c (CTUh)	1.26E-09	2.30E-09	1.29E-09	4.86E-09
PEF-CTUh-nc (CTUh)	5.30E-08	1.06E-07	2.82E-08	1.87E-07
PEF-Epf (kg P eq.)	2.54E-05	5.67E-05	5.81E-05	1.40E-04
PEF-Epm (kg N eq.)	5.11E-03	1.28E-02	1.77E-03	1.97E-02
PEF-Ept (mol N eq.)	3.29E-02	1.61E-01	2.04E-02	2.15E-01
PEF-GWP (kg CO2 eq.)	4.26E+00	1.93E+01	2.03E+00	2.56E+01
PEF-IR (kg U235 eq.)	1.16E+01	1.48E+01	3.33E+01	5.96E+01
PEF-ODP (kg CFC-11 eq.)	1.08E-06	4.06E-06	1.34E-07	5.27E-06
PEF-PM (Disease occurrence)	1.92E-07	7.23E-07	2.96E-07	1.21E-06
PEF-POCP (kg NMVOC eq.)	1.05E-02	4.14E-02	5.19E-03	5.70E-02

3. Bill of materials – Products

Flow	Unit	Sum	Terminals	Network	Datacenter
ecoivent - antimony	kg	1.19E-06	0.00E+00	0.00E+00	1.19E-06
ecoivent - copper oxide	kg	1.41E-07	1.29E-07	2.09E-09	9.19E-09
ecoivent - flat glass, uncoated	kg	1.11E-03	1.11E-03	0.00E+00	1.45E-10
ecoivent - flux, for wave soldering	kg	1.65E-04	1.64E-04	3.50E-07	5.57E-11
ecoivent - graphite	kg	2.96E-04	2.96E-04	0.00E+00	0.00E+00
ecoivent - iron pellet	kg	5.80E-05	4.18E-05	1.42E-05	2.06E-06

ecoivent - palladium	kg	1.99E-07	1.65E-07	1.31E-08	2.10E-08
ecoivent - phosphate rock, as P2O5, beneficiated, dry	kg	4.38E-12	0.00E+00	0.00E+00	4.38E-12
ecoivent - phosphorus, white, liquid	kg	2.62E-07	1.89E-07	6.28E-08	1.09E-08
Energy carriers and technologies / Natural gas based fuels - natural gas	kg	2.38E-04	0.00E+00	2.38E-04	0.00E+00
Materials production / Composites - bisphenol A epoxy based Vinyl Ester Resin (VER); production mix, at plant	kg	5.59E-05	5.59E-05	0.00E+00	3.78E-09
Materials production / Fibres or filaments / Artificial - cellulose acetate fibres; from beech wood pulp; production mix, at plant	kg	7.68E-10	0.00E+00	0.00E+00	7.68E-10
Materials production / Glass and ceramics - ceramic	kg	1.79E-05	0.00E+00	1.23E-05	5.67E-06
Materials production / Glass and ceramics - ceramic; electronic grade	kg	5.30E-06	1.52E-08	5.25E-06	4.08E-08
Materials production / Glass and ceramics - glass	kg	9.27E-05	6.66E-06	5.20E-05	3.40E-05
Materials production / Glass and ceramics - glass fibre	kg	1.00E-02	1.27E-03	8.20E-03	5.52E-04
Materials production / Inorganic chemicals - alumine	kg	1.84E-04	1.32E-04	3.98E-05	1.19E-05
Materials production / Inorganic chemicals - ammonia	kg	5.04E-06	0.00E+00	5.04E-06	2.01E-11
Materials production / Inorganic chemicals - antimony trioxide	kg	1.06E-05	3.23E-06	4.03E-06	3.37E-06
Materials production / Inorganic chemicals - Argon, crude, liquid; at plant	kg	5.14E-08	0.00E+00	0.00E+00	5.14E-08
Materials production / Inorganic chemicals - Argon; liquid; at plant	kg	1.77E-05	0.00E+00	1.77E-05	0.00E+00
Materials production / Inorganic chemicals - barium oxide	kg	1.68E-04	1.52E-04	4.97E-06	1.14E-05
Materials production / Inorganic chemicals - bauxite	kg	8.76E-03	1.28E-07	8.76E-03	1.55E-08
Materials production / Inorganic chemicals - calcium carbonate	kg	7.66E-07	0.00E+00	5.55E-07	2.11E-07
Materials production / Inorganic chemicals - chlorine; production mix for PVC production, at plant	kg	3.70E-07	0.00E+00	0.00E+00	3.70E-07
Materials production / Inorganic chemicals - chlorine; production mix, at plant; liquid	kg	3.66E-08	7.03E-10	3.59E-08	1.14E-12
Materials production / Inorganic chemicals - chromium oxide; production mix, at plant	kg	1.10E-07	0.00E+00	0.00E+00	1.10E-07
Materials production / Inorganic chemicals - chromium trioxide	kg	2.98E-07	0.00E+00	2.98E-07	6.86E-11
Materials production / Inorganic chemicals - cobalt oxide	kg	7.08E-07	0.00E+00	7.08E-07	1.63E-10
Materials production / Inorganic chemicals - concrete	kg	8.15E-03	0.00E+00	0.00E+00	8.15E-03
Materials production / Inorganic chemicals - enamel coating; technology mix, at plant	kg	1.59E-07	0.00E+00	0.00E+00	1.59E-07
Materials production / Inorganic chemicals - fluorhydric acid	kg	5.43E-06	0.00E+00	5.43E-06	0.00E+00

