

**CONNECTED DEVICES AND RELATED SERVICES ENVIRONMENTAL
IMPACTS:
ORDER OF MAGNITUDE AND METHODOLOGICAL RECOMMENDATIONS**

Summary

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SCORE LCA is an association that has been created to financially support collaborative research on LCA and related topics. It aims to promote and organize cooperation between companies, institutional and scientists in order to support the evolution of LCA methods and its practical implementation at European and international level.

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- ✓ The views and recommendations expressed in this publication are those of the authors and do not necessarily reflect, unless otherwise stated, the views of all members of SCORE LCA.
- ✓ The information and conclusions presented in this document were established on the basis of scientific and technical data and regulatory and normative framework in force at the date of the publication of documents.

A. INTRODUCTION

a. Context

Digital transition can be a part of answering the ecological transition need. However, as the digital services and software sector is often perceived as immaterial (impacts are not local to the users, and regularly forgotten), the multiplication of connected services is not devoid of environmental impacts [1] [2], and their development can lead to unwanted rebound effects [3] [4]. In this context, the evaluation of digital technology remains an emerging subject [5].

b. Objectives

In order to ensure that digital transition will not be detrimental to the ecological transition, it is necessary to have consolidated environmental impacts determination methods. That can be achieved with stakeholder upskill, and with the elaboration of sectorial rules allowing to manage specificities of connected devices, harmonize and simplify practices.

To perform this task, it is crucial to carry out a bibliographical state of the art of existing and ongoing works, the current knowledge and practices, and the potential agreements and disagreements.

This study aims to:

- Perform a state of the art and a detailed methodological analysis of connected devices and related services environmental evaluations
- Analyse methodological choices and impact results for those devices and services
- Recommend good practices
- Recommend robust data
- Identify future trends

The study has been performed by the Negaocet consortium, composed of LCIE Bureau Veritas, APL Datacenter, DDemain and GreenIT.fr.

B. PHASE 1 – STATE OF THE ART – BIBLIOGRAPHY

Publications selection

This first phase of the analysis aims at identifying, classifying and analysing published studies based on different criteria, in order to:

- Establish a cartography of covered or not covered services
- Identify the level of maturity of digital services environmental assessment
- Identify analysis methods used
- Identify strong and weak points of selected studies
- Identify methodological discrepancies and opinion and results differences
- Identify publications that will be further analysed in phase 2

The identification and selection of assessed sources is based on the following process:

Step 1 – publications identification

Based on specific keywords, more than 750 publications that could fit the study purpose have been identified. A first order analysis reduced the number to 170.

Step 2 – Screening

Then, abstracts have been read and described to narrow it down to 48 publications

Step 3 – Sample analysis

A more thorough analysis has been performed in order to:

- Get a first level of response to the study objectives
- Select publications that will be subjected to a further analysis in phase 2
- Give insight for the elaboration of recommendations and a PCR related to digital services

