D2.2

Exploring possible Digital Product Passport (DPP) use cases in battery, electronics and textile value chains

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Abstract:	One of the main tasks of the CIRPASS project is to explore the benefits and barriers to the use of a Digital Product Passport by key actors along the value chain. To do this, we consulted over 40 stakeholders and qualitatively analyzed six DPP use cases linked to specific circular economy actions in the three priority sectors (Battery, Electronics and Textile). The exploration of the DPP use cases in circular economy activities of the three sectors has revealed a compelling potential to address persistent data challenges. This report summarizes our main findings which highlight the ability of the DPP to reduce information asymmetry and foster trust in second-hand markets and life-extension applications, as well as to increase the recovery rate of valuable materials and products at end of their life (or use). These findings advocate for large-scale piloting of DPP use cases to further quantify the benefits and enrich the repository of use cases. Finally, we also identified barriers to the deployment of the DPP, which are summarized in the form of actionable recommendations.
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CIRPASS Consortium			
#	Participant Organisation Name	Short Name	Country
1	COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	CEA	FR
2	SLR ENVIRONMENTAL CONSULTING(IRELAND)LIMITED	SLR Consulting	IE
3	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	Fraunhofer	DE
4	WUPPERTAL INSTITUT FUR KLIMA, UMWELT, ENERGIE GGMBH	WUPPERTALINSTIT	DE
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6	VDE VERBAND DER ELEKTROTECHNIK ELEKTRONIK INFORMATIONSTECHNIK EV	VDE	DE
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20	Energy Web Stiftung (Energy Web Foundation)	EWF	CH
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22	SyncForce BV	SyncForce	NL
23	ASOCIACION DE EMPRESAS TECNOLOGICAS ES INNOVALIA	INNOVALIA	ES
24	Textile Exchange	TextileExchange	US
25	Responsible Business Alliance	RBA	US
26	WORLDLINE FRANCE	WORLDLINE	FR
27	RISE RESEARCH INSTITUTES OF SWEDEN AB	RISE	SE
28	IPOINT-SYSTEMS GMBH	iPoint	DE
29	Global Electronics Council	GEC	US
30	Avery Dennison Atma GmbH	atma.io	AT
31	Global Battery Alliance	GBA	BE

Preparing the ground for the gradual piloting and deployment of DPPs from 2023 onwards, focusing on developing a roadmap for prototypes in three value chains: electronics, batteries and textiles.

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Acronyms

List of Abbreviations and Acronyms	
AAS	Asset Administration Shell
B2B	Business to Business
B2C	Business to Consumer
BMS	Battery Management System
C2C	Customer to Customer
CEI	Circular Electronics Initiatives
CLP	Classification, Labelling and Packaging of substances and mixtures
DPP	Digital Product Passport
EV	Electric Vehicle
ESPR	Ecodesign for Sustainable Products Regulation
EPREL	European Product Registry for Energy Labelling
EU	European Union
GHG	Greenhouse Gas Emissions
IEA	International Energy Agency
IMDS	International Material Data System
JRC	Joint Research Centre
LCA	Life Cycle Analysis
LCD	Light Crystal Display
LIB	Lithium-Ion Batteries
LMT	Light Means of Transport
OEM	Original Equipment Manufacturer
QR code	Quick Response code
REACH	Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals
RFID	Radio Frequency Identification
RoHS	Restriction of Hazardous Substances Directive
SCIP database	Substances of Concern In articles as such or in complex objects (Products) database
SoC	State of Change
PCB	Printed Circuit Board
PEF	Product Environmental Footprint
POP	Persistent Organic Pollutants
WEEE	Waste from Electrical and Electronic Equipment

Terms and definitions

List of definitions	
DPP use case	A DPP use case is the description of the use of a Digital Product Passport (DPP) related to a scenario of circular economy actions to serve one or several of the following objectives: 1) sustainable products and production 2) new business opportunities for economic actors through circular value retention and optimization 3) sustainable choices by consumers 4) verification of product compliance with legal obligations.
Economic operator	Manufacturer, Authorized representative, Importer, Distributor, Dealer, Fulfilment, Service Provider (as defined in the ESPR)
Market surveillance	Activities carried out and measures taken by market surveillance authorities to ensure that products comply with the requirements set out in the applicable Union harmonization legislation and to ensure protection of the public interest covered by that legislation
Market surveillance authority	Authority designated by a Member State as responsible for carrying out market surveillance in the territory of that Member State

About CIRPASS

The European Commission is very interested in and ambitious about emerging technologies to support the "twin" green and digital transitions, and in particular the development of a Digital Product Passport (DPP). The DPP is defined by the CIRPASS consortium as a structured collection of product related data with pre-defined scope and agreed data management and access rights conveyed through a unique identifier, and that is accessible via electronic means through a data carrier. The intended scope of the DPP is information relating to sustainability, circularity, value retention for reuse, remanufacturing and recycling.

The aim of CIRPASS is to prepare the ground for a gradual deployment of DPPs, with an initial focus on the electronics, batteries, and textile sectors. Spurred by the need to accelerate the transition to a more circular and sustainable economy, combined with new opportunities offered by a burgeoning data market, a large number of European and international initiatives have emerged recently. The CIRPASS methodology consists in uniting representatives from a large number of these early DPP pilots in order to build a balanced, open and transparent community dedicated to the design and roll-out of the upcoming European DPP.

To ensure a neutral and technology agnostic stance, CIRPASS relies heavily on the involvement of leading European Research and Technology organizations, supported by three standardization organizations, an experienced pool of circular economy (CE) and sustainability consultancies, several large European industry associations, digital technologies and web experts and digital solution providers. The CIRPASS consortium is made up of 31 partners in total.

By bringing together this community of expertise, the project will build consensus and momentum around the DPP concept and contribute to the development of common principles, prototypes, and roadmaps to secure the interoperability of DPPs across value chains, sectors and market participants. Enhanced stakeholder dialogue will be achieved through extensive consultations addressing key DPP aspects such as ontologies, technical requirements and standardization needs.

1 Introduction

As emphasized by the EU Commission, one of the main goals of the Digital Product Passport (DPP) is to provide efficient access to product data which can unlock circular economy opportunities and enable cost-effective circular economy loops (e.g., maintenance, repair, refurbishment, remanufacturing, recycling). Based on the experience of existing DPP-related initiatives, one key challenge for the scalability and adoption of the DPP will be the identification of reward mechanisms and incentives for product information provision which go beyond compliance.

One of the main tasks of the CIRPASS project is to explore the benefits and barriers to the use of a DPP by key actors along the value chain. To do this, we consulted a range of stakeholders and qualitatively analyzed DPP use cases linked to specific circular economy actions in the three priority sectors (Battery, Electronics, Textile). While a previous CIRPASS report ("Deriving an initial set of information requirements to serve as a basis for future discussions"[1]) provided an initial list of DPP information by mapping the information requirements in legislation and the ones used in current DPP-related initiatives, the present report intends to generate knowledge of required DPP information and benefits from a use-case perspective.

This report is structured in four parts. The first part provides the definition of a DPP use case to ensure a common understanding of its meaning. Then in the second part, we describe the methodology that was used to select the DPP-related use cases. In the third part, we present the analysis of two DPP use cases for each of the three sectors. In the fourth part, we provide a summary of the results in terms of benefits and barriers for implementing and/or using a DPP. We conclude with a list of recommendations for future DPP deployment.

https://cirpassproject.eu/project-results/

[1] Available on .

2 Definition of a DPP use case

As highlighted by the European Commission in the draft Ecodesign for Sustainable Products Regulation[2] (DRAFT ESPR), the Digital Product Passport is “an important tool for making information available to the entire value chain” with the following objectives listed in Table 1.

Table 1 - DPP objectives

DPP Objectives		Description
O1	**Sustainable products and production**	Support sustainable products and production boosting material and energy efficiency, extending product lifetimes and optimizing product design, use and end of life handling
O2	**New business opportunities for economic actors through circular value retention and optimization**	Provide new business opportunities to economic actors through circular value retention and optimization based on improved access to data. (e.g. Repair, servicing, remanufacturing, recycling, extended producer responsibility and product-as-a-service activities)
O3	**Sustainable choices by consumers**	Support consumers in making sustainable choices by allowing them to have access to relevant and verified information on products they own or are considering to buy/rent (e.g., using apps to access this information)
O4	**Verification of product compliance with legal obligations**	Support market surveillance and customs authorities with necessary checks and streamline the monitoring and enforcement of the regulation carried out by EU and Member State authorities

Sources: https://hadea.ec.europa.eu/calls-proposals/digital-product-passport_en and https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/digital-2021-trust-01-digipass

Consequently, the choice of a DPP use case must be aligned with at least one of these four objectives. In other words, the use case must describe how improved access to product-specific circularity and sustainability related information contributes to one or several of the DPP objectives. Building on this, the CIRPASS consortium elaborated the following definition of a DPP use case:

[2] Available online via https://environment.ec.europa.eu/publications/proposal-ecodesign-sustainable-products-regulation_en.