Materials production / Inorganic chemicals - hydrocyanic acid	kg	3.17E-12	0.00E+00	7.35E-15	3.16E-12
Materials production / Inorganic chemicals - hydrogen	kg	3.04E-06	0.00E+00	3.04E-06	1.27E-11
Materials production / Inorganic chemicals - hydrogen chloride	kg	1.36E-05	0.00E+00	1.36E-05	7.06E-12
Materials production / Inorganic chemicals - hydrogen peroxide	kg	4.06E-05	0.00E+00	4.06E-05	0.00E+00
Materials production / Inorganic chemicals - hydrogen; gaseous	kg	1.45E-09	0.00E+00	0.00E+00	1.45E-09
Materials production / Inorganic chemicals - Krypton, gaseous; at plant	kg	5.14E-08	0.00E+00	0.00E+00	5.14E-08
Materials production / Inorganic chemicals - lead oxide	kg	3.23E-07	7.77E-08	1.81E-07	6.47E-08
Materials production / Inorganic chemicals - lithium hydroxide	kg	4.12E-07	0.00E+00	0.00E+00	4.12E-07
Materials production / Inorganic chemicals - Lithium nickel cobalt manganese hydroxide; production mix, at plant	kg	6.63E-04	6.63E-04	0.00E+00	0.00E+00
Materials production / Inorganic chemicals - magnesium hydroxide	kg	3.37E-03	0.00E+00	3.37E-03	5.87E-09
Materials production / Inorganic chemicals - magnesium oxide	kg	9.42E-07	8.38E-07	1.36E-08	9.02E-08
Materials production / Inorganic chemicals - manganese dioxide	kg	1.08E-05	1.01E-05	2.14E-07	5.07E-07
Materials production / Inorganic chemicals - monocristalline wafers	kg	2.21E-09	0.00E+00	5.10E-12	2.21E-09
Materials production / Inorganic chemicals - nickel oxides (unspecified)	kg	1.46E-07	0.00E+00	1.46E-07	3.35E-11
Materials production / Inorganic chemicals - nickel/lithitum oxides (unspecified)	kg	2.33E-11	0.00E+00	0.00E+00	2.33E-11
Materials production / Inorganic chemicals - nitric acid	kg	5.74E-07	0.00E+00	5.74E-07	0. 00E+00
Materials production / Inorganic chemicals - nitrogen	kg	1.52E-12	0.00E+00	0.00E+00	1.52E-12
Materials production / Inorganic chemicals - Nitrogen liquid; at plant	kg	1.27E-03	0.00E+00	1.27E-03	0.00E+00
Materials production / Inorganic chemicals - Oxygen liquid; at plant	kg	1.03E-05	0.00E+00	1.03E-05	0.00E+00
Materials production / Inorganic chemicals - phosphoric acid; at plant; 85% in H2O	kg	2.04E-06	0.00E+00	2.04E-06	0.00E+00
Materials production / Inorganic chemicals - portland cement	kg	2.91E-06	0.00E+00	0.00E+00	2.91E-06
Materials production / Inorganic chemicals - potassium hydroxide	kg	2.33E-06	1.66E-06	5.84E-07	8.39E-08
Materials production / Inorganic chemicals - quartz sand	kg	2.90E-04	1.39E-04	9.31E-05	5.72E-05
Materials production / Inorganic chemicals - quick lime	kg	3.64E-05	5.02E-06	3.08E-05	6.04E-07
Materials production / Inorganic chemicals - rock wool	kg	2.11E-05	0.00E+00	0.00E+00	2.11E-05
Materials production / Inorganic chemicals - sand	kg	8.26E-07	3.96E-08	7.51E-07	3.54E-08

Materials production / Inorganic chemicals - silane	kg	2.87E-08	0.00E+00	2.87E-08	0.00E+00
Materials production / Inorganic chemicals - sodium chloride	kg	1.86E-07	0.00E+00	1.86E-07	0.00E+00
Materials production / Inorganic chemicals - sodium hydroxide	kg	2.42E-06	0.00E+00	2.42E-06	9.57E-10
Materials production / Inorganic chemicals - sodium hydroxide; production mix for PVC production, at plant; 100% NaOH	kg	4.00E-07	0.00E+00	0.00E+00	4.00E-07
Materials production / Inorganic chemicals - sodium hypochlorite; production mix, at plant; 15% in H2O	kg	1.02E-06	0.00E+00	1.02E-06	0.00E+00
Materials production / Inorganic chemicals - sulfur dioxide	kg	9.99E-08	0.00E+00	0.00E+00	9.99E-08
Materials production / Inorganic chemicals - sulfur hexafluoride	kg	3.12E-08	0.00E+00	1.36E-08	1.76E-08
Materials production / Inorganic chemicals - sulfuric acid	kg	6.92E-05	0.00E+00	6.26E-05	6.63E-06
Materials production / Inorganic chemicals - talc	kg	2.47E-07	2.41E-07	1.05E-09	4.90E-09
Materials production / Inorganic chemicals - tetrachlorosilane; trichlorosilane hydrogenation; production mix, at plant	kg	8.37E-07	0.00E+00	8.37E-07	0.00E+00
Materials production / Inorganic chemicals - thionyl chloride	kg	2.95E-06	0.00E+00	0.00E+00	2.95E-06
Materials production / Inorganic chemicals - titanium dioxide	kg	2.41E-04	1.29E-04	1.06E-04	5.18E-06
Materials production / Inorganic chemicals - zinc oxide	kg	3.08E-05	1.39E-07	3.07E-05	1.41E-08
Materials production / Metals and semimetals - alloy	kg	8.15E-05	5.61E-05	[illegible]	[illegible]
Materials production / Metals and semimetals - aluminium	kg	2.36E-03	1.07E-03	[illegible]	[illegible]
Materials production / Metals and semimetals - aluminium alloy 6082; primary production; production mix, at plant	kg	9.49E-10	0.00E+00	0.00E+00	9.49E-10
Materials production / Metals and semimetals - aluminium extrusion profile; primary production; production mix, at plant; aluminium semi-finished extrusion product, including primary production, transformation and recycling	kg	3.22E-05	0.00E+00	3.22E-05	0.00E+00
Materials production / Metals and semimetals - aluminum alloy 5083; primary production; production mix, at plant	kg	8.56E-08	0.00E+00	0.00E+00	8.56E-08
Materials production / Metals and semimetals - aluminum alloy AlNiCo; primary production; production mix, at plant	kg	1.62E-08	0.00E+00	0.00E+00	1.62E-08
Materials production / Metals and semimetals - aluminum sheet; primary production; production mix, at plant; thickness from 0,2 to 6 mm	kg	2.89E-05	0.00E+00	2.89E-05	4.51E-08

