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Supplementary Materials S1. The Product Circularity Data Sheet

A Standardized Digital Fingerprint for Circular Economy Data about Products

State of Play Analysis and IT Ecosystem Structure. Amended excerpts from "Ministry of the Economy, Luxembourg Circularity Dataset Standardization Initiative, Creating a digital circularity fingerprint for products Phase 1 Final report" [1]

Terminology [2]

Dataset. A collection of information or properties.

Data sheet. A document providing the dataset in a human-readable format.

Data template. A blank form with a standardized structure to enter information. Once the information is filled in the template, it becomes a data sheet.

Dataset Working Group. A consultative body whose main purpose is to co-create a Circularity Dataset Standardization protocol.

Industry Standard. In this context, an industry standard is an informal standard that is generally accepted by participants in the Dataset Working Group. It is not an officially accepted standard, as this requires a formal approval process by a standards organization.

Product Circularity Data Sheet. A product declaration which presents standardized and trustworthy information on the circularity aspects of a product i.e., the circularity dataset, which could be used partially or entirely by other stakeholders (e.g., databases, platforms or consultants) to enable circular evaluation of products.

A "light" or "basic" PCDS contains a limited set of information related to the circularity aspects of the product and which are non-confidential. The "light" PCDS is primarily intended for use in business-to-business communication, but its use in business-to-consumer communication under certain conditions is not precluded.

Recyclable. Constituent materials in a product are recoverable for safe use in other products.

Stakeholders Group. An informal group whose main purpose is to provide feedback on how a Proof of Concept could be implemented in their respective organizations, and to support the PCDS initiative moving forward.

***State-of-Play Analysis** [3]*

A fragmented circularity data marketplace

The number of initiatives promoting the use of sustainability- and circularity-related data has been increasing. These include research projects, databases, platforms, certifications, and product data declaration across a range of products, from built environment to electronics and FMCG. Some product schemes focus primarily on health, environmental or other aspects (sourcing of materials, social issues, etc.). Reputability, assessment requirements, and acceptability/adoption scale vary widely. These are divided into standardization, EU regulation and platforms. A similar set of initiatives is divided according to sectors. Geographically, some are based in Europe, while others are globalized, namely the Ellen MacArthur Foundation Material Circularity Indicator [4], Global Battery Alliance Battery Passport [5], World Business Council for Sustainable Development (WBCSD) Circular Transition Indicators [6], Underwriters Laboratories (UL) Circularity Facts [7], Circular Cars Initiative [8], Auto Data Alliance [9], C2CPII Materials Passport [10], Circular Fashion [11], and Mindful Materials [12]. Some platforms also reach beyond circularity. For example, Underwriters Laboratories has its UL safety mark. In the building sector, Cobuilder offers data management solutions for the built environment in Northwestern Europe, including a standard-based data management solution which helps organizations

to create and maintain Data Templates according to the ISO 23386 and ISO 23387. In summary, the investigation showed that platforms are split into two distinct groups; those that focus strongly on circularity-related criteria, and those that add CE criteria to much larger platforms.

Due to multiple CE product schemes being developed, there is currently no widely accepted one. This can be explained by the following influencing factors:

a. No common definition of what the circularity of product is

Among the initiatives with a high emphasis on circularity, there is no collectively agreed way to define and assess circularity in relation to products. A few widescale rollouts of circularity have started via e.g., the WBCSD and EMF, but these platforms still differ in interpretations of data, structure, and scope. Some are at company level and others at material flow level.

b. Policy fragmentation

Some standards are beginning to integrate circularity. Some are being developed globally such as ISO TC 323 [13]. Some are at national levels and/or sector specific. For example, the BSI standard BS 8001:20177, was published by the British standardization organization (BSI) 2017, describing a framework and guidance for organizations to implement the principles of the circular economy [14]. Platform CB'23 was launched in the Netherlands with the aim to establish national, construction-sector-wide agreements on circular construction by 2023 [15]. However, there is currently no widely adopted policy on basic circular economy data for products.