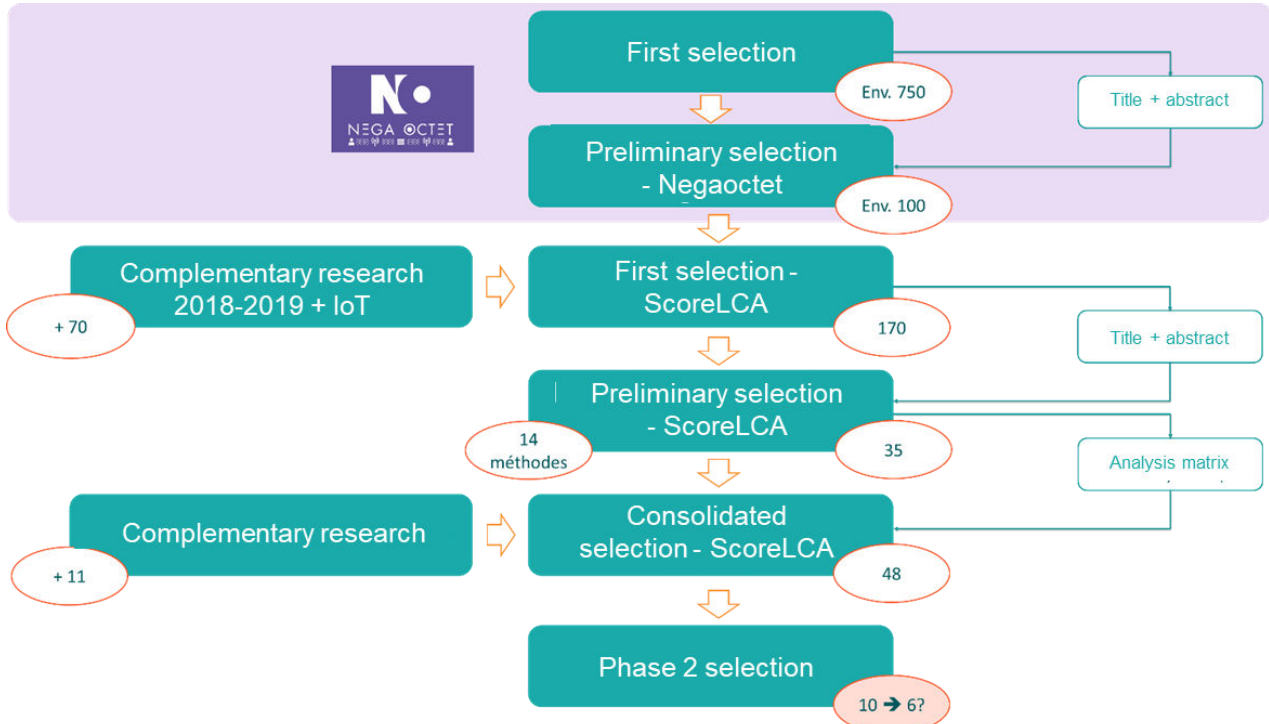


Figure 1 - Method – Sample definition and identification of relevant sources method

The analysis matrix allowed the project team to work in subgroups in a homogeneous way. Parameters for each publication are:

Parameters filled out during step 2

- Publication date
- Data collection date: it is generally different from the publication date and provide a clearer idea of the temporal representativeness of a study.
- Language: English or French
- Title
- Authors
- Sponsor
- Journal
- Type of document: Scientific publication, reference document / method / standard / PCR, private publication, CSR report, book, tool, LCA report, white paper, thesis, editorial, student project, conference paper, bibliography
- Category 1: Environmental impact study, technical documentation, method, prospective/trajjectory, preliminary study, survey, reference document
- Category 2: Monocriteria – carbon footprint; Monocriteria - energy; Multicriteria - LCA; Multicriteria – simplified LCA; MFA - Material Flow Analysis; I/O - Input/Output; Qualitative method; Generalist IT IT; energy management; ecodesign; definition, digital sobriety

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- Category 3: Equipment; peripheral equipment; network; digital service; electronic components; sector; information system; IoT; software; Datacentre
- Keywords

Parameters filled out during step 3

- Reviewer notes
- LCA type
- Standards used
- Products and services / sectors covered
- Functional unit
- Objectives – family and description
- Scope
- Identification of substituted products and services
- Geographical perimeter
- Covered impact categories
- End of life accounting
- Identification of benefits associated with digital services
- Allocation factors – Terminals, network, datacentre

Global analysis

Thanks to the compilation of 170 publications from 2001 to 2020, the following points are detailed:

- Methodological documents (17 identified) have been developed for each tier of the digital infrastructure, and some are referring to digital services globally.
- Publications studying each tier (software, terminals, networks, datacentres) independently exist. Those are rarely combined to study the environmental assessment of whole services on the complete information chain. Only 10% are studying the internet of things.
- The most used environmental assessment method is the life cycle assessment, either complete or only calculating the climate change or primary energy impacts.
- Most studies about all 3 tiers are generally focusing either:
 - o On the use phase
 - o On the production and use phase, where the production phase is assessed only through energy inputs

Only a few studies integrate the whole life cycles.