Materials production / Metals and semimetals - aluminum; 48% recycled from clean scrap; production mix, at plant	kg	5.07E-03	5.02E-03	0.00E+00	4.92E-05
Materials production / Metals and semimetals - aluminum; secondary production; production mix, at plant; 100% recycled from clean scrap	kg	1.17E-05	0.00E+00	1.17E-05	0.00E+00
Materials production / Metals and semimetals - brass	kg	8.21E-04	5.61E-04	8.13E-05	1.79E-04
Materials production / Metals and semimetals - bronze	kg	2.60E-05	2.25E-05	8.26E-08	3.51E-06
Materials production / Metals and semimetals - cadmium	kg	2.81E-09	0.00E+00	0.00E+00	2.81E-09
Materials production / Metals and semimetals - cast iron	kg	3.57E-06	0.00E+00	0.00E+00	3.57E-06
Materials production / Metals and semimetals - chromium	kg	7.94E-08	1.55E-08	2.51E-10	6.37E-08
Materials production / Metals and semimetals - Cobalt; at plant	kg	2.81E-09	2.77E-09	0.00E+00	4.01E-11
Materials production / Metals and semimetals - copper	kg	3.32E-03	2.06E-03	9.91E-04	2.64E-04
Materials production / Metals and semimetals - copper wire	kg	1.72E-03	1.02E-04	1.62E-03	1.84E-06
Materials production / Metals and semimetals - ferrite magnet; production mix, at plant; MnZn	kg	2.76E-08	0.00E+00	0.00E+00	2.76E-08
Materials production / Metals and semimetals - ferrites	kg	7.55E-04	3.69E-04	3.49E-04	3.78E-05
Materials production / Metals and semimetals - gallium arsenide	kg	5.26E-12	0.00E+00	0.00E+00	5.26E-12
Materials production / Metals and semimetals - gold	kg	4.43E-06	2.55E-06	1.11E-0[illegible]	[illegible]
Materials production / Metals and semimetals - invar	kg	8.21E-06	0.00E+00	8.20E-06	7.61E-09
Materials production / Metals and semimetals - iron	kg	5.21E-05	4.64E-06	2.76E-05	1.99E-05
Materials production / Metals and semimetals - ITO, sintered target; production mix, at plant	kg	1.04E-06	1.04E-06	4.05E-09	1.41E-13
Materials production / Metals and semimetals - lead	kg	6.28E-05	1.15E-06	2.17E-05	4.00E-05
Materials production / Metals and semimetals - lead; primary; consumption mix, at plant	kg	7.83E-07	0.00E+00	7.49E-07	3.37E-08
Materials production / Metals and semimetals - lithium	kg	3.51E-07	0.00E+00	1.68E-08	3.34E-07
Materials production / Metals and semimetals - magnesium	kg	4.87E-08	4.33E-08	0.00E+00	5.34E-09
Materials production / Metals and semimetals - mercury	kg	4.21E-10	0.00E+00	0.00E+00	4.21E-10
Materials production / Metals and semimetals - neodymium rare earth magnet; production mix, at plant; Nd2Fe14B	kg	3.46E-08	0.00E+00	0.00E+00	3.46E-08
Materials production / Metals and semimetals - nickel	kg	1.49E-04	6.48E-05	6.67E-05	1.76E-05

Materials production / Metals and semimetals - palladium	kg	9.46E-10	9.44E-10	0.00E+00	1.54E-12
Materials production / Metals and semimetals - Palladium; primary; at refinery	kg	7.86E-10	7.86E-10	0.00E+00	8.42E-13
Materials production / Metals and semimetals - silicon	kg	2.76E-04	4.98E-05	2.16E-04	1.07E-05
Materials production / Metals and semimetals - silver	kg	3.88E-05	1.60E-05	1.76E-05	5.27E-06
Materials production / Metals and semimetals - silver; 27,3% recycled content; production mix, at plant	kg	6.57E-06	4.64E-06	1.11E-06	8.10E-07
Materials production / Metals and semimetals - stainless steel hot rolled coil, annealed and pickled; electric arc furnace route; production mix, at plant; grade 304 (austenitic, 18% chromium, 10% nickel)	kg	2.27E-04	0.00E+00	2.27E-04	0.00E+00
Materials production / Metals and semimetals - stainless steel with chrome	kg	2.52E-03	2.46E-03	4.81E-05	7.80E-06
Materials production / Metals and semimetals - steel	kg	8.65E-04	8.64E-04	0.00E+00	4.73E-07
Materials production / Metals and semimetals - steel ABS, grade A; primary production, hot rolled plate; production mix, at plant	kg	1.47E-11	0.00E+00	0.00E+00	1.47E-11
Materials production / Metals and semimetals - steel cold rolled coil; 35% recycled; production mix, at plant; thickness 0,15 to 3 mm, width 600 to 2100 mm	kg	6.13E-07	0.00E+00	0.00E+00	6.13E-07
Materials production / Metals and semimetals - steel electrogalvanised; 35% recycled; production mix, at plant; thickness 0,3 to 3 mm, width 600 to 2100 mm	kg	4.39E-02	1.65E-03	7.66E-04	4.15E-02
Materials production / Metals and semimetals - steel engineering, grade A2; primary production, hot rolled plate; production mix, at plant; air-hardening	kg	3.73E-06	0.00E+00	1.87E-06	1.85E-06
Materials production / Metals and semimetals - steel finished cold rolled coil; 35% recycled; production mix, at plant; thickness 0,3 to 3 mm, width 600 to 2100 mm	kg	6.96E-05	0.00E+00	6.68E-05	2.79E-06
Materials production / Metals and semimetals - steel hot dip galvanized; 35% recycled; production mix, at plant; thickness 0,3 to 3 mm, width 600 to 2100 mm	kg	1.38E-04	0.00E+00	0.00E+00	1.38E-04
Materials production / Metals and semimetals - steel low alloyed; primary production, hot rolled plate; production mix, at plant; 25CrMo4	kg	1.08E-08	0.00E+00	0.00E+00	1.08E-08
Materials production / Metals and semimetals - steel organic coated;	kg	3.30E-07	0.00E+00	0.00E+00	3.30E-07