A DPP use case is the description of the use of a Digital Product Passport (DPP) related to a scenario of circular economy actions to serve one or several of the following objectives:

1) sustainable products and production
2) new business opportunities for economic actors through circular value retention and optimization
3) sustainable choices by consumers
4) verification of product compliance with legal obligations

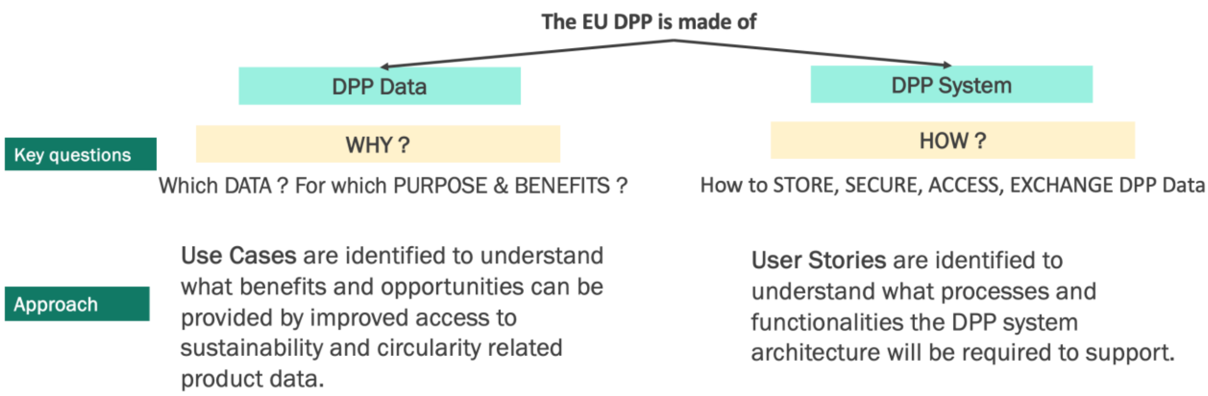
It is important to note that solutions improving product traceability and increasing transparency along the value chain are considered as complementary tools and enablers for DPP implementation.

2.1 Difference between use cases and user stories

Within the CIRPASS project, we use the terms use case and user story with different purposes. To ensure a common understanding of such wording within the CIRPASS consortium, as well as to provide clear and consistent communication to external stakeholders and other DPP related projects, we first defined the difference between a "use case" and a "user story". This is illustrated in Figure 1.

In the context of the CIRPASS project, a user story focuses on the processes and functionalities of the DPP system. It describes a step-by-step process for how value chain stakeholders issue, store, access, exchange and modify DPP data. Use cases focus on the potential benefits resulting from access to circular economy data contained in a DPP, as well as the barriers that could be experienced. Consequently, several user stories could potentially be linked to a single DPP use case. Within this report, we concentrate on the exploration of use cases.

Figure 1 - Difference between use cases and user stories



2.2 Mandatory and non-mandatory information requirements

The current DRAFT ESPR (version December 2023) requires that products regulated under a Delegated Act of the ESPR and placed on the EU market must be accompanied by a DPP. Article 7 (Information Requirements) and Annex III of the DRAFT ESPR set out the mandatory information requirements of the DPP. Specific information requirements will be specified for each product category by specific regulation (i.e. Delegated Acts). For example, the new regulation on batteries and waste batteries[3] (referenced as the “EU Battery Regulation”) sets out the information requirements for a Battery Digital Passport (see Annex XIII of the regulation). The Construction Products Regulation (under revision[4]) will prescribe the basis for product DPPs in the construction sector. In parallel to these new regulations, an increasing number of DPP-like solutions and initiatives provide valuable insights into the information requirements that could apply.

CIRPASS report “Deriving an initial set of information requirements to serve as a basis for future discussions”)[5] defined an initial set of information requirements for each of the three sector groups (battery, electronics, and textile), by mapping both mandatory information and information that is used in current DPP-related initiatives. In the scope of this use case analysis, we considered both the mandatory DPP information requirements (as currently expressed in draft regulations), as well as any additional optional information that could bring added value to the DPP users or creators.

3 Methodology

As specified in the previous section, the aim of this CIRPASS project task is to illustrate the benefits and opportunities of the DPP via the description of use cases. In this section, we present the challenges faced in attempting to identify DPP use cases, the scope of work, and the process used to address these challenges.

3.1 Challenges for identifying relevant DPP use cases and their benefits

Identifying relevant DPP use cases and understanding their potential benefits is complex and has numerous challenges. Several factors contribute to this complexity:

1. **Non-defined information requirements and diversity within the same sector**. While DPP information requirements and data carrier specifications have been clearly defined for batteries, they remain undefined for the other sectors like textiles and electronics. The absence of defined data parameters for these sectors hinders the creation of accurate DPP use cases by companies, limiting their reliability and applicability in the future. Another challenge is that the DPP information requirements will be defined by a delegated act for each product category. This could create a situation where the specificity and depth of data needed for DPPs differs significantly from one product category to another within the same sector (e.g. home appliances and small consumer electronics such as smartphones and laptops). This diversity of requirements makes it difficult to identify common use cases and benefits.
2. **Underspecified EU DPP System.** The full specifications for the EU DPP system are still lacking. A first draft for the development plan of IT standards and protocols for the DPP system was presented by the European Commission in June 2023. Without clear guidelines for the IT infrastructure, it is challenging for businesses and stakeholders to build a comprehensive

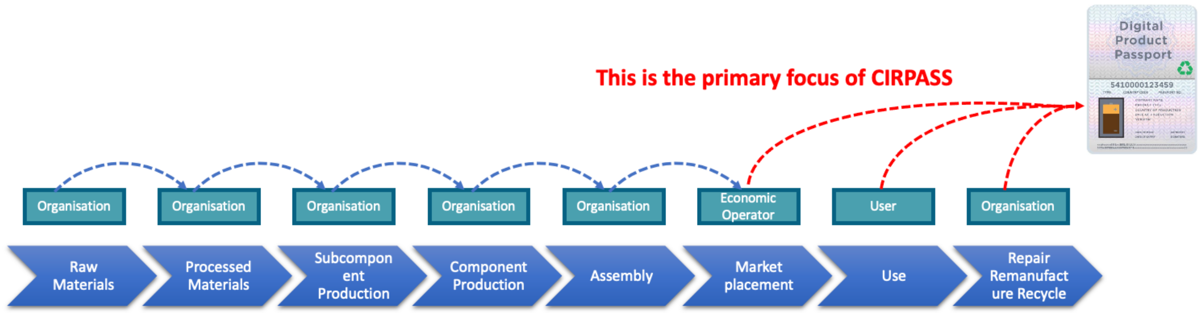
[3] EU Proposal For A Regulation of the European Parliament and of the Council Concerning Batteries And Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020 (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020PC0798).
[4] https://ec.europa.eu/docsroom/documents/49315.
[5] Available online via https://cirpassproject.eu/wp-content/uploads/2023/07/D2.1_July_2023.pdf.

picture of DPP development and implementation, including access to data, updating DPP data, etc.

3. **Proliferation of DPP-like pilots with a large variability of scope**. There is a growing number of DPP-like pilots developed by IT solution providers and individual companies, as presented in the state of play report "Benchmark of existing DPP-oriented reference architectures"[6] (see also the updated CIRPASS DPP related initiatives dataset). The development of DPP-like solutions further accelerated following the publication of the DRAFT ESPR in March 2022. However, these pilot initiatives are often limited to specific use cases with proprietary IT technologies, resulting in a fragmented landscape. While these pilots generate expectations of the DPP potential benefits, there is little evidence-based data to support these claims. The absence of real-world implementation limits the understanding of the true advantages that DPPs can offer (including evaluation of economic benefits).

In view of the above challenges, establishing an exhaustive list of DPP use cases and benefits is not reasonable within the timeframe of the CIRPASS project. In order to overcome these difficulties, we have chosen to focus our analysis on circular economy activities already in place in the value chains of the 3 sectors (e.g., recycling of batteries, refurbishment of electronics, and reselling of garments, etc.). As illustrated in Figure 2, we focused the selection of DPP use cases on downstream applications including both B2B and B2C activities.