- When all 3 tiers are considered, authors generally have different level of expertise for each tier, which leads to discrepancies and heterogeneity of the assessment.
The different approaches should be summarized in an operational method.
- The software development and human resources part is never treated in digital services studies. It is sometimes treated within a specific study, but never combined with the technical architectures. Approaches focusing on the software mainly focus on terminals energy consumption.
- Most LCA studies are in fact screening or mono-criteria studies. About 30 of them are quoting ISO 14040 without fully applying it. 2 studies are referring to the GHG protocol, and 3 to the standard ETSI 103 199 or ETSI 203 199
- 16 studies are based on LCA tools and consolidated databases (such as Ecoinvent, EIME or ELCD). The other ones are referring to emission factors from literature. Most studies are based on heterogeneous data with little documentation.

- Impact analyses and indicators are heterogeneous.

C. PHASE 2 – ANALYSES AND SPECIFICITIES FOR THE LCA METHODOLOGY

a. Publication selection

The selection has been performed by SCORELCA members, based on recommendation from the consortium. Members also wished to reintegrate some studies that were not selected or analysed after phase 1.

Selected studies:

- CLIMAT : L'INSOUTENABLE USAGE DE LA VIDÉO EN LIGNE - Un cas pratique pour la sobriété numérique ; The Shift Project - Maxime Efoui-Hess ; 2019 [14]
- "Integrative approaches to environmental life cycle assessment of consumer electronics and connected media" ; Paul Teehan ; 2014 [15]
- "Lessons learned – Review of LCAs for ICT products and services" ; Yevgeniya Arushanyan, Elisabeth Ekener-Petersen, Goran Finnveden ; 2014 [16]
- « Life Cycle Assessment of Connected and Automated Vehicles: Sensing and Computing Subsystem and Vehicle Level Effects » ; James H. Gawron, Gregory A. Keoleian, Robert De Kleine, Timothy J. Wallington, and Hyung Chul Kim ; 2018 [17]
- "Assessing Indirect Environmental Effects of Information and Communication Technology (ICT): A Systematic Literature Review" ; Jan C. T. Bieser and Lorenz M. Hilty ; 2018 [18]
- "An Integrated Method for Environmental Assessment and Ecodesign of ICT- based Optimization Services" ; Jeremy Bonvoisin, Alan Lelah, Fabrice Mathieux, Daniel Brissaud ; 2014 [19]

b. In-depth analysis - Methodology

The in-depth analysis use the Excel analysis document created in phase 1, and completes it with additional categories, allowing to provide insight on learnings and limits, and to have a better understanding of the documents.

The categories are:

- Limits and uncertainties documentation
- Matching between objectives and results
- Study learnings / conclusion
- Global evaluation
- Study specificities

c. In-depth analysis - Results

Following this analysis, general learnings can be extracted. While some were already confirmed with the bibliography analysis (lack of shared reference document or data), others could be identified thanks to in-depth analyses (there are no study that could be used as a reference, indirect effects are difficult to quantify).

Lack of shared hypotheses

Each document analysed is based on its own hypotheses and methodological rules, without using shared reference documents.

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Beyond results interpretation and comprehension, this sources heterogeneity leads to the impossibility to perform comparison or macroscopic analyses from published studies without taking into account each assessment and hypothesis.

It increases the need for having digital services sectorial rules in order to share homogeneous hypotheses.

Lack of primary and secondary data

Digital services LCA suffer from a lack of primary and secondary data. LCA practitioners, manufacturers and users do not have access to complete information on the global digital services value chain (terminals, networks, datacentres).

They are led to use hypotheses and secondary data to estimate lacking information and impacts, but secondary data are also lacking or not shared among all practitioners.

Beyond results heterogeneity, adding to hypotheses heterogeneity, most studies choose to limit the study perimeter by choosing impact indicators and life cycle phases with the most available data, being mostly the use phase, the energy consumption and the global warming potential indicator.

That issue constitutes a strong limitation to LCA methodology, by removing two main characteristics of LCA:

- Multi-steps
- Multi-criteria

Published results do not provide an exhaustive view of impacts, even direct impacts, of digital services, and lead to a risk of not identifying potential pollution transfers.