35% recycled; production mix, at plant; thickness 0,15 to 1,5 mm, width 600 to 1300 mm					
Materials production / Metals and semimetals - steel plate	kg	9.69E-05	0.00E+00	0.00E+00	9.69E-05
Materials production / Metals and semimetals - steel rank S355NL; primary production, hot rolled plate; production mix, at plant	kg	3.19E-09	0.00E+00	0.00E+00	3.19E-09
Materials production / Metals and semimetals - steel S235 JR; primary production, hot rolled plate; production mix, at plant	kg	1.56E-07	0.00E+00	0.00E+00	1.56E-07
Materials production / Metals and semimetals - steel; tinplated	kg	1.68E-03	2.77E-05	1.66E-03	1.03E-11
Materials production / Metals and semimetals - tantalum	kg	6.60E-06	2.11E-09	0.00E+00	6.59E-06
Materials production / Metals and semimetals - tin	kg	4.69E-04	2.06E-04	1.82E-04	8.08E-05
Materials production / Metals and semimetals - titanium	kg	1.41E-05	1.26E-05	1.05E-10	1.50E-06
Materials production / Metals and semimetals - tungsten	kg	8.05E-11	8.04E-11	0.00E+00	1.31E-13
Materials production / Metals and semimetals - zamak	kg	1.86E-09	0.00E+00	0.00E+00	1.86E-09
Materials production / Metals and semimetals - zinc	kg	2.85E-05	5.07E-06	2.03E-05	3.10E-06
Materials production / Organic chemicals - 2-cyanoguanidine	kg	4.67E-12	0.00E+00	0.00E+00	4.67E-12
Materials production / Organic chemicals - acetic acid	kg	6.02E-06	0.00E+00	1.82E-07	5.84E-06
Materials production / Organic chemicals - acetone	kg	7.43E-07	0.00E+00	7.43E-07	0.00E+00
Materials production / Organic chemicals - acrylic glue	kg	9.60E-08	0.00E+00	8.50E-08	1.10E-08
Materials production / Organic chemicals - benzene	kg	5.81E-06	0.00E+00	0.00E+00	5.81E-06
Materials production / Organic chemicals - bitumen	kg	3.36E-04	0.00E+00	0.00E+00	3.36E-04
Materials production / Organic chemicals - butadiene	kg	3.87E-07	3.28E-10	3.83E-07	4.14E-09
Materials production / Organic chemicals - butyl acrylate	kg	1.07E-05	1.06E-05	4.94E-08	8.88E-13
Materials production / Organic chemicals - carbon	kg	1.46E-06	1.11E-06	0.00E+00	3.54E-07
Materials production / Organic chemicals - carbon black	kg	6.95E-05	6.87E-05	2.93E-07	5.70E-07
Materials production / Organic chemicals - carbon dioxide; out of waste gases; production mix, at plant; liquid	kg	4.81E-08	0.00E+00	4.81E-08	0.00E+00
Materials production / Organic chemicals - carbon monoxide; from heavy fuel oil; production mix, at plant	kg	1.53E-08	0.00E+00	1.53E-08	0.00E+00
Materials production / Organic chemicals - Dipropylene glycol monomethyl ether; at plant	kg	3.50E-07	0.00E+00	0.00E+00	3.50E-07

