Exploring the Influence of Database Selection on the Life Cycle Assessment of Digital Services

Augustin Wattiez[1,*], Kelly Le Goff[2] and David Bol[1,*]

[1]Université catholique de Louvain, ICTEAM/ECS, Louvain-la-Neuve, Belgium
[2]Mavana, Rivière d'Enbusquière Moulin d'en Jacqou 31290, Lagarde, France

Abstract

In Life Cycle Assessment (LCA) studies of digital services, practitioners rely on databases that model electronic components, devices, and systems. However, it is acknowledged in the scientific literature that LCA results can be sensitive to the choice of database. For this reason, the present work aims to assess how database selection influences (1) absolute impact estimates and (2) contribution analysis results when conducting a LCA for a digital service. We modeled a case study - music streaming - using three databases: Managed LCA Content, CODDE, and Ecoinvent. This work highlights significant variations in impact estimates for specific indicators. Additionally, environmental hotspots may differ when using different databases. These disparities stem from inconsistencies in background modeling and in granularity between the databases, especially for integrated circuits and Li-ion batteries.

Keywords

Life cycle assessment, database selection, environmental impact of digital services.

1. Context and Research Question

Life Cycle Assessment (LCA) is the most common approach for estimating the direct environmental impacts of products and services, including those related to the Internet and Communications Technology (ICT). The ISO standard for LCA [1, 2] mandates an inventory assessment, during which the practitioner models the resource (resp. emission) flows that the object under study uses (resp. releases) throughout its life cycle. For digital services, modeling the inventory at the flow level is complex as it requires an understanding of all the flows in the supply chain and in the service's supporting infrastructure. Instead, LCA practitioners rely on databases that model electronic components, devices, and systems as datasets at the flow level. Hence, they can model digital services at a higher level of abstraction.

Scientific literature acknowledges that LCA results are sensitive to numerous sources of uncertainty [3]. Nevertheless, in many LCA studies, uncertainty is handled solely by propagating input parameter uncertainties to output results [4]. Given that these analyses usually occur after database selection, we sought to answer the following research question: *To what extent does the choice of the database influence the absolute impact estimates and the contribution analysis results of a digital service?* The effect of database selection was covered in [5] only for plastic packaging. In [6], a digital service was modeled in two databases, but the authors did not thoroughly explore the modeling details needed to justify the observed difference among databases. To address our question, we modeled music streaming as a case study within three databases.

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*Corresponding author.
augustin.wattiez@uclouvain.be (A. Wattiez); kelly@mavana.earth (K. Le Goff); david.bol@uclouvain.be (D. Bol)
0009-0003-0108-1519 (A. Wattiez); 0000-0002-2678-1613 (D. Bol)

2. Methodological Choices

The Functional Unit (FU) is: *Two years of music streaming in Belgium using wireless headphones, assuming an average consumer profile.* It is modeled in three databases: Sphera Managed LCA Content (MLC) 2023.1, CODDE 2023-02, and Ecoinvent (EI) 3.9. We limited the Life Cycle Impact Assessment (LCIA) to four indicators from the EF 3.0 impact method, see Figure 2.

The scope of the study is kept identical across all models in the three databases, enabling a fair comparison of LCA results. Figure 1 (a) outlines the life-cycle phases included in the scope of the analysis. Figure 1 (b) shows the activities and components contributing to fulfilling the FU. The items marked in blue (resp. in red) are included in (resp. excluded from) the scope. We excluded data centers and communication networks due to a lack of relevant datasets in the databases. This choice has a limited effect on the LCIA results [7]. The smartphone's impact is reduced to the percentage of energy dedicated to music streaming in the device [8] for the duration of the FU. Figure 1 (c) illustrates the subdivision of the headphones and charging case into functional sub-modules. This enables a finer hot spot analysis, as will be presented in Section 3. The units used for scaling sub-modules to datasets are written in green with bold font. Figure 1 also displays (in italics) the energy values consumed during the use phase.

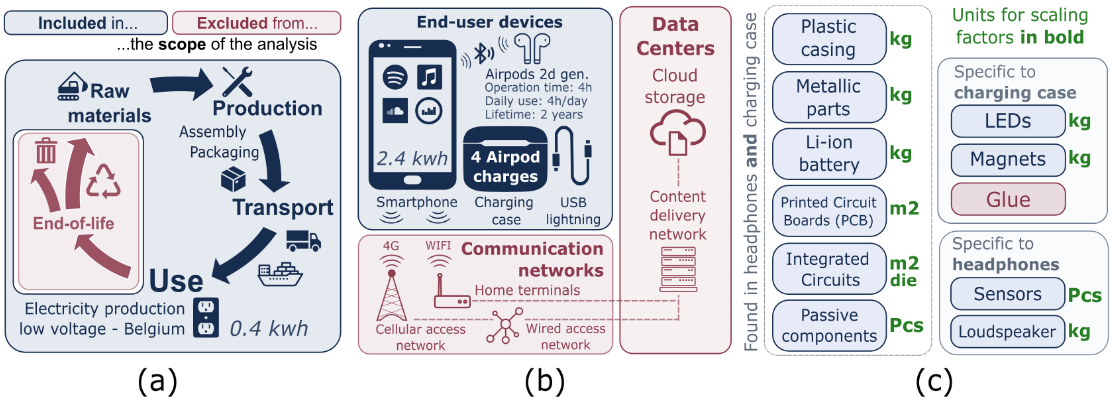

Figure 1: Scope of the LCA. **(a)** Life cycle phases included in the scope of the study. Cradle-to-Gate assessment. **(b)** Communication networks and data centers are not included. **(c)** Headphones and charging case sub-modules.