Figure 2 - Focus of CIRPASS project for DPP applications



3.2 Process to choose and describe DPP use cases

The following steps outline the process we used to select, describe, and validate DPP use cases (including the benefits and barriers) for some sector-specific circular economy actions.

Step 1: Definition of the product and DPP content
Step 1 focused on defining the type of products to be taken into account in each sector and their characteristics. It also provides an overview of likely DPP data composition, based on existing regulations and on the analysis of existing initiatives (cf. section 2.2).

Step 2: Identification of circular economy actions already implemented in the value chain
Step 2 sought to identify existing circular economy actions within each sector value chain (battery, textile, electronics) that hold potential for DPP usage. These business activities contribute to at least one of the following circular economy objectives: extending product lifetime, optimizing product use, and closing material loops (in alignment with Objective 2 of the EU DPP). We selected the circular economy actions based on the value chain characteristics, information from the CIRPASS survey on stakeholders' perspective on the data gathering effort

[6] Available online via https://cirpassproject.eu/wp-content/uploads/2023/03/CIRPASS_Benchmark-of-existing-DPP-oriented-reference-architectures.pdf.

vs. value of information requirements, expertise from CIRPASS partners, and from other DPP-related leading initiatives (e.g., Battery Pass project, etc.) which provided valuable insights regarding sector-specific challenges and opportunities.

Step 3: Identification of stakeholders and in-depth interviews to collect inputs and document DPP use cases
Step 3 involved the collection of inputs from both internal and external stakeholders who have a vested interest in the DPP. The stakeholder identification process was based on the CIRPASS list of stakeholders, the network of CIRPASS partners and participants from the above mentioned survey on DPP information requirements. Stakeholders included manufacturers, brands, product lifetime extension actors (repair, reconditioning, resell, etc.), recyclers, and DPP-like solution providers. Once a suitable pool of stakeholders had been identified, we undertook a series of in-depth interviews to investigate the specific DPP use cases and validate the related benefits and barriers. We focused the discussion on DPP use cases relating to a specific aspect of a circular economy action. For instance, "improving the efficiency of second life product sorting processes" or "streamlining the online registration of used products to facilitate resale". In total, we consulted more than 40 external stakeholders. For the Battery sector, we also had several exchanges with the Battery Pass consortium. This feedback was critical for refining the use cases and ensuring that they align with real-world needs and expectations. When data on the business case (investment costs and quantitative economic benefits) were available, we incorporated these inputs in the DPP use case description.

Step 4: Description specific DPP use cases
Step 4 focused on describing specific DPP use cases. This included providing a description of the current step-by-step process, its challenges and data gaps, and how the stakeholders envision the use of a DPP would alter this, and the resulting benefits and/or barriers to implementation.

The principal outcome of this process is an appraisal of how the DPP can unlock opportunities for stakeholders (**beyond legal compliance**), by responding to the existing data challenges that hinder the implementation of circular economy actions. It includes a description of the identified DPP use cases per sector and a compilation of the benefits and barriers perceived by the stakeholders. It is worth noting that this report does not aim to provide an exhaustive and comprehensive list of DPP use cases or a feasibility assessment of the business case. But rather, it provides inputs in the form of recommendations for the development of the EU DPP and guidance for the future adoption and implementation of the DPP by stakeholders along the value chain.

4 DPP use cases by sector

This section summarizes the DPP use cases, and the potential benefits and barriers arising, which have been reviewed internally with CIRPASS partners and externally through interviews. It is structured in three parts, for the three sectors of batteries, electronics and textiles respectively. For each sector, we provide a brief description of the products considered for the sector, the content of the DPP based on regulations and on the analysis of existing initiatives, and the value chain characteristics highlighting the circular economy actions already implemented. We then summarize the analysis of the specific DPP use cases selected, each of which is structured in three parts:

- Current situation explaining the step-by-step process related to the circular economy action and where the challenges and data gaps are;
- Potential improvements made possible by the DPP, describing which specific data can lead to which process improvement;
- Conclusions on the benefits and barriers.

Table 2 lists the DPP use cases selected to illustrate the potential benefits of the DPP by sector.

Table 2 - List of DPP use cases selected

Sector	DPP use case – short name	
Battery	**Use case 1**	*Increase volume of EV battery reuse in energy storage applications*
	Use case 2	*Increase recovery rate of critical raw materials at EV battery end of life*
Electronics	**Use case 3**	*Increase volume of refurbished mobile phones by improving the quality and transparency of the refurbishment process*
	Use case 4	*Increase recovery rate of critical raw materials of small electronics equipment*
Textile	**Use case 5**	*Improve the efficiency of textile product sorting to favor reuse and increase sales of secondhand textile over recycling*
	Use case 6	*Increase the value of secondhand clothing sales*

4.1 Battery

Since the new regulation on batteries and waste batteries (referenced as "EU Battery Regulation") entered into force in 2023, batteries will be required to have a DPP by February 2027. With the introduction of a digital battery passport, the European Commission aims to support the sustainable and circular management of batteries by requesting comprehensive data along the entire battery value chain to be documented and exchanged through a digital infrastructure. The objective is to extend the life cycle of the entire battery system as far as possible, as well as the recycling of the raw materials, materials, and components at the end of the life cycle. Data availability is also expected to reduce costs for circular business models along the batteries' life cycle.

In order to qualitatively assess the DPP use cases, we consulted a series of external expert stakeholders[7] involved in the battery value chain and we had several exchanges with the Battery Pass consortium who had performed a deep dive analysis of battery DPP use cases (see https://thebatterypass.eu/assets/images/value-assessment/pdf/2024_BatteryPassport_Value_Assessment.pdf).

4.1.1 Description of a battery

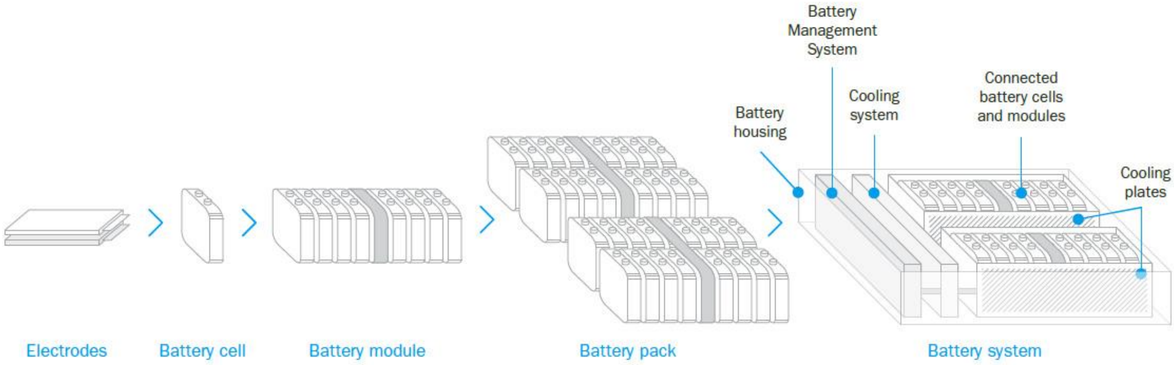
The EU defines a battery as follows: "*any source of electrical energy generated by direct conversion of chemical energy and consisting of one or more non-rechargeable or rechargeable battery cells, modules or of packs of them, including a battery that has been subject to preparing for re-use, preparing for repurpose or repurposing, or remanufacturing*" (Article 2(1), EU Battery Regulation).

The internal structure of a battery varies greatly from one manufacturer to another and from one application to another, but it typically comprises four encapsulated components (cf. Figure 3):

- **Battery cells** are the basic functional unit in a battery and primary energy storage component typically consisting of electrodes (anode and cathode), a separator and an electrolyte solution, encased in a container with terminals;
- **Battery module** refers to a set of battery cells that are connected together or encapsulated within an outer casing to protect the cells against external impact, and which is meant to be used either stand-alone or in combination with other modules;
- **Battery pack** refers to any set of battery cells or modules that are connected together or encapsulated within an outer casing, so as to form a complete unit that the end-user is not intended to split up or open;
- **Battery management system** is an electronic device that: controls or manages the electric and thermal functions of the battery; manages and stores the data on the parameters used to determine the state of health and expected lifetime of batteries; and that communicates with the vehicle or appliance in which the battery is incorporated or with a public or private charging infrastructure.