Materials production / Organic chemicals - epoxy resin glue	kg	2.49E-07	8.66E-08	1.62E-07	1.15E-10
Materials production / Organic chemicals - ethanol	kg	1.02E-07	0.00E+00	1.02E-07	0.00E+00
Materials production / Organic chemicals - ethylene butyl acrylate	kg	7.30E-07	7.29E-07	0.00E+00	1.19E-09
Materials production / Organic chemicals - ethylene glycol; oxidation of ethylene oxide; production mix, at plant	kg	3.39E-08	0.00E+00	3.39E-08	3.77E-12
Materials production / Organic chemicals - ethylene oxide	kg	7.08E-07	7.07E-07	0.00E+00	1.15E-09
Materials production / Organic chemicals - glue (unspecified)	kg	2.71E-06	0.00E+00	2.71E-06	1.85E-10
Materials production / Organic chemicals - Isopropanol; at plant	kg	6.79E-06	0.00E+00	6.79E-06	0.00E+00
Materials production / Organic chemicals - liquid cristal polymer	kg	6.16E-06	1.02E-06	2.49E-06	2.65E-06
Materials production / Organic chemicals - lubricant (unspecified)	kg	1.37E-07	0.00E+00	1.36E-07	1.01E-09
Materials production / Organic chemicals - methyl ethyl ketone	kg	7.92E-06	0.00E+00	7.92E-06	1.38E-11
Materials production / Organic chemicals - methyl methacrylate	kg	8.42E-07	0.00E+00	8.42E-07	0.00E+00
Materials production / Organic chemicals - organic pigment	kg	2.31E-04	0.00E+00	2.31E-04	3.93E-10
Materials production / Organic chemicals - polyoxymethylene	kg	2.98E-08	2.98E-08	0.00E+00	3.42E-16
Materials production / Organic chemicals - polyphenylene oxide	kg	3.19E-06	3.11E-06	3.24E-08	4.03E-08
Materials production / Organic chemicals - polyphenylene sulfide	kg	9.38E-06	0.00E+00	9.38E-06	0.00E+00
Materials production / Organic chemicals - polyurethane glue	kg	1.87E-07	0.00E+00	1.87E-07	0.00E+00
Materials production / Organic chemicals - polyvinylidene fluoride	kg	2.57E-12	0.00E+00	0.00E+00	2.57E-12
Materials production / Organic chemicals - propene	kg	2.21E-07	0.00E+00	0.00E+00	2.21E-07
Materials production / Organic chemicals - solvent (unspecified)	kg	1.05E-05	0.00E+00	0.00E+00	1.05E-05
Materials production / Organic chemicals - tetrabromobisphenol A	kg	2.42E-04	1.11E-04	8.29E-05	4.82E-05
Materials production / Organic chemicals - triphenyl phosphate	kg	1.05E-04	1.00E-04	3.50E-06	1.37E-06
Materials production / Other materials - dye (unspecified)	kg	8.80E-05	5.25E-06	8.27E-05	2.91E-09
Materials production / Other materials - electrolyte (unspecified)	kg	9.60E-05	0.00E+00	7.85E-05	1.75E-05
Materials production / Other materials - flame retardant agent (unspecified)	kg	1.93E-06	0.00E+00	1.71E-06	2.25E-07
Materials production / Other materials - hardener	kg	8.84E-11	0.00E+00	0.00E+00	8.84E-11
Materials production / Other materials - ink (unspecified)	kg	1.58E-12	0.00E+00	0.00E+00	1.58E-12
Materials production / Other materials - laminate (unspecified)	kg	3.83E-05	3.83E-05	0.00E+00	0.00E+00

Materials production / Other materials - oil (unspecified)	kg	3.36E-08	0.00E+00	0.00E+00	3.36E-08
Materials production / Other materials - plaster	kg	3.12E-05	0.00E+00	0.00E+00	3.12E-05
Materials production / Other materials - raw materials (unspecified)	kg	9.88E-04	4.61E-04	5.25E-04	2.07E-06
Materials production / Other materials - silicone oil	kg	2.14E-09	0.00E+00	0.00E+00	2.14E-09
Materials production / Other materials - synthetic oil	kg	5.35E-11	0.00E+00	0.00E+00	5.35E-11
Materials production / Other mineralic materials - gravel 2/32; wet and dry quarry; production mix, at plant; undried	kg	1.10E-02	0.00E+00	0.00E+00	1.10E-02
Materials production / Other mineralic materials - Phosphorus; white, liquid; at plant	kg	3.93E-09	3.93E-09	0.00E+00	5.30E-12
Materials production / Other mineralic materials - Rare earth concentrate; 70% REO, from bastnasite; at benefication	kg	1.03E-07	0.00E+00	0.00E+00	1.03E-07
Materials production / Other mineralic materials - single crystalline silicon; Czochralski process; at plant; electronic grade	kg	1.70E-04	2.33E-05	1.18E-06	1.45E-04
Materials production / Paper and cardboards - corrugated cardboard; 5 layers; production mix, at plant; 85% recycled	kg	7.09E-08	0.00E+00	0.00E+00	7.09E-08
Materials production / Paper and cardboards - corrugated cardboard; 5 layers; production mix, at plant; primary production	kg	4.43E-07	0.00E+00	0.00E+00	4.43E-07
Materials production / Paper and cardboards - duplex-triplex cardboard; primary production; production mix, at plant	kg	2.96E-03	0.00E+00	2.96E-03	5.31E-08
Materials production / Paper and cardboards - kraft cardboard; 5 layers, secondary production, 80% recycled; production mix, at plant	kg	1.62E-06	0.00E+00	0.00E+00	1.62E-06
Materials production / Paper and cardboards - paper	kg	1.47E-04	3.69E-05	1.05E-04	4.50E-06
Materials production / Paper and cardboards - paper; 100% recycled, from waste paper; production mix, at plant; without deinking	kg	1.01E-03	0.00E+00	1.01E-03	1.44E-09
Materials production / Paper and cardboards - paper; 100% recycled, from wastepaper; production mix, at plant; with deinking	kg	2.35E-09	0.00E+00	0.00E+00	2.35E-09
Materials production / Paper and cardboards - paper; from virgin fiber; production mix, at plant	kg	3.88E-08	0.00E+00	0.00E+00	3.88E-08
Materials production / Plastics - acrylate Resin	kg	1.20E-04	0.00E+00	1.20E-04	6.74E-10