There are no study that could be used as a reference

LCA studies having been analysed in phase 2 have too many limitations to be used as references.

It is essential to cross-check sources, and to collect information from as large a number of LCA studies and environmental studies as possible, whether global or partial, before using sources as references.

Indirect effects are difficult to take into account

The 2 assessed studies accounting for indirect effects do not conclude on a precise method for indirect effect accounting.

If they are difficult to quantify, it is essential to, at least, qualify them.

Due to the indirect effects importance, work must be performed in this regards. This aspect is discussed in detailed in phase 3 on recommendations.

D. PHASE 3 – RECOMMENDATION OF ROBUST DATA

Identified robust data are of three kinds:

- Data on digital services, globally
- Data on equipment used for digital services
- Technical data on equipment used for digital services within organizations

On this basis, the different identified sources of data have been detailed following the criteria:

- Perimeter: territory, use/service or equipment
- Free or commercial data
- Type of data: collection data, monocriteria impact data, LCIA/LCA
- Development status: done or in development

Data on digital services, globally

The following data have been identified:

- GreenIT.fr studies
- 1byte model – The Shift Project
- The Shift Project studies
- Negaoctet studies
- ADEME-ARCEP study

Data on equipment used for digital services

The following data have been identified:

- Manufacturers data
- EIME
- Ecodiag
- PEP ecopassport® program
- ADEME studies
- Negaoctet
- PAIA
- GaBi
- Base Impacts
- PEF/OEF database

Technical data on equipment used for digital services within organizations

The following data have been identified:

- CMDB
- Datasheets
- BOAVIZTA method

E. PHASE 3 – RECOMMANDATIONS

This part aims at defining a list or recommendations related to performing digital services LCA. This list represent the vision of the Negaoctet consortium, completed and discussed with SCORELCA members. It opens work prospects on all treated subjects in order to find shared positions. In this regards, it can be used as a base for sectorial rules (PCR) elaboration.

Recommendations treat the following subjects:

LCA level classification

Classification of all or part of LCA on three levels:

- Screening: to quickly and simply identify environmental issues and provide decision-making information. Use of heterogeneous and/or LCIA datasets.
- Simplified: integrates secondary data and limited simplifications. Use of generic LCI or UPR datasets.

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- Complete: integrates primary data gotten after several iterations and a field collection at multiple steps of the value chain. Use of specific LCI or UPR datasets.

Functional unit

For a considered digital service, functions depends on the study objectives and the target audience. Each one will have a different use of the service. Functions must be identified in relation with stakeholders and the target audience.

Lifespan

The study reference lifespan must be indicated specifically depending on different scenarios. In order of importance, it is necessary to:

- Characterise the functional, or standard-based, lifespan of the digital service. Corresponds to a digital service, globally?
- If not possible, define a use duration. Corresponds to a user account.
- If not possible, the lifespan is not taken into account. Corresponds to a job.

Functional diagram and flow diagram

It is necessary to determine three elements:

- The workflow: precise all performed operations allowing the functional unit to be fulfilled.
- The functional diagram: details the constitutive elements of the digital service, allowing the workflow to be performed.
- The flow diagram: indicated the successive actions occurring during use.

Cut-off rule

When the cut-off rule cannot be based on mass, energy or impact criteria, it is recommended to use the following criterion:

Use phase energy consumption of assessed elements compared to the use phase energy consumption of all elements related to the digital service, for each tier (terminals, networks, datacentres).

Impact categories selection

The recommended impact categories for digital services are:

- Abiotic resource depletion (elements)
- Climate change
- Acidification
- Respiratory inorganics
- Ionizing radiations
- Water scarcity

Specifically for connected devices, they can, and generally are included in common systems based on physical objects with specific and different main impact categories. In order to get a complete vision of environmental issues on those systems, it is necessary that impact categories include those of digital and physical services under study.

Comparison

Impact categories included in a comparative LCA between different systems must cover relevant environmental issues of all sectors, particularly when comparing digital and physical services.

Data collection

Primary data must be collected over a 1-year period to avoid seasonal variations.

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If the digital service considered has a total lifespan inferior to one year, the collection period must include the whole lifespan.