[7] Li-cycle, Stena Recycling, Northvolt, CATL, BMW, The Mobility House.

Figure 3 – Typical battery structure and its components



Source: *https://bssa.org.uk/ev-battery-casings-guide/*

One of the main challenges for battery lifetime extension and recycling is the current lack of standardization for EV battery systems within the automotive industry. Not only does each OEM require a different design to suit the vehicle platform, but the battery modules may also have to accommodate three different types of cells: pouch, cylindrical or prismatic. In addition, the conventional structure "cell-to-module" consists of a pack of multiple battery modules which could facilitate replacement of modules and components to extend the battery useful life. But, in recent years, to reduce cost and to optimize battery capacity, a "cell-to-pack" structure has become increasingly popular, limiting the modularity and interchangeability of components.

In terms of **product composition**, Lithium-Ion Batteries (LIBs) are the most technologically mature technology. Lithium is contained in dissolved form in a liquid electrolyte and is the key metal used for energy storage. The anode consists of a copper foil coated with a thin layer of black graphite and the cathode consists of a thin sheet of aluminum-based foil whose chemistry can vary significantly between batteries. The cathode chemistry is the key element that determines the main battery characteristics and performance (e.g. capacity, energy density, power density, etc.). It is also the most expensive battery component, due to the use of highly valuable materials such as cobalt, nickel and manganese. That is why the LIBs are typically classified based on the composition of their cathodes (e.g. NMC (Nickel Manganese Cobalt), NCA (Nickel Cobalt Aluminum), LFP (Lithium Iron Phosphate))[8]. While nickel-rich chemistries currently predominate (66% of the market), nickel-free LFP batteries are expected to significantly increase their market share, driven by Chinese demand for light-duty EVs[9]. The chemistry shift has been influenced by performance, as well as the price and accessibility of key raw materials (lithium, nickel, and cobalt). Finally, to substitute lithium as the principal energy storage material, batteries based on more abundant metals like sodium are currently also being developed.

4.1.2 Battery digital passport

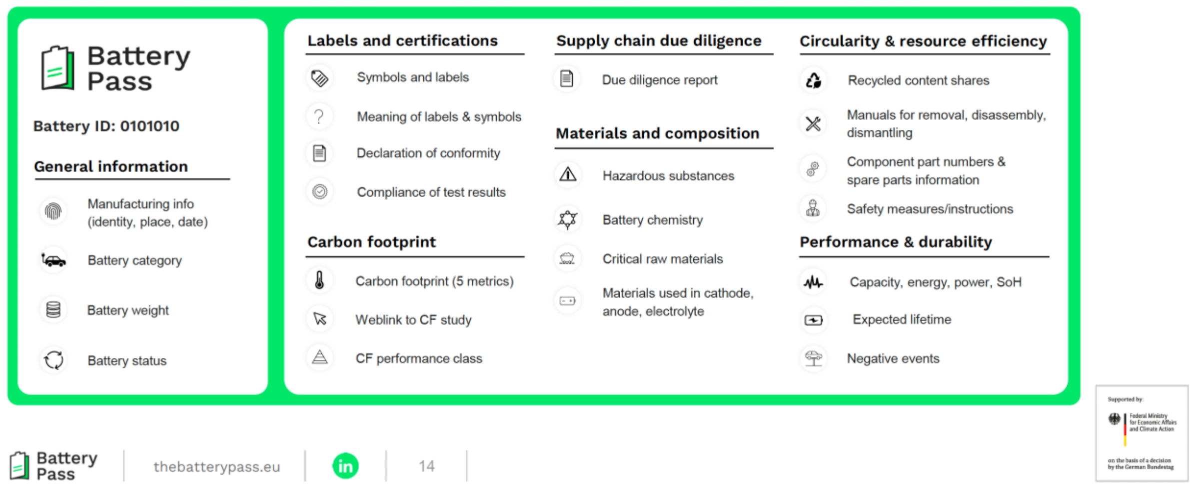
All batteries in Light Means of Transport (LMT), industrial batteries with a capacity above 2 kWh and Electric Vehicle (EV) batteries placed or put into service on the EU market will be required to have a DPP by February 2027. DPP data should be made accessible through a data carrier (such as a QR code), printed or engraved visibly, clearly legibly and indelibly on the battery, connected to a unique identifier.

[8] Miao, Yu, Patrick Hynan, Annette von Jouanne, and Alexandre Yokochi (2019). "Current Li-Ion Battery Technologies in Electric Vehicles and Opportunities for Advancements" Energies 12, no. 6: 1074. https://doi.org/10.3390/en12061074.
[9] International Energy Agency (2023) "Global EV Outlook 2023: Catching up with climate ambitions". Available online via https://www.iea.org/reports/global-ev-outlook-2023/trends-in-batteries.

The battery passport shall contain information relating to the battery model and information specific to the individual battery, including the use of that battery. Details are described in Annex XIII of the EU Battery Regulation and Figure 4 provides a high-level overview of the required data attributes which are grouped into seven content clusters. Part of the DPP data shall be made publicly available and access to specific information shall be restricted on the basis of the access rights specified in Annex XIII and the implementing act adopted pursuant to Article 65(9).

The list of mandatory information requirements (which includes around 80 individual data attributes) was used as baseline when exploring the benefits of the DPP in the selected use cases. In addition, whereas several initiatives are working on the development of Battery Digital Passports (which are listed in the CIRPASS DPP-related Initiatives Dataset[10] and CIRPASS report on DPP-oriented reference architectures[11]), there is currently no solution that has been implemented beyond the prototyping and piloting stage.

Figure 4 - Data categories for the battery passport



Source: Battery Pass (2023)

4.1.3 The battery value chain and circular economy actions

The battery market is very dynamic and growing rapidly as a result of the gradual move away from fossil fuels in the transport and energy sectors. Electrification of the mobility sector (in particular passenger vehicles) accounts for 90% of this increase in demand. To give an idea of current global demand for EV batteries, in 2022 this was estimated to amount to an equivalent energy storage capacity of 550 gigawatt hours (GWh). According to the International Energy Agency (IEA), global battery demand is expected to increase exponentially to over 5.5 terawatt-hours (TWh) by 2030 and 6.4 TWh by 2040[9]. Demand for stationary energy storage applications is also increasing, but represents only 5% of worldwide battery demand.

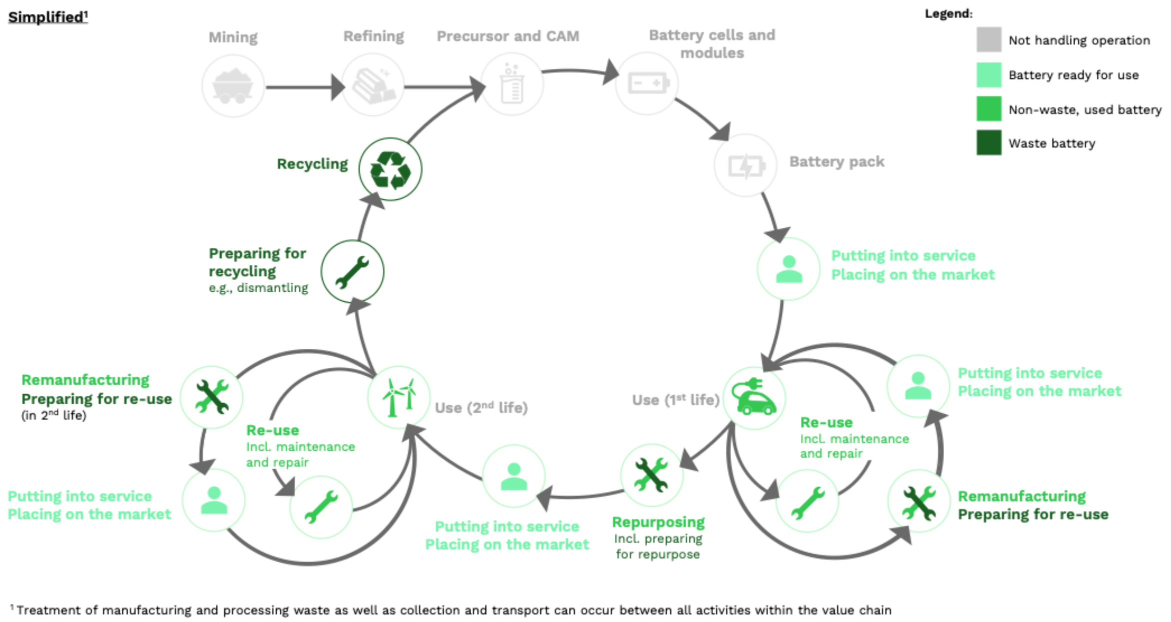
The rapid growth of the battery market is stimulating demand for critical materials, which may lead to a supply shortage. In 2021 and 2022, lithium demand exceeded supply despite the 180% increase in production since 2017. For the year 2022, IEA estimated that around 60% of lithium, 30% of cobalt and 10% of nickel global production was needed for EV batteries[9]. In addition, this fast-growing market will create a huge volume of "waste" batteries that will need to be handled in the coming years. EV batteries are estimated to reach the end of the first useful "life" after eight to ten

[10] Available online via https://cirpassproject.eu/dpp-related-initiatives-dataset/.
[11] Available online via https://cirpassproject.eu/wp-content/uploads/2023/08/CIRPASS_Benchmark-of-existing-DPP-oriented-reference-architectures.pdf.

years of service as the warranty provided by the OEMs covers typically that time (which is around 150,000 kilometers depending on the vehicle model). At this stage, they can still deliver around 70-80% of their original power, which is sufficient for further use in less demanding applications such as stationary energy storage.