Materials production / Plastics - acrylonitrile Butadiene Stryrene (ABS) granulate; 100% from waste recycling, at plant	kg	4.61E-08	0.00E+00	0.00E+00	4.61E-08
Materials production / Plastics - acrylonitrile butadiene styrene	kg	4.65E-03	4.45E-03	1.06E-04	9.41E-05
Materials production / Plastics - acrylonitrile butadiene styrene (ABS); moulded by injection; production mix	kg	1.58E-03	0.00E+00	1.58E-03	5.68E-08
Materials production / Plastics - epoxy resin	kg	1.95E-03	9.48E-04	6.45E-04	3.58E-04
Materials production / Plastics - epoxy resin liquid; production mix, at plant	kg	1.22E-03	1.08E-03	1.02E-04	3.08E-05
Materials production / Plastics - ethylene propylene copolymer	kg	2.01E-05	2.01E-05	0.00E+00	3.70E-12
Materials production / Plastics - ethylene propylene diene	kg	3.43E-05	0.00E+00	3.43E-05	4.79E-08
Materials production / Plastics - Ethylene vinyl acetate copolymer; at plant	kg	5.91E-07	0.00E+00	0.00E+00	5.91E-07
Materials production / Plastics - expandable polystyrene	kg	6.48E-10	0.00E+00	0.00E+00	6.48E-10
Materials production / Plastics - flexible polyurethane foam	kg	4.87E-06	9.19E-10	1.21E-06	3.66E-06
Materials production / Plastics - general purpose polystyrene	kg	1.13E-04	0.00E+00	1.13E-04	1.91E-07
Materials production / Plastics - high impact polystyrene	kg	8.90E-04	8.90E-04	0.00E+00	0.00E+00
Materials production / Plastics - high impact polystyrene granulate (HIPS); production mix, at plant	kg	2.46E-06	0.00E+00	0.00E+00	2.46E-06
Materials production / Plastics - nitril rubber	kg	2.75E-07	0.00E+00	0.00E+00	2.75E-07
Materials production / Plastics - nylon 66 granulate (PA 66); production mix, at plant	kg	8.45E-10	0.00E+00	0.00E+00	8.45E-10
Materials production / Plastics - oriented polypropylene (OPP) film; production mix, at plant; without additives	kg	8.37E-09	0.00E+00	6.03E-09	2.34E-09
Materials production / Plastics - phenolic resin	kg	1.45E-04	5.65E-05	8.01E-05	8.19E-06
Materials production / Plastics - polyamide 6	kg	8.63E-05	0.00E+00	7.29E-05	1.34E-05
Materials production / Plastics - polyamide 6 (PA6) with 30% glass fibers; production mix, at plant	kg	2.20E-06	0.00E+00	0.00E+00	2.20E-06
Materials production / Plastics - polyamide 6.6 (PA6.6) with 30% glass fibers; production mix, at plant	kg	1.35E-07	0.00E+00	1.33E-07	1.97E-09
Materials production / Plastics - polyamide 66	kg	8.34E-04	2.67E-04	3.21E-05	5.34E-04
Materials production / Plastics - polyamide resin 6 (PA6); moulded by injection; production mix, at plant; without additives	kg	8.17E-06	0.00E+00	8.17E-06	0.00E+00

Materials production / Plastics - polyamide resin 6.6 (PA 6.6); production mix, at plant; without additives	kg	1.36E-07	0.00E+00	0.00E+00	1.36E-07
Materials production / Plastics - polyamide resin 6.6 (PA6.6); moulded by injection; production mix, at plant; without additives	kg	3.08E-04	2.62E-04	4.59E-05	1.85E-12
Materials production / Plastics - polybuthylene terephtahalate	kg	2.78E-04	5.44E-06	2.56E-04	1.66E-05
Materials production / Plastics - polycarbonate (PC) granulate; 100% from waste recycling, at plant	kg	9.17E-08	0.00E+00	0.00E+00	9.17E-08
Materials production / Plastics - polycarbonate (PC); moulded by injection, without surface treatment; production mix, at plant	kg	2.97E-04	0.00E+00	1.48E-04	1.49E-04
Materials production / Plastics - polycarbonate granulate (PC); production mix, at plant	kg	3.65E-03	3.58E-03	2.21E-07	7.88E-05
Materials production / Plastics - polycarbonates	kg	3.53E-05	0.00E+00	3.25E-05	2.87E-06
Materials production / Plastics - polyester resin	kg	4.20E-04	2.68E-04	3.94E-05	1.12E-04
Materials production / Plastics - polyester resin reinforced glass fiber; production mix, at plant; 40% glass fiber, 41% polyester resin, 15.5% PVC, 3.5% PELD, epoxy resin and steel	kg	8.19E-10	0.00E+00	0.00E+00	8.19E-10
Materials production / Plastics - polyether fibre	kg	1.32E-08	0.00E+00	0.00E+00	1.32E-08
Materials production / Plastics - polyethylene	kg	3.25E-04	1.53E-05	3.04E-04	6.02E-06
Materials production / Plastics - polyethylene co-vinyl acetate	kg	5.55E-03	0.00E+00	5.55E-03	9.66E-09
Materials production / Plastics - polyethylene high density granulate (PE-HD); production mix, at plant	kg	5.59E-04	0.00E+00	5.58E-04	1.45E-06
Materials production / Plastics - polyethylene low density (PE-LD) film; production mix, at plant	kg	8.88E-08	0.00E+00	0.00E+00	8.88E-08
Materials production / Plastics - polyethylene low density granulate (PE-LD); production mix, at plant	kg	9.27E-04	5.47E-05	8.72E-04	1.36E-08
Materials production / Plastics - polyethylene terephthalate	kg	3.59E-04	5.73E-05	2.99E-04	2.53E-06
Materials production / Plastics - polyethylene terephthalate (PET) film; production mix, at plant	kg	5.64E-04	5.64E-04	0.00E+00	4.09E-09
Materials production / Plastics - polyethylene terephthalate (PET); production mix, at plant; amorphous grade, without additives	kg	8.19E-05	8.11E-05	0.00E+00	8.46E-07
Materials production / Plastics - polyethylene terephthalate resin	kg	8.38E-08	0.00E+00	0.00E+00	8.38E-08
Materials production / Plastics - polyimide	kg	1.40E-04	1.40E-04	2.76E-07	2.73E-09