3. Impact Assessment and Research Results

Figure 2 presents the LCIA results for each impact category, distinguishing the results obtained from the three databases. Across databases, production (comprising extraction of raw materials) emerges as the dominant phase. This was anticipated for a service reliant on a battery-powered product [9]. This phase is further divided to show the contribution of Integrated Circuits (ICs). For GWP and ADPf, the order of magnitude remains consistent across databases, with the relative contribution of ICs being stable. Between the absolute impact obtained with MLC and EI databases, there is still a 3.2× factor for GWP and 3.14× for ADPf. This discrepancy can be attributed to disparities in background modeling for IC datasets. When analyzing the EI IC dataset at the flow level for instance, we observe that it overestimates the mass of gold per kilo of packaged IC compared to similar datasets in MLC and CODDE databases. This is reflected in the results, as gold extraction is a resource-intensive industrial process.

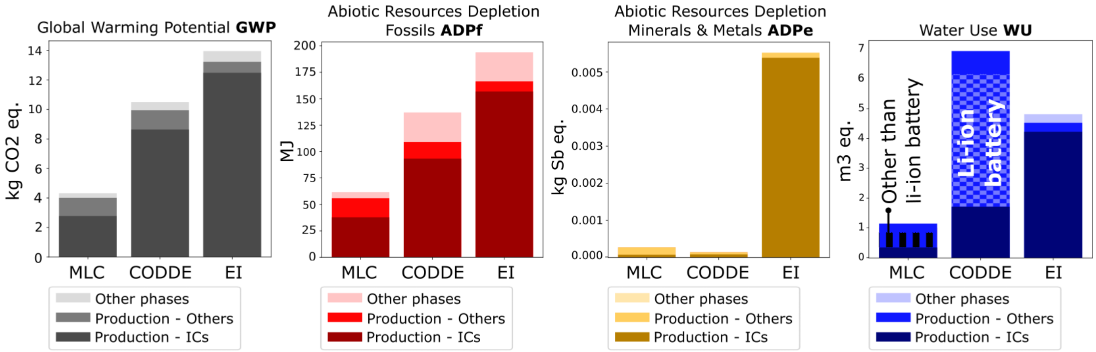

Figure 2: LCIA results obtained with the EF 3.0 impact method for the FU described in Section 2. These results are displayed by impact indicator and for each database.

The disparity in background modeling for IC datasets is not an issue for GWP and ADPf, as it does not significantly influence the conclusions drawn from the LCA regarding absolute impacts and contribution analysis. However, this does not hold for the ADPe category, where the estimated absolute impact differ by one order of magnitude (20× between MLC and EI). Regarding the WU category, the CODDE database identifies the Li-ion battery as the dominant hot spot, while its impact appears negligible in MLC and EI. Indeed, the water volume required to produce one kilogram of Li-Ion battery in CODDE exceeds the assumptions of Sphera and EI by several orders of magnitude. While this disparity does not affect the absolute order of magnitude, as observed with ADPe, it does alter the primary hot spot identified in the contribution analysis. Consequently, ecodesign priorities may vary across databases for the WU category. The number of datasets and their respective level of technical aggregation vary among databases. In this work we refer this as the database granularity level. For example, EI provides a single dataset for modeling logic ICs, whereas MLC offers multiple datasets, each with distinct technological specifications. The low granularity level for logic ICs in EI exacerbates the disparity in absolute impact estimates with respect to other databases. Indeed, as EI has only one dataset, each logic IC is systematically modeled using this dataset. Moreover, we stated earlier that the EI dataset overestimates the amount of gold required to produce one kilogram of packaged IC compared to similar datasets in MLC. Considering both effects, we notice a 71× factor between the contribution of ICs estimated by MLC and EI to ADPe (sensitive to gold flows).

4. Discussion - Relevance and Novelty

Though it was established in the scientific literature that the choice of database could influence LCIA results, it had yet to be formally demonstrated how significant this influence could be for a digital service. For a digital service, the choice of database can change the estimated absolute impact by an order of magnitude for the ADPe category. The primary hot spot shifts for the WU category when modeling in different databases. Discrepancies between databases in background modeling for critical datasets such as ICs or Li-ion batteries explain these results. Varying levels of granularity exacerbate this. These findings highlight that eco-design guidelines can be database-dependent for a limited number of impact categories. In other words, policymakers seeking to make informed decisions based on LCIA results should assess these decisions by modeling their FU in different databases. In future works, expanding the set of indicators to toxicity-related impact categories would be interesting.

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