Therefore, to retain and optimize the intrinsic value of batteries, several circular economy actions can be implemented and are illustrated in Figure 5. As 90% of global LIB demand is driven by EV batteries[12], we decided to focus on this type of product for the DPP use cases. In what follows, we describe the most promising circular economy pathways for EV batteries.

Figure 5 - Battery value chain and circular economy actions



Source: Battery Pass (2023) Battery Passport Content Guidance. Available online via https://thebatterypass.eu/assets/images/content-uidance/pdf/2023_Battery_Passport_Content_Guidance.pdf

- **Lifetime extension**
  - EV batteries are typically replaced when they reach the end of their useful life in a vehicle (i.e. when they reach 70-80% of the original capacity). These used EV batteries are collected by third-party workshops or by OEMs/battery manufacturers themselves. At that stage, they are assessed for potential reuse or repurposing. If their capacity is too deteriorated for second life application, they are sent for recycling. Both reuse and repurposing may require an element of **remanufacturing**[13].

[12] Battery 2030: Resilient, sustainable, and circular', McKinsey, Jan. 2023. Available online via https://www.mckinsey.com/industries/automotive-andassembly/our-insights/battery-2030-resilient-sustainable-and-circular.

[13] Remanufacturing means any technical operation on a used battery that includes the disassembly and evaluation of all its battery modules and cells and the use of a certain amount of battery cells and modules, new, used or recovered from waste, or other battery components, to restore the battery capacity to at least 90% of the original rated battery capacity, and where the state of health of all individual battery cells is homogeneous, not differing more than 3% from one another, and results in the battery being used for the same purpose or application than the one for which the battery was originally designed. (EU Battery Regulation, Article 2,1(26a))

- **Reuse** means the complete or partial re-use of the battery for the original purpose the battery was designed for (i.e. in the same type of EV). This will require a minimal reconditioning process of the battery pack (including analysis of the state of health and replacement of degraded modules and/or cells). This circular economy pathway is expected to be limited to a small proportion of used batteries as the economic case is considered unfavorable by OEMs, and cheaper and improved battery technologies may be available superseding older or technologically obsolete reconditioned batteries[14].

- **Repurposing** refers to the complete or partial re-use of the battery for a different purpose/application than that for which the battery was originally designed. For example, reusing EV batteries in energy storage systems for stationary power grid application. A circular economy pathway of this type is an attractive business case for both automotive OEMs and energy storage solution providers. On the one hand, the responsibility for recycling EV batteries lies with the vehicle's OEM, who must pay a recycling fee to recyclers for each kilogram of battery processed. Depending on the nature of contracts agreed with repurposing companies (direct sale or leasing), OEMs would be able to save the recycling fee and also able to generate an additional revenue by selling the collected batteries. From the perspective of the repurposing companies, they also benefit as they are able to obtain second life batteries at a price around 40% lower than that of new batteries[14].

  However, the allocation of liabilities and responsibilities relating to second-life batteries performance, or their potential failure, is complex due to the change of product “ownership” from their first- to their second life. Data on the first-life operation and strict requirements on performance and safety are critical factors to enable effective sourcing of modules for repurposing and mitigation of risks.

- **Closing material loops**
  Batteries considered “too exhausted” for second life applications, or some used batteries that exhibit premature degradation would have to be recycled.
  - **Recycling** means any recovery operation by which waste materials are reprocessed into products, materials, or substances, whether for the original or other purposes. Battery recycling presents a crucial opportunity to recover high-grade metals and other materials from used batteries (such as copper, nickel, manganese, cobalt and lithium). While manufacturing scrap from battery production and return of faulty EV batteries currently predominates the recycling input, end-of life batteries will account for the large majority of recycling feedstock by 2040[15]. As mentioned previously, battery chemistries vary from one EV application to another and are still evolving. This implies that the recovery rates of valuable materials will also vary, impacting the efficiency of recycling proceses, as well as their profitability.

To provide a projection of scale, it is estimated that 125,000 older electric vehicles will be “retired” in the EU during the year 2030, meaning that their batteries will need to be processed[14]:

- Around 15% will be too deteriorated for second life applications and thus will be sent for recycling, generating almost 2,800 tons of valuable metals.
- Almost 105,000 EV batteries, representing around 2.25 GWh of residual capacity, would be potentially fit for a second life application. Which could be added to the approximate 250,000 EV batteries that would have already entered second life applications prior to 2030.

[14] Element Energy (2019) “Batteries on wheels: the role of battery electric cars in the EU power system and beyond”.
[15] McKinsey (2023) “Battery recycling takes the driver’s seat”. Available online via https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-recycling-takes-the-drivers-seat

When considering the current trends of the battery market, both repurposing and recycling solutions and processes will play a crucial role in enhancing the circularity of the battery value chain. These two approaches are not exclusive but rather complementary. They will increase autonomy and resilience of regional supply chains by reducing virgin material demand and EU dependency on critical raw materials (currently supplied from outside Europe). In addition, and as emphasized by the North-West Europe (NEW) project STEPS[16], they will support the deployment of electricity storage for smart grid infrastructures using renewable energy sources. Therefore, when discussing DPP use cases with external stakeholders, we focused on two DPP use cases:

- **DPP use case 1** describes the potential opportunity for the DPP to facilitate the evaluation of battery health and its remaining capacity, and to support the development of EV battery repurposing.
- **DPP use case 2** describes how the DPP can provide potential benefits to battery recyclers, as recycling technology and capability are still at an early stage of development in Europe.

4.1.4 DPP use case 1: Increase volume of EV battery reuse in energy storage applications

4.1.4.1 Current situation

After 8 to 10 years in EVs, lithium-ion batteries are likely to retain more than two thirds of their usable energy storage. Depending on their condition, used EV batteries could deliver an additional 5-8 years of service in a secondary application. One promising second life application is energy storage. The repurposing of lithium-ion modules or packs from electric cars in battery storage units practically doubles their commercial service life. In addition, high-performance battery storage units are an important component in the successful transition to renewable energy. With an increasing supply of electricity from fluctuating renewable energies, such as wind farms or solar arrays, they can help stabilize power grids, levelling out energy fluctuations with virtually no overall loss of energy (a role that is partly fulfilled by fossil power plants at present).

Large-scale industrial projects for second life batteries started in the early 2010s. Since then, many automotive OEMs have initiated the launch of second-life battery projects with third-party operators. For example, Groupe Renault and Connected Energy signed a deal in 2016 to collaborate on second-life battery energy storage technology, with the first large scale project, the E-STOR system (720 kWh and 1.2MW storage capacity), installed in 2020 at the Umicore industrial site in Belgium[17]. In 2016, Daimler AG teamed up with The Mobility House and GETEC to install the world's largest second-use storage battery, with a capacity of 13 MWh[18]. In order that they can be used for stationary storage in this way, used EV batteries must undergo process consisting of several steps, including battery testing, partial pack disassembly and module separation, and reassembly into new packs. This process has two main objectives:

1) **To determine the remaining state of health of an EV battery pack**, as this can vary for each used battery depending on factors that range from climate to individual driving behavior. The ability of a battery to retain and rapidly discharge electricity degrades with use and the passing of time. For example, repeated utilization of the maximum storage potential of the battery, rapid charge and discharge cycles, and exposure to high temperatures are all likely to reduce battery performance.