Materials production / Plastics - polymethyl methacrylate (PMMA) beads; production mix, at plant	kg	1.09E-03	8.10E-04	2.81E-04	2.33E-08
Materials production / Plastics - polyoxymethylene (POM) granulate; 100% from waste recycling, at plant	kg	3.12E-07	1.35E-08	2.66E-07	3.26E-08
Materials production / Plastics - polyphenylene ether (PPE); production mix, at plant; without additives	kg	2.63E-04	0.00E+00	2.63E-04	0.00E+00
Materials production / Plastics - polypropylene	kg	3.24E-04	1.88E-05	2.96E-04	9.22E-06
Materials production / Plastics - polypropylene (PP) granulate; 100% from waste recycling, at plant	kg	1.03E-08	0.00E+00	0.00E+00	1.03E-08
Materials production / Plastics - polypropylene (PP); moulded by injection, from polypropylene; production mix, at plant; without additives	kg	6.69E-09	0.00E+00	0.00E+00	6.69E-09
Materials production / Plastics - polypropylene granulate (PP); production mix, at plant	kg	5.47E-05	5.47E-05	0.00E+00	0.00E+00
Materials production / Plastics - polystyrene	kg	1.16E-05	1.15E-05	1.93E-08	8.07E-08
Materials production / Plastics - polystyrene expandable granulate (EPS); production mix, at plant	kg	1.48E-06	0.00E+00	0.00E+00	1.48E-06
Materials production / Plastics - polytetrafluoroethylene	kg	9.33E-09	0.00E+00	0.00E+00	9.33E-09
Materials production / Plastics - polyvinyl chloride	kg	4.47E-03	3.26E-04	4.13E-03	6.46E-06
Materials production / Plastics - polyvinylchloride (PVC) granulate; 100% from waste recycling, at plant	kg	1.64E-09	0.00E+00	0.00E+00	1.64E-09
Materials production / Plastics - polyvinylchloride (PVC) pipe; production mix, at plant	kg	6.69E-06	0.00E+00	0.00E+00	6.69E-06
Materials production / Plastics - polyvinylchloride (PVC) sheet; production mix, at plant	kg	2.47E-06	0.00E+00	0.00E+00	2.47E-06
Materials production / Plastics - polyvinylchloride (PVC); moulded by injection; production mix, at plant	kg	2.79E-04	0.00E+00	2.79E-04	4.99E-08
Materials production / Plastics - polyvinylchloride resin (S-PVC); suspension polymerisation; production mix, at plant	kg	1.48E-04	0.00E+00	1.48E-04	0.00E+00
Materials production / Plastics - resin (unspecified)	kg	5.47E-13	0.00E+00	0.00E+00	5.47E-13
Materials production / Plastics - rigid polyurethane foam	kg	2.97E-05	1.77E-06	2.79E-05	1.20E-09
Materials production / Plastics - silicon rubber	kg	4.24E-04	0.00E+00	4.24E-04	8.66E-08
Materials production / Plastics - Styrene acrylonitrile (SAN), a-Methyl styrene acrylonitrile (AMSAN)	kg	1.31E-06	0.00E+00	0.00E+00	1.31E-06

Materials production / Plastics - styrene butadiene rubber	kg	1.03E-05	0.00E+00	8.41E-06	1.88E-06
Materials production / Plastics - teflon (polytetrafluroroethylene) granulate (PTFE); suspension polymerisation; production mix, at plant	kg	7.66E-05	7.66E-05	0.00E+00	1.68E-10
Materials production / Plastics - thermoset (unspecified)	kg	8.20E-05	5.77E-05	1.67E-05	7.51E-06
Materials production / Plastics - viscoelastic; production mix, at plant; 50% PU and 50% PVC	kg	9.88E-10	0.00E+00	0.00E+00	9.88E-10
Materials production / Water - water	kg	2.48E-02	0.00E+00	2.48E-02	1.71E-05
Materials production / Water - water; high purified	kg	2.51E-06	2.39E-06	0.00E+00	1.21E-07
Materials production / Wood - oregon pine wood; production mix	kg	4.01E-06	0.00E+00	0.00E+00	4.01E-06
Materials production / Wood - plain wood; for pallet; to manufacturing site; 42% maritime pine, 32% poplar and 26% scot pine	kg	4.95E-07	0.00E+00	0.00E+00	4.95E-07
Materials production / Wood - wood, high density fiberboard (HDF); production mix, at plant	kg	1.64E-05	0.00E+00	0.00E+00	1.64E-05
Materials production / Wood - wood, medium density fiberboard (MDF); production mix, at plant	kg	1.53E-06	0.00E+00	0.00E+00	1.53E-06
Materials production / Wood - wood, particulate board; production mix, at plant	kg	1.43E-07	0.00E+00	0.00E+00	1.43E-07
Materials production / Wood - wood, plywood; production mix, at plant	kg	5.76E-09	0.00E+00	0.00E+00	5.76E-09
Systems / Electrics and electronics / Others - Monocrystalline silicon; CZ, photovoltaic application; at plant	kg	3.54E-07	0.00E+00	0.00E+00	3.54E-07
Systems / Paints and chemical preparations - Metallization paste; back side; at plant	kg	2.19E-09	0.00E+00	0.00E+00	2.19E-09
Systems / Paints and chemical preparations - paint (unspecified)	kg	1.78E-04	1.78E-04	0.00E+00	1.38E-10
Systems / Paints and chemical preparations - varnish (unspecified)	kg	2.93E-10	0.00E+00	0.00E+00	2.93E-10
Systems / Paints and chemical preparations - water based alkyd paint	kg	8.63E-06	0.00E+00	0.00E+00	8.63E-06