Digital services environmental impacts are generally dependent on the service maturity level, mainly in terms of dimensioning related to users numbers. It is important to evaluate impact variations related to use variation and service dimensioning.

There are two approaches:

- Reality-based determination: the capacity utilisation is determined based on the data collection. It must be displayed.
- Hypothesis-based determination: the capacity utilisation is a hypothesis. In this case, it must be displayed, and several hypotheses must be calculated as sensitivity analyses in order to understand the impact influence of this hypothesis.

Allocations

Due to their complexity, digital services can be separated into different elements. A non-exhaustive list:

- Connected devices: bandwidth, use time, number of operations
- Terminals: CPU use, GPU use, ROM use, RAM use, use time
- Networks: bandwidth
- Datacentres: CPU use, GPU use, ROM use, RAM use, number of operations

Indirect effects

Accounting indirect effects is crucial due to the relative importance of those, both in terms of impact reduction potential (ITT for green) and risk of unwanted impact increase. The order of magnitude of indirect effects is not well known currently.

Those impacts are difficult to quantify with affordable resources and time for most LCA practitioners, and require the intervention of experts from various domains. They generate a strong uncertainty due to their projected nature, especially in a sector such as digital services, subjected to strong evolutions and technology leaps.

Nonetheless, it is possible to identify and categorize them. To do so, different classifications are possible. The study "Known unknowns: indirect energy effects of information and communication technology" [11] represents the state of the art of what can be achieved today. Even though it focuses on the energy, its methodology can be applied to LCA.

Different levels of indirect effects, both positive and negative, are introduced, depending on their reach in relation with the socio-economical ecosystem, from direct effects to systemic transformations:

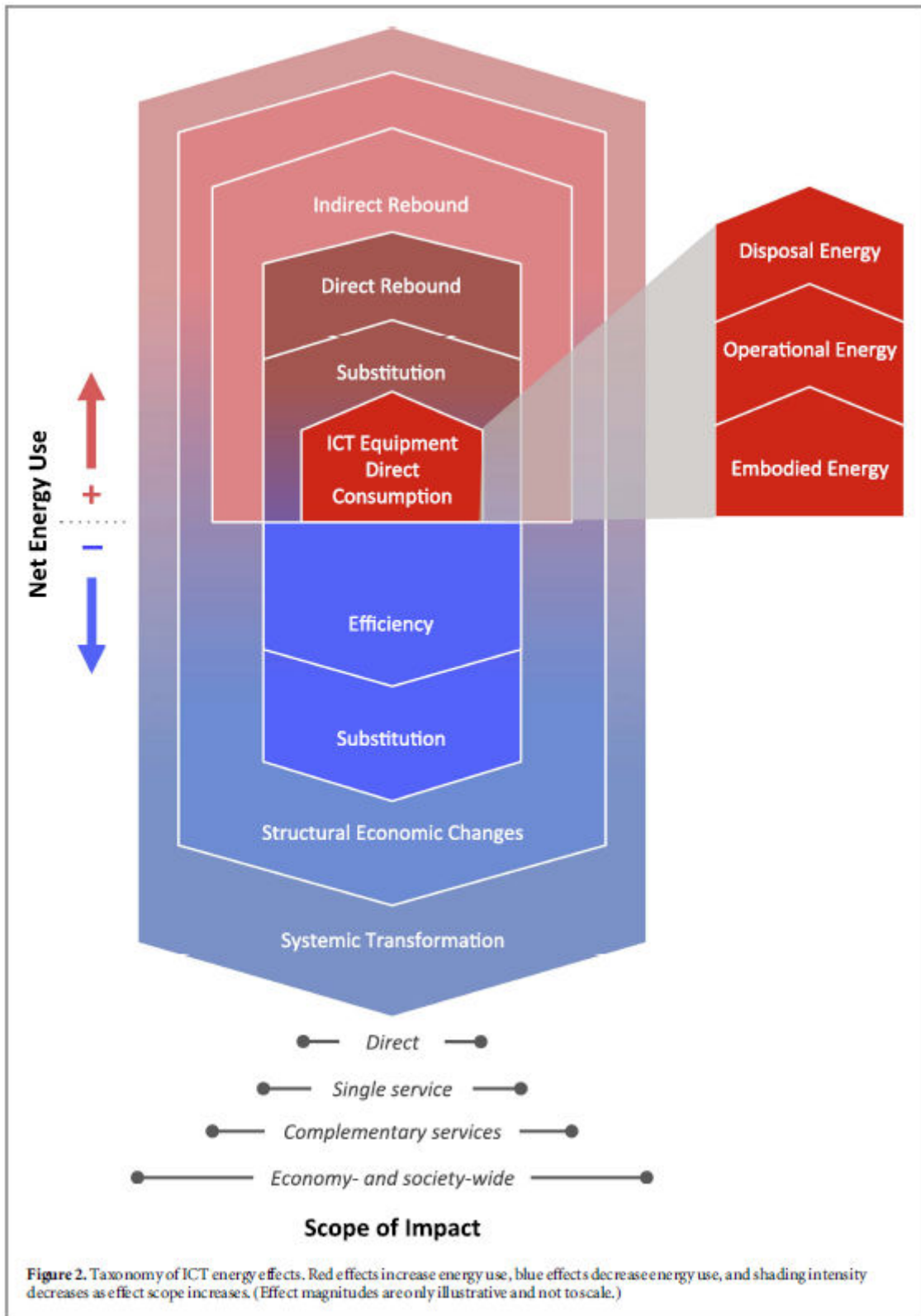


Figure 2 – Classification of indirect effects, extracted from [11]

The categories are detailed below:

Effect	Reach	Explanation	Example (considered system: GPS)
Manufacturing and transportation impacts	Direct	Negative effect	GPS production and transport
Use impacts		Negative effect	GPS energy and data consumption
End of life impacts		Negative effect	GPS end of life treatment
Efficiency	Indirect – related to the considered service	Positive effects, reduction of resources used related to the consumption optimisation allowed by the digital service	More efficient traffic due to the shortest route identification
Substitution		Positive or negative effect, replacement of a service with another	Paper maps replacement
Direct rebound effect		Negative effect, increase of a service consumption because of its cost reduction or easiness of use	More trips due to the travel time and congestion reduction
Indirect rebound effect	Indirect – unrelated to the considered service	Negative effect, increase of other services consumption because of savings generated by the studied service cost reduction	Use of the time and money saved thanks to travel time and fuel use reduction
Structural economic changes	Indirect – economic level	Positive or negative effects, macroeconomic modifications linked to the introduction of new services, and adjustment of existing sectors	GPS pave the way to autonomous vehicles
Systemic transformation	Indirect – societal level	Positive or negative effects, modification of human behaviours and social and economic institutions	Autonomous vehicles modify schemes and habits in terms of housing and workplace

Figure 3 – Classification detail of indirect effects, adapted from [11]

Possession environmental cost and use environmental cost

When moving from a classic service to a digital service, there often is a transfer of impacts from the production, distribution, installation and end of life phases, to the use phase. Digital services use energy-consuming and data-consuming equipment that generate environmental impacts.

This creates a modification of a part of impact causes from a possession cost (impacts are related to the product acquisition) to a use cost (impacts are related to the product use).

When identifying ecodesign strategies, it is recommended to identify impacts caused by acquiring equipment, and those caused by using equipment. The use cost includes the life cycle of network and datacentre equipment, allowing the transport, treatment and storage of data.

Average environmental cost and marginal environmental cost

Digital services generally are interconnected due to shared equipment. This equipment often is present independently of the studied service.

Two visions are possible:

- Average cost calculation: common LCA calculation: impacts related to the production are allocated to the service based on an allocation factor which depends on each situation
- Marginal cost calculation: cost linked to the increase of environmental impacts related to the service, compared to the previous situation. Excludes the production of equipment already in use

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In the case of marginal cost calculation, an equipment can have both impacts associated with the service (electricity consumption in active mode), and others not (fabrication, electricity consumption in stand-by).

F. PHASE 3 – OPEN ISSUES

Digital services is not a mature sector yet. It has a strong economic, technical and functional evolution.