Circularity product schemes are complex

The schemes often focus on the content of final assembled products, rather than also characterizing the individual input products as components. Still, they all face the issue of collecting the required information backward throughout the supply chain, especially information that companies are not necessarily ready to disclose, except to consulting firms under confidentiality agreement. This suggests the absence of a tool that works across supply chains and across sectors. It also suggests especially for SMEs, that costs of doing this due to complexity are a major barrier to adoption. The complexity and cost are also a consideration when structuring the audit process

Companies still struggle to see the circularity value

Many of the analyzed initiatives were recently developed in the building sector in order to respond to the demand for more transparency on product content and its toxicology (e.g., Health Product Declaration, Declare Label, Toxnot). For other sectors such as packaging, the added value is not often perceived by manufacturers. Therefore, it seems important to link the PCDS to sector-specific business cases in order to ensure its adoption.

Barriers and opportunities in accessing circularity data

For assessing and promoting product circularity, a range of product information is needed from and by different actors along the supply and use value chain. However, in the current linear economy, basic data for circular evaluation are being lost through the value chain. Contributing factors include:

c. Some information is available from traditional sources such as certifications and environmental declarations, but not in shared standardized formats. For example, Environmental Product Declarations (EPDs) [16] and Blue Angel Certifications [17] each have different ways of evaluating and displaying similar green characteristics of products.

d. Other types of information are not publicly available due to manufacturers reluctance to divulge trade secrets [18].
e. Data critical for creating a trustful environment are often not verified, or the validation source is difficult to trace [19**]**.
f. Most circularity-related data are based on diverse proprietary centralized databases, thus there is no universal and open mechanism to easily exchange basic data throughout the supply chain. PositiveImpaKT assembled an unpublished Excel database of proprietary platforms that offer circularity data to their clients. To date, 59 platforms have been identified.
g. Information about product circularity often changes when one product becomes a component in another. For example, if a component is described by a supplier as designed for clean demounting from an assembly, it loses this property if it is glued or welded into a larger product assembly by a product assembler. As a result, the information becomes inaccurate.

Circularity data are often missing, as data generation and handling require too many human and financial resources. To enable efficient and secure exchange of product circularity information along the value chain, standardization of the data and format is needed, as well as an auditing process.

Product circularity data sheet (PCDS) [20]

In order to address the barriers and opportunities identified during the consultation process, the PCDS was jointly developed between the Ministry of the Economy, the consultancy PositiveImpaKT, and more than 50 manufacturers, data aggregation platforms and standards agencies.

Overview of the PCDS system

Objectives

1. Provide basic data on a product's circularity to all relevant stakeholders.
2. Improve the sharing efficiency of circularity data across supply chains.
3. Encourage the improvement of product performance in terms of circularity.

Design Principles

1. Support other systems

The PCDS is designed to enable later circular evaluations of a product by providing basic information to others (for example, platforms or consultants). It is not designed for ranking or rating product circularity itself, although it might refer to certifications or labels that have already evaluated aspects of the product performance. Therefore, the content of the PCDS is simply designed with a standard text set, facilitating the extraction of data.

2. Limit predictions of subsequent usage

The PCDS describes the relevant properties of a product at a particular point in the supply chain. The PCDS is completed on the basis on how the manufacturer designed its own product to be used, and not on how the next user in the value chain intends to use this product. There are several reasons for this. (A) The manufacturer often cannot predict or control all possible uses of the product. (B) If the product becomes part of another product, the characteristic could change. For example, the section of a PCDS that describes the reusability of a part will no longer be valid if that part is welded or glued into another product. In that case, a manufacturer designed a product X to be demountable or recyclable, but the next user in the value chain uses product X in product Y in a way that is not

demountable or recyclable. Due to this, the original PCDS is only valid at the point in the supply chain when it is not part of another product.

3. Balance confidentiality with transparency

To solve the conflict between confidentiality of information and the need for transparency when implementing a true circular approach, the PCDS is structured around "statements" to describe a certain set of features that can be transparently stated as true or false without having to disclose to every party the manufacturer's trade secrets. To ensure trustworthy content, the originating data are verified by an independent audit.

4. Standalone content

The content of a PCDS is designed to have standalone content, which does not rely on a centralized database.