[16] https://vb.nweurope.eu/projects/project-search/steps-storage-of-energy-power-systems-in-nwe/#tab-1
[17] https://connected-energy.co.uk/news/battery-energy-storage/
[18] https://www.mobilityhouse.com/int_en/our-company/newsroom/article/worlds-largest-2nd-use-battery-storage-is-starting-up

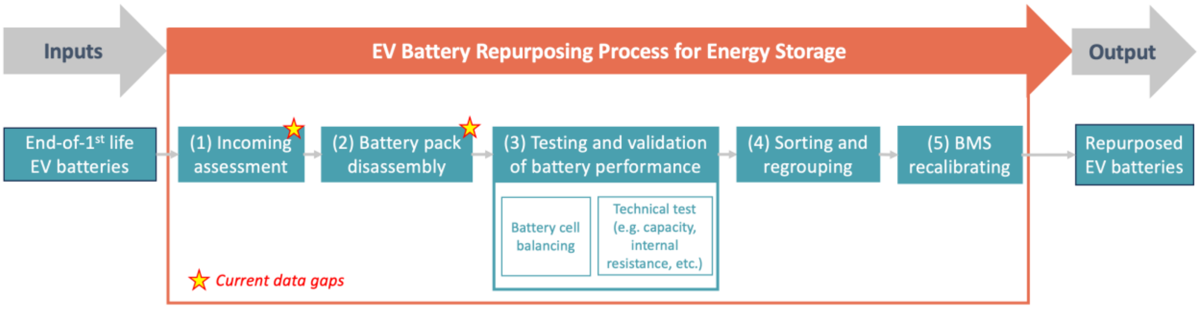
2) **To reconfigure EV battery packs to meet the energy storage application requirements**. In many cases, packs are disassembled before modules are tested, equipped with a new battery management system (BMS), and re-packaged depending on the application requirements.

Figure 6 - Installation of repurposed EV battery packs in an energy storage facility

Source: The Mobility House

The repurposing process for EV batteries is still in its infancy and there is no harmonized approach used by the stakeholders involved[19]. We mapped the main process steps used for EV battery repurposing for stationary energy applications in Figure 7 and indicated where the current data gaps occur. These steps are also briefly described below.

Figure 7 - Repurposing process of used EV batteries for energy stationary applications



Inputs to the repurposing process

Energy storage solution providers typically have contracts with automotive OEMs, which enable them to use EV batteries in their installation. These batteries consist of two types:

- **1st life EV batteries used for spare parts**. OEMs typically overproduce EV batteries as a provision for aftersales and warranty, to help ensure that an adequate supply of spare parts is available beyond the active vehicle production period. To be suitable for use in vehicles, batteries need to be carefully charged and discharged on a regular basis. To maximize the value of these replacement EV batteries, OEMs establish a leasing contract that specifies the operational conditions of the energy storage facilities (e.g. rate of discharge, interval charge). In this case, the complete EV battery packs are used, including the BMS.

[19] Zhu J, Mathews I, Ren D, Li W, Cogswell D, Xing B, et al. End-of-life or second-life options for retired electric vehicle batteries. Cell Reports Physical Science. 2021;2(8): 100537, ISSN 2666-3864. https://doi.org/10.1016/j.xcrp.2021.100537.

- **2nd life EV batteries**.
  Used batteries that are viable for second-life energy storage applications are typically identified at the collection point and sold by OEMs to repurposing workshops. Energy storage solution providers told us that they do not accept used EV battery with a state of health[20] (SoH) below 60%.

Step 1: Incoming assessment

The used EV batteries removed from the electric vehicles are typically shipped to the repurposing companies with the complete battery pack and BMS. On arrival, each battery pack is registered with a serial number for internal traceability and asset management. Then, the repurposing operators perform an assessment of the battery to decide at which appropriate level the used battery should be repurposed (pack level, module or cell) and for which type of application. To ensure an accurate assessment, access to the following information is essential:

- Technical functional parameters of the battery as designed (capacity, internal resistance, etc.) and their current status (data should be available at module and cell level);
- Reasons for retirement (reaching end of warranty period, damage, fault, etc.);
- Historical data related to the use phase (e.g. the number of full equivalent cycles and maintenance record).

When the repurposing process is handled by an OEM or under a contract between an OEM and a repurposing operator, the first two data sets may be accessible, but it is often more challenging to get historical use data. In other cases, access to such information is very challenging and thus costly and time-consuming physical testing must be performed to assess the SoH of the used battery.

Step 2: Disassembly of battery packs

Two main approaches for the repurposing of EV batteries are currently used depending on the assessment results from Step 1:

- **Pack level**: direct reuse of the EV battery pack in its current form, replacing the BMS or reprogramming this if access is granted. EV battery packs with similar performance (e.g. remaining capacity, etc.) are then linked together in the storage system.
- **Module level**: battery packs are disassembled in order that the performance of individual modules can be measured, leading to the modules being re-sorted and re-packed based on their functional parameters.

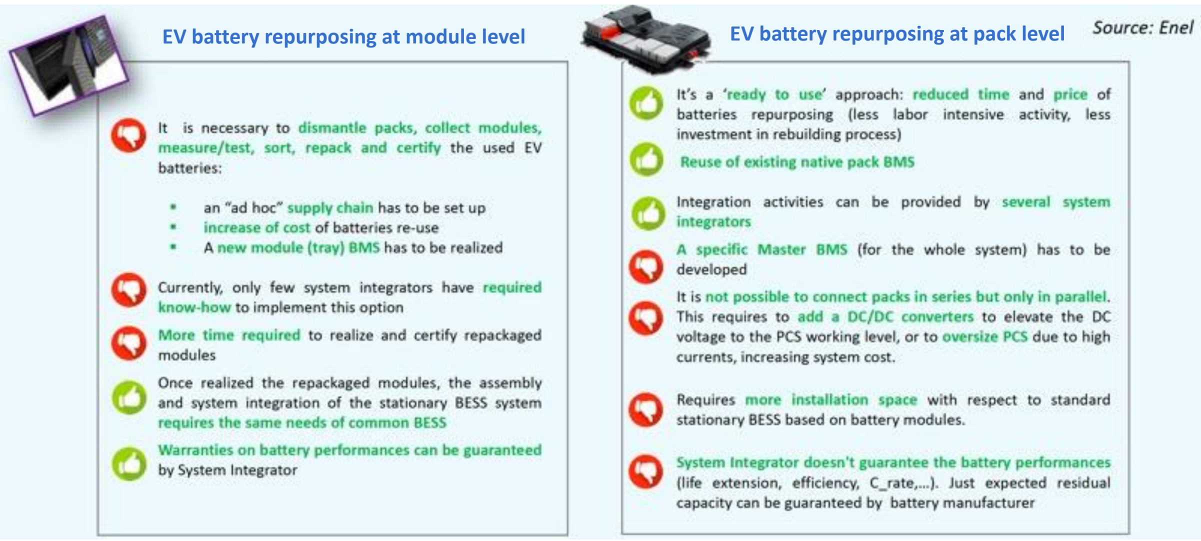
While the option of reusing the entire pack as is appears to be most attractive from an economic point of view, certain operational and technical aspects need to be taken into account in the overall balance as illustrated in Figure 8.

Depending on the option selected, Step 2 may involve the opening of the battery pack casing and disassembly of the battery modules. As part of this disassembly process, the mechanical integrity of pack and modules is checked through visual inspection. Modules with mechanical deformation are a safety risk for internal short circuits, thermal runaway, and fire, and thus should be excluded. Due to the large variety of battery pack designs, the disassembly process is undertaken

[20] SoH is a measurement that indicates the level of degradation and its ability to deliver the specified performance compared with a new battery. For EV batteries, there is no commonly agreed definition and method to assess the state of health. Some SoH values takes into account several factors such as charge acceptance, internal resistance, voltage and self-discharge. However, in most cases, SoH values refer to the ratio of the current maximum available capacity to the initial maximum capacity.

manually and, therefore, relies heavily on human labor, which is expensive and time-consuming compared to an automated process.

Figure 8 - Approaches to EV battery repurposing - Pros and Cons



Source: Enel

Step 3: testing and validation of battery performance

This step aims to verify the performance, reliability, and safety of the repurposed battery packs or modules through several tests, resulting in an evaluation of the battery's ability to meet energy storage requirements and withstand operational conditions.