Those evolutions have deeply modified LCA practice in this sector. Methods have not increased quickly enough to follow digital services. The methodological delay accumulated lead to a reaction latency of the LCA sector in terms of environmental impacts quantification in a time when the public and institution have a growing awareness of the important environmental impacts of this sector.

In order to limit the gap between digital services and LCA methodology in the future, it is necessary to have proactive vision of coming evolutions and related issues.

The focus points are:

Digital services distribution level

Digital services are more and more distributed, from a software installed on an isolated equipment (on premise), towards a global interconnection through networks.

It will lead to an increased interlocking of digital services: a digital service can use other digital services, often managed by third parties. Their impact will get more difficult to assess.

Workaround: LCA on existing services must be performed and communicated in a transparent way in order to create a digital services LCI or UPR database

Programmatic nature

Digital services tend to get more and more optimised in terms of calculation resource consumption, in order to reduce costs. It implies a dynamic choice of servers providing calculation or storage functions, depending on their charge. The servers can be distributed all around the globe.

The dynamic nature of this choice implies the impossibility to get a complete vision of current digital resources, furthermore projected ones, and associated impacts.

Workaround: use trackers allowing the identification of resources used by each digital service, and provide statistical data.

Electric and electronic equipment end of life

Despite the restrictive regulations, most WEEE (Waste Electrical and Electronic Equipment) are not treated in regulated sectors. It is hard to assess unregulated sectors due to lack of data.

With the increase of connected devices, the proportion and volume of related WEEE will increase

Workaround: Regulation reinforcement to have a better knowledge of WEEE flows, control and reduce them, in relation with the increase of connected devices. Improvement of dismantling to separate easily electronic parts from the rest. Increase the awareness of the public and institutions.

Cultural adaptation vs. greenwashing

Digital services environmental impacts is an issue that has arisen in the general public during the past few years. If that allows for a better accounting of environmental impacts due to the need of companies to address the public expectations, it also leads to an increased risk of greenwashing.

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The absence of concerted and shared method, or of constraining regulation, environmental communication possibilities are focusing mainly on type 2 communication (auto declaration, ISO 14021). It leave a large freedom to companies and leads to a risk of greenwashing or studies drop of quality.

Workaround: creation of concerted and share methods, reinforcement of regulation.

Regulatory evolutions

On the French level, current regulatory evolutions that are being discussed (except those already adopted in the regulation 2020-05 called “loi AGEC”) are the “Convention Citoyenne pour le Climat” and the Sénat law propositions. They include regulations to force the ecodesign of services, websites and software.

Workaround: perform a regulatory surveillance and alert public authorities when necessary.

Connected devices multiplication

The number and variety of connected devices flows, having complex and diverse manufacturing chains (smart home, textile, hygiene, etc.) have the spread of studies difficult, as the assessments are varied and actors only master the digital part, or the product part.

Workaround: reinforcement of digital services developers knowledge on LCA and environmental impacts globally.

Artificial intelligence, blockchain, cryptocurrency

Those subjects will be developing in the coming years. There are currently no unique definitions. There are many technologies, protocols and architectures, each with its own difficulties to calculate associated environmental impacts.

Workaround: work in collaboration with actors from the relevant sectors

Technology leap

Digital services have benefited from important functional and technological leaps.

Those leaps modify collection and LCI data necessary. Due to trade secrets surrounding new technologies, environmental evaluations can only be precise with hindsight, after the technology has been deployed, so there are environmental evaluations only when the technology has spread and that conception, functional and marketing choices are made.

Workaround: increase transparency and communication around new technologies environmental impacts, at LCIA if necessary.

Engineers training to LCA and greenIT practices

Cultural adaptation of engineers, developers and designers of digital services to LCA practice is a developing subject. Engineering schools and universities integrate more and more LCA and environment courses. If those are currently not as developed in computer schools, this will change as companies and the general public are getting increasingly aware of the subject.

It will allow new aware actors to facilitate the dialogue between the digital service and LCA sectors.

Workaround: provide trainings to computer schools, lead partnerships on research projects.

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