5. Supplier network integration

The PCDS is designed to be integrated throughout the supply chain. A standardized approach allows the assembly of information from multiple sheets in cases where a product contains multiple components each with its own PCDS. Statements are formulated to facilitate the assembly of information, which is being automated.

Who Creates the PCDS?

A new PCDS is created and managed by a manufacturer at each stage where one product becomes part of another. This includes remanufacturers or refurbishers: if a product is refurbished or remanufactured, it receives a new PCDS. Each manufacturer is responsible for this, and for the storage of the documents and for making the PCDS accessible to other stakeholders. Accordingly:

A PCDS is only modifiable by the original manufacturer of a product. If the product is modified by a third party after manufacture e.g., refurbished, then a new PCDS is created to reflect those modifications.

The PCDS should be revised as soon as there is a change in product composition or when new information or regulations on related hazards or other circular characteristics becomes available.

Who Uses the PCDS?

The main target group is any manufacturing company and the relevant stakeholders involved in establishing circular business models.

At any stage of the supply chain, manufacturers receive multiple PCDS' from their suppliers and integrate the data into a new PCDS for their own products for delivery to customers. As described earlier, if the characteristics of constituent materials are modified at that point e.g., two materials are laminated, then changes to circularity characteristics like reversibility are reflected in the new PCDS. It is the responsibility of the manufacturer to report this.

The PCDS is designed to be harmonized with major current circularity tools and platforms. In that regard, the content of PCDS has been reviewed with leading circularity leaders to ensure alignment in terms of definitions (e.g., C2C Product Innovation Institute, Ellen MacArthur Foundation, World Business Council for Sustainable Development, Underwriters Laboratories).

The PCDS is designed to support a wider digital product passport (DPP) system that is emerging in various sectors and being propelled by European Commission and ISO initiatives. (See, Figure 10 in main body of this study showing how the PCDS supports circularity data flow in the construction sector). Examples were also created for the textiles sector (not shown).

PCDS Structure Overview

The PCDS system is organized around the 'product' level. See nomenclature in main body of this article. The system has five components.

(1) Data template containing standardized, trustworthy statements on product circularity in a true/false format. This format helps to reduce work and facilitate automation of document creation and reading. The template is organized into five major sections which describe the key characteristics of a product's circularity. Each statement is numbered according to a logic given by the overall PCDS structure. (See Supplementary Materials 2 for a description of these sections.)

(2) *Guidance to complete a PCDS.* It became evident during piloting that without this document the PCDS could not be used effectively by a larger group of people. In addition, this provides a strong basis for the development of a standard for the PCDS.

See Supplementary Materials S2 for PCDS pilot template and Guidance.

(3) IT Ecosystem with standardized data exchange protocols based on decentralized data storage and the following protocols:

a. Standardized data structure for storing the PCDS, based on the PCDS structure and including the creation of a unique ID for each PCDS.
b. Standardized data exchange protocol using Application Program Interface (API) between a manufacturer and a customer (e.g., platform, user of their product, etc.). Scope of standardization includes definition of the data format for the exchange (e.g., xml and json), description of the exchange protocol as well as a standardized PCDS layout for publication in a PDF-secured document.
c. Standardized protocols to ensure an efficient exchange of the PCDS throughout the supply chain.
d. Protocol to create a PCDS from data contained in multiple PCDS sheets.
e. Protocol to inform relevant stakeholders when a PCDS revision is made.