Appendix 2: Information document on data created for a EIME database

	TREE VIEW			MATERIALS / COMPOSANTS				
	Level	Quantity	Name	Name	Quantity	Unit	Total mass (kg)	Version
Fabrication + End of life	1	1.0	Ratio on the lifetime					
	2		Case 1 - 16 Go					
	3	1.0	motherboard	Motherboard	15.0000	g	0.0150	01.00.000
	3	1.0	Die	Die, caracteristics : 125,88mm², 94,64 mm² of losses; 40 mask layers	0.2500	item(s)	0.0000220	01.00.000
	2		Case 2 - 32 Go					
	3	1.0	motherboard	motherboard	9.1000	g	0.0091	01.00.000
	3	1.0	Die	Die, caracteristics : 125,88mm², 94,64 mm² of losses; 40 mask layers	0.5000	item(s)	0.0000440	01.00.000
	2		Case 3 - 128 Go					
	3	1.0	motherboard	Motherboard	10.0000	g	0.0100	01.00.000
	3	1.0	Die	Die, caracteristics: 125,88mm², 94,64 mm² of losses; 40 mask layers	2.0000	item(s)	0.000177	01.00.000

Process information	Corresponds to the ISO/TS 14048 section "Process description". It comprises the following six sub-sections: 1) "Data set information" for data set identification and overarching information items, 2) "Quantitative					
Key Data set information	General data set information. Section covers all single fields in the ISO/TS 14048 "Process description", which are not part of the other sub-sections. In ISO/TS 14048 no own sub-section is foreseen for these enti					
Location	RAS					
Geographical representativeness description	Production in Asia (semi conductors in Taiwan, rest of the production in China)					
Reference year	2020					
Name	base name	treatment standards, routes	mix and location types	quantitative product or processes properties	Country name	Country Code
	USB key			xx GB capacity	Asia	RAS
Complete name	USB key; ; ; xx GB capacity; RAS					
Short name	USB key; ; xx GB capacity; Asia, RAS					
Identifier of sub-data set						
Use advice for data set	Default electricity consumption is xxxx kWh/year					
Technical purpose of product or processes						
Synonyms						
Complementing processes						
Complementing process (process data set)						
Classification	classification system name	classes				
	Modified ILCD classification for EIME	EIME Classification				
Class name	Hierarchy level n°1	Hierarchy level n°2	unique class identifier			
	Systems	Electrics and electronics	Others			
Tags						
General comment on data set						
Copyright ?	Yes					
Owner of data set (contact data set)	Negaoctet					
Data set LCA report, background info (source data set)						
Quantitative reference	This section names the quantitative reference used for this data set, i.e. the reference to which the inputs and outputs quantiatively relate.					
Reference flow	base name	treatment standards, routes	mix and location types	quantitative product or processes properties		
	USB key	0	0	xx GB capacity		
Reference flow name	USB key; 0; 0; xx GB capacity					
Functional unit, production period or other parameter	Production of a USB key					
Category of reference flow	Product flows / Systems / Electrics and electronics / Others					
Amount	1.0					
Unit/ reference weight	d (units of time, day)					
Time representativeness	Provides information about the time representativeness of the data set.					
Data set valid until	2025					
Time representativeness description	Data are from 2020 products					
Geographical representativeness	Provides information about the geographical representativeness of the data set.					
Sub-location						
Geographical representativeness description	Production in Asia (semi conductors in Taiwan, rest of the production in China)					

Appendix 3: ILCD guidance to solve multifunctionality by allocation on physical causality [8] *ILCD (International Reference Life Cycle Data System) Handbook. General guide for lyfe cycle assessment*.

Table 11: Allocation on physical causality for services

Services	Allocation on physical causality
Goods transport	Time or distance AND mass or volume
Personal transport	Time or distance AND weight of passengers
Staff business travel	Added value of system
Retailing	Time of shelf-life AND mass or volume of good
Storage and shelter	Time of use AND volume of goods OR area occupied by the goods
Storage and others	Time of use AND area occupied by the good
Transport and communication on roads, railways	Time AND intensity OR bandwidth of use
Heating/cooling of space	Time AND area of volume heated/cooled
Heating/cooling of goods	Heat capacity of good
Private administration services	Person time or cost charged for admin services OR market value of sales
Public administration services	Person time or cost charged for admin services or number of cases services
Cleaning services	Surface area cleaned
Guarding services	Share of product's value among guarded products AND/OR the production/provision facilities' value of the product among guarded site/object, depending what is the purpose of the guarding
Marketing services	Share of product implicitly or explicitly addressed by marketing
Teaching/training services	Person time of training AND number of individuals taught/trained
R&D services	Person time OR cost charged for R&D services

Table 12: Allocation on physical causality for production processes

Production processes	Allocation on physical causality
Extraction processes	For process-related flows the market value, for product-related flows the specific physical properties of the co-products
Chemical conversion and waste processing	Quantitative change of the to-be-allocated flows in dependency of quantitative changes in the products or functions delivered by the system. If unknown: the chemical or physical properties that determine the amount of the other flows
Manufacturing and mechanical waste processing	Length, surface, volume, or mass OR number of items OR time of processing
Recycling, energy-recovery, reuse	See specific provisions in chapter 7.9.3 and details on allocation of waste inputs see annex 14.4.
General processes by other capital goods' input directly to multifunctional processes	Time (duration) of use OR mass, volume, length of produced good