As a minimum, repurposing operators told us that they perform a battery cell balancing and a capacity test. The ratio of the current measured capacity in comparison to the battery's rated capacity when first produced, provides an indication of the overall battery state of health. Depending on the level of accuracy and trust in the information received, complementary technical tests may be run to increase confidence in the remaining useful lifetime of the battery. These include:

- **Battery cell balancing** to ensure that they are equally charged. No two cells (even if they have the same model number, manufacturer, production) have the same State of Charge (SOC), discharge rate, impedance, temperature, and capacity. Cell balancing improves the overall potential lifetime of the battery pack and enhances the SOC of the battery. An imbalance is created when every cell in the connected series of the battery pack has a different SOC. Such an imbalance results in the overall battery capacity equal to the weakest cell in the battery pack.
- **Capacity test.** Capacity testing is a dynamic assessment whereby a simulated load (in ampere or watts) is imposed on the battery system for a specified time. It is also known as load testing or discharge testing. The discharge continues to a defined end-of-discharge (EOD) voltage, referencing a measured battery temperature taken at the start of the test. This type of test allows for the determination of actual capacity. Furthermore, it enables comparison of the rated capacity to the test result and if multiple values are available, they can be used to evaluate capacity loss as the battery ages.

Step 4: Sorting and regrouping

This step includes two main tasks:

- matching battery modules based on capacity, state of health, and compatibility to create battery packs with balanced performance.
- grouping batteries with similar characteristics and performance levels to optimize the efficiency and reliability of the energy storage system.

Step 5: BMS calibration to ensure best use of the battery based on the state of health.

As repurposed batteries have reduced energy and power capabilities, optimal battery sizing and appropriate control are necessary for smoothing power output, avoiding overcharge or over-discharge, and extending life cycle. If repurposing operators have access to the BMS of the original battery pack, they may be able reuse it and reprogram it. Otherwise, they need to install a new BMS and program it for the repurposed battery.

When we discussed these steps with battery repurposing operators, we identified the following **current data gaps**:

- **Lack of reliable and standardized information related to the battery performance and functional parameters** (e.g. capacity, energy, power). Repurposing operators typically aim to gain access to the BMS, which includes relevant technical information about the EV battery. However, accessing the BMS is challenging as it is typically protected by OEMs. In addition, there is no common BMS interface between OEMs, making it challenging to work with different EV batteries. Finally, while there is a general agreement on the type of tests needed to assess the performance parameters, there are significant differences in the test conditions depending on the test method used[21]. This makes it difficult to compare the EV battery performance parameters of different manufacturers.

- **Lack of data on battery first-life operation** (e.g., temperature curves, voltage, current, vibration, negative events and stress factors). Battery ageing and performance degradation is not a linear phenomenon. For example, capacity fading of the battery may vary depending on a series of factors, such as battery chemistry and temperature during discharge/charge cycles. The more historical information is available, the easier it is to assess the state of health of the battery and its remaining useful life. Without historical battery information, many of these procedures become more challenging.

To cope with these data gaps, repurposing companies are building battery analytics and algorithms to better evaluate the remaining useful life and potential risk of failure during second life applications. But these are still in the learning phase due to the low volume of collected data.

Beyond the data gaps, there is a series of technical challenges that affecting the efficiency of the repurposing process:

- **Large number of battery-pack designs** in terms of size, electrode chemistry and format (cylindrical, prismatic, and pouch). It is estimated that up to 250 new EV models will exist by 2025, featuring batteries from more than 15 manufacturers[19]. Lack of standardization of EV battery modules results in requirements for tailored solutions that hinder the industrialization of repurposing processes (disassembly process, remaining useful life assessment, space for the energy storage facility) and increase costs.

[21] Ruiz V., Standards for the performance and durability assessment of electric vehicle batteries - Possible performance criteria for an Ecodesign Regulation, EUR 29371 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-94179-5, doi:10.2760/24743, JRC113420.

- **No EU standard for assessing the repurposing of EV batteries**. There is currently one standard UL 1974, published by the US-based accredited standards developer Underwriters Lab (UL). This standard provides requirements for the sorting and grading process of batteries that are intended for repurposing, but it lacks detailed steps and specifics related to test methods. Standards are required to create a transparent and harmonized way to document and exchange data supporting the repurposing of batteries for use in energy storage applications.

4.1.4.2 Potential improvements made possible by the use of a DPP

The potential improvements of the battery repurposing process enabled through the battery passport are summarized in Table 3. These arise mainly due to the improved information availability for the incoming assessment step.

Table 3 - Potential improvement of battery repurposing process enabled by a DPP

DPP data attributes	**Required per Battery Regulation?** Yes/No (granularity level[22])	Potential Improvements
Unique identification and QR code	Yes (Item)	- Eliminate the need to build an internal identification system for traceability
Information on battery functional parameters - Rated capacity - Capacity fade - Internal battery cell and pack resistance - Internal resistance increase - State of certified energy (SOCE)	-Yes (Model) -Yes (Item) -Yes (Model) -Yes (Item) -Yes (Item)	- Reduce efforts and limit the technical tests to get data points on the key functional parameters (capacity, energy, internal resistance, etc.) - To estimate the ageing behavior and the remaining useful lifetime, several data points at regular intervals would be beneficial. - Information should be provided at module level as repurposing typically includes a repack of modules.
- Date of manufacturing of the battery - Expected lifetime in number of charge-discharge cycles - Original power capability - Power fade **Information and data on its use phase,** including: - the number of charging and discharging cycles - negative events, such as accidents / deep discharge - periodically recorded information on the operating environmental conditions, including temperature, and on the state of charge.	-Yes (Item) -Yes (Model) -Yes (Model) - Yes (Item) - Yes (Item)	- Improve the accuracy of the assessment of remaining useful lifetime, safety and failure risks, suitable 2nd life application. - For example, time spent charging during extreme temperatures and time spent in extreme temperatures are considered as important data points for repurposing operators.
Disassembly information, including:	Yes (Model)	- Optimize battery disassembly process. - Possibility to automate the battery disassembly process.

[22] Model versus individual battery (i.e. item).

- Exploded diagrams of the battery system/pack showing the location of battery cells - Disassembly sequences - Type and number of fastening techniques to be unlocked - Tools required for disassembly - Warnings if risk of damaging parts exists - Number of cells used and layout		This requires machine-readable format and standardized method to document disassembly process enabling the set-up of automated disassembly equipment.

4.1.4.3 Benefits and barriers

Information made available via the battery passport (data on battery functional parameters and battery first-life operation, disassembly information) leads to the following benefits.

- Economic
  - **Reduction of technical testing costs** to assess battery state of health and suitability for a second life application, especially for independent second life operators that do not already have access to this information through the BMS.
  - **Reduction of disassembly costs** (which can be further reduced through automated disassembly processes)
- Qualitative
  - **Improvement of worker safety** dealing with storage and assessment of the used batteries.
  - **Reduction of incident risks** during the second life application of the battery.