References

1. *Luxembourg Circularity Dataset Standardization Initiative, Creating a Digital Circularity Fingerprint for Products PHASE 1—FINAL REPORT*; Ministry of the Economy: Luxembourg, 2020; p. 5 Available online: https://pcds.lu/wp-content/uploads/2020/11/MECO_CEDataSet_PCDS_Public-27072020.pdf (accessed on 2 January 2022).
2. *Luxembourg Circularity Dataset Standardization Initiative, Creating a Digital Circularity Fingerprint for Products PHASE 1—FINAL REPORT*; Ministry of the Economy: Luxembourg, 2020; p. 3. Available online: https://pcds.lu/wp-content/uploads/2020/11/MECO_CEDataSet_PCDS_Public-27072020.pdf (accessed on 2 January 2022).
3. *Luxembourg Circularity Dataset Standardization Initiative, Creating a Digital Circularity Fingerprint for Products PHASE 1—FINAL REPORT*; Ministry of the Economy: Luxembourg, 2020; pp. 9–11. Available online: https://pcds.lu/wp-content/uploads/2020/11/MECO_CEDataSet_PCDS_Public-27072020.pdf (accessed on 2 January 2022).
4. Material Circularity Indicator (MCI). Available online: https://ellenmacarthurfoundation.org/material-circularity-indicator (accessed on 2 March 2022).
5. Global Battery Alliance Battery Passport. 2021. Available online: https://www.globalbattery.org/battery-passport/.https://www.globalbattery.org/battery-passport/ (accessed on 15 February 2021).
6. Circular Transition Indicators (CTI). World Business Council for Sustainable Development. 2021. Available online: https://www.wbcsd.org/Programs/Circular-Economy/Metrics-Measurement/Circular-transition-indicators (accessed on 2 January 2022).
7. Fact Sheet, Circularity Facts Program. Underwriters Laboratories. Available online: https://www.ul.com/resources/circularity-facts-program (accessed on 2 January 2022).
8. The Circular Cars Initiative. World Economic Forum. Available online: https://www.weforum.org/projects/the-circular-cars-initiative (accessed on 2 January 2022).
9. The Alliance for Secure and Cross-Company Data Exchange in the Automotive Industry Is Picking Up Speed. Available online: https://www.press.bmwgroup.com/canada/article/detail/T0326861EN/the-alliance-for-secure-and-cross-company-data-exchange-in-the-automotive-industry-is-picking-up-speed?language=en (accessed on 2 March 2021).
10. CRADLE TO CRADLE CERTIFIED™ PRODUCT STANDARD VERSION 4 MATERIALS PASSPORT. (Cradle-to-Cradle Product Innovation Institute). Available online: https://cdn.c2ccertified.org/resources/certification/v4_Materials_Passport_DRAFT_FOR_PUBLIC_COMMENT_FINAL_080319.pdf (accessed on 2 January 2022).
11. Circular Fashion. Available online: https://circular.fashion/en/ (accessed on 3 January 2022).
12. Mindful Materials. Available online: https://www.mindfulmaterials.com/ (accessed on 2 January 2022).

13. ISO/TC 323 Circular economy. Available online: https://www.iso.org/committee/7203984.html (accessed on 2 February 2022).
14. BSI. The Rise of the Circular Economy, BS 8001—A New Standard Is. Available online: https://www.bsigroup.com/en-GB/standards/benefits-of-using-standards/becoming-more-sustainable-with-standards/BS8001-Circular-Economy/ (accessed on 3 December 2021).
15. Platform CB '23. Available online: https://platformcb23.nl/english (accessed on 5 January 2022).
16. The International EPD System. Available online: https://www.environdec.com/home (accessed on 5 January 2022).
17. Blue Angel. Available online: https://www.blauer-engel.de/en (accessed on 2 January 2022).
18. Jang, M.; Yoon, C.; Park, J.; Kwon, O. Evaluation of hazardous chemicals with material safety data sheet and by-products of a photoresist used in the semiconductor-manufacturing industry. *Saf. Health Work.* **2019**, *10*, 114–121. https://doi.org/10.1016/j.shaw.2018.08.001.
19. Candelon, B.; Hasse, J.; Lajaunie, Q. ESG-Washing in the Mutual Funds Industry? From Information Asymmetry to Regulation. *Risks* **2021**, *9*, 199. https://doi.org/10.3390/risks9110199.
20. *Luxembourg Circularity Dataset Standardization Initiative, Creating a Digital Circularity Fingerprint for Products PHASE 1—FINAL REPORT*; Ministry of the Economy: Luxembourg, 2020; pp. 14–16. Available online: https://pcds.lu/wp-content/uploads/2020/11/MECO_CEDataSet_PCDS_Public-27072020.pdf (accessed on 2 January 2022).