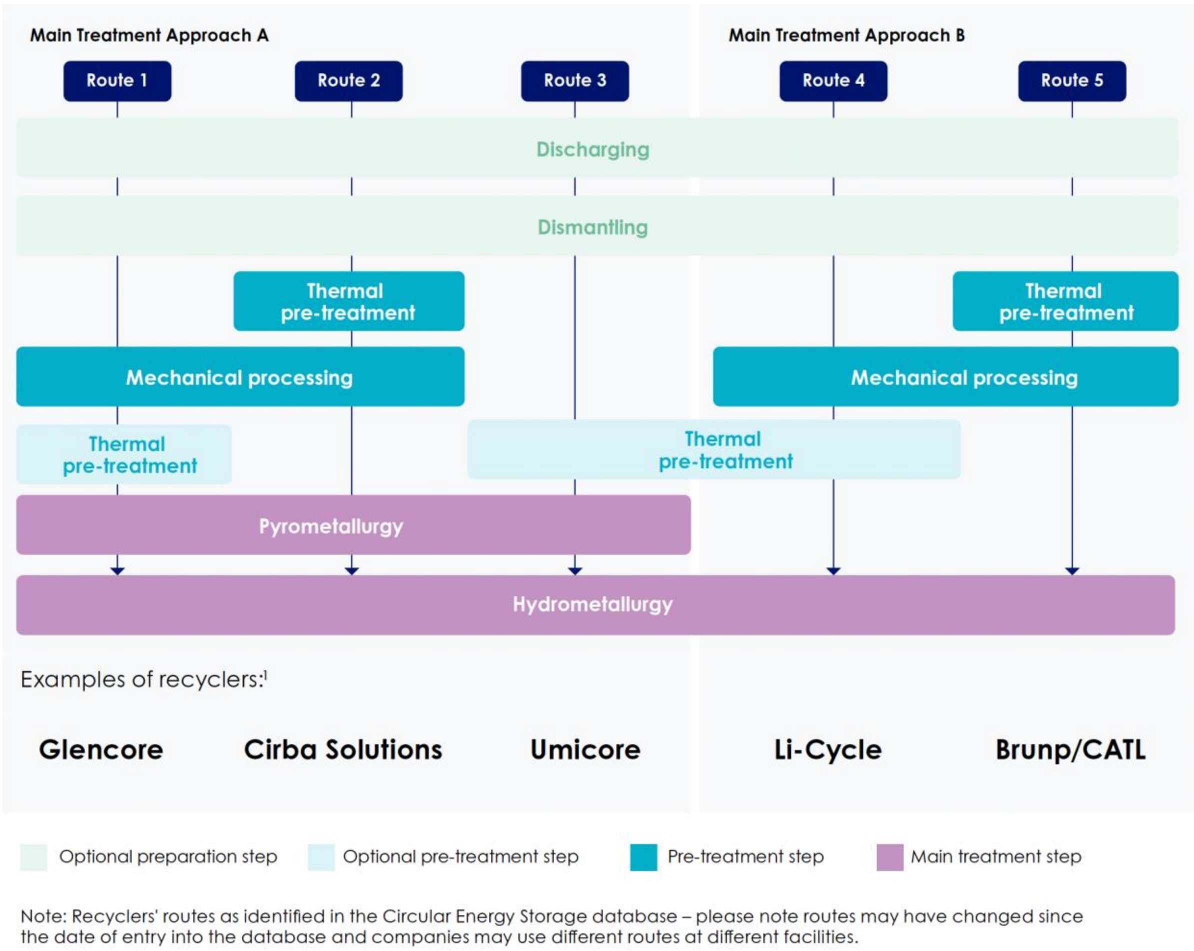
The economics of second-life battery storage depend on the cost of the repurposed system compared with purchase of new battery storage. The reduction of technical testing costs enabled by the battery passport could lead to an increase in used EV batteries going into a second life application as this supports their economic competitiveness compared to new batteries. However, cheaper first life batteries, due to new battery technologies and chemistries, can present a potential challenge. In addition, automotive OEMs collecting used EV batteries may favor recycling over 2nd life application to recover the valuable raw materials, especially for NMC and NCA batteries during times of high commodity prices. While the costs for repurposing of batteries are estimated to remain competitive in 2030 (around ~60% of the cost of a new battery[12]), a combination of reduced lifetime for second use (vs new batteries) and potential rapid reduction in new battery costs creates uncertainties for the economic competitiveness of second life batteries.

4.1.5 DPP use case 2: Increase recovery rate of critical raw materials at EV battery end of life

4.1.5.1 Current situation

Battery recycling presents a crucial opportunity to recover high-grade metals and other materials from used batteries (such as copper, nickel, manganese, cobalt and lithium). The battery recycling sector is constantly evolving due to technological advances, changing stakeholder engagement and changing market dynamics. Lithium-Ion Battery (LIB) recycling processes typically involve a multi-step approach which can be categorized into three distinct phases: 1) Preparation, 2) Pre-treatment, and 3) Main Treatment. In 2023, SYSTEMIQ published a thorough analysis of recycling routes, which demonstrates the complexity and the large variety of industrial practices. Five distinct and representative industrial approaches for LIB recycling have been identified as represented in Figure 9. The suitability of the main treatment approach varies depending on the battery chemistry. Pyrometallurgical recycling dominates today, while hydrometallurgical is predicted to gain market share due to the higher recovery rates of materials that can be achieved.

Figure 9 - Main recycling routes identified for Lithium-ion battery

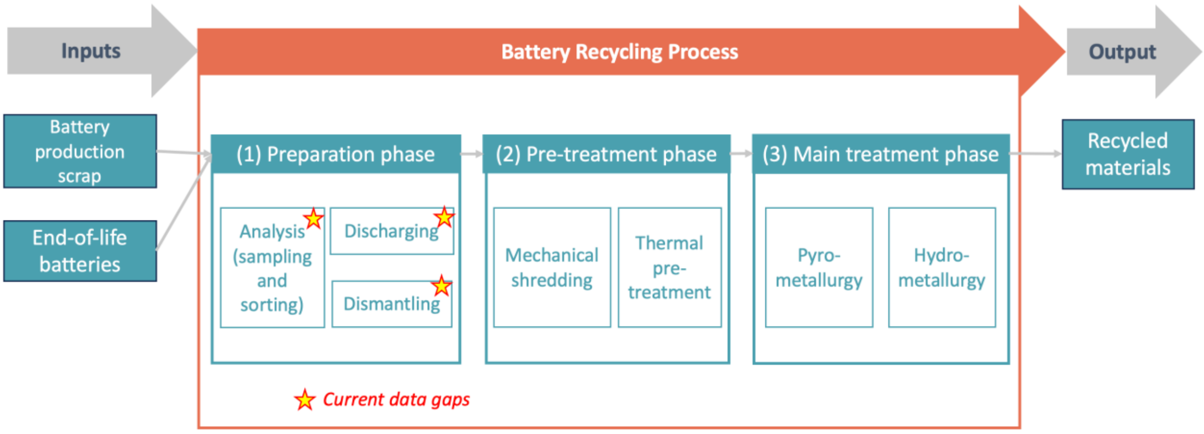


Source: SYSTEMIQ (2023) Advancing sustainable battery recycling: towards a circular battery system.

The battery recyclers we spoke to use several of the routes illustrated in Figure 9. For example, Li-Cycle, with their 'Spoke and Refine' technologies[23], do not need to discharge and dismantle the battery packs which are sent directly to the mechanical shredder after sampling and sorting. Some of the final stages to refine the black mass[24] and other materials (pyrometallurgy or hydrometallurgy) may be subcontracted[25]. In addition, for many recycling companies, not all stages of the recycling process take place in the same location, in order to optimize the cost of the main treatment due to the current low volume of the market.

Given this complexity, we mapped the main process steps of EV LIB recycling in Figure 10 and indicated where the current data gaps occur. The main steps of the battery recycling process are also briefly described below.

Figure 10 - Overview of battery recycling process and current data gaps



Materials input to the recycling process comes from two main sources: battery manufacturing scrap or from end-of-life batteries (electric vehicles and energy storage). As mentioned previously, battery manufacturing waste is currently the main feedstock in the recycling process, but end-of life batteries are expected to account for the vast majority of input by 2040[26]. The used batteries, including the complete battery pack and the BMS, are shipped to the recycling facility. As the responsibility to ensure collection and treatment of used batteries lies with automotive OEMs or battery manufacturers, recyclers have generally signed contracts with these players to process end-of-life batteries.

1. **Preparation phase** – this includes steps to ensure safe and efficient further treatment.
   a. **Analysis (sampling and sorting)**
   On arrival at the facility gate, each battery is recorded with an internal serial number to ensure traceability throughout the process. This step includes a visual inspection to check for deterioration or damage. Following this, batteries are sorted based on their state of health and chemistry. If no or limited information is available, sampling and state of health testing is undertaken. Based on the results, batteries with highly deteriorated state of health are processed as a priority, to limit the risk of accident.

[23] https://li-cycle.com/technology/
[24] Black mass is a fine powder containing the valuable cathode and anode materials (mainly lithium, cobalt, nickel and manganese). Its composition can differ significantly between different manufacturers depending on the chemistry used in the battery.
[25] https://www.stenarecycling.com/what-we-offer/material-recycling/batteries/
[26] 'Battery recycling takes the driver's seat', McKinsey, March 2023. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-recycling-takes-the-drivers-seat

   b. **Discharging**. When batteries arrive at the recycling facility, they must be discharged, to ensure their safe handling by technicians and to mitigate the fire risks due to high voltage and flammable constituents. There are two common industrial practices for battery deactivation: 1) discharge of the battery by connecting it to the local electrical grid; and 2) immersion in a salted solution. Ideally, deep discharge should be available via the BMS. However, for most recyclers, access to the BMS is not possible due to the protection of proprietary systems held by automotive OEMs.
   c. **Dismantling**. As the most valuable materials are contained within the battery cells, packs are often disassembled to either the module or cell level to facilitate more targeted recovery of these materials. Due to the large variety of battery design, this task is undertaken manually by trained technicians. Even when discharged, battery packs can still hold residual power that pose electrification risk to workers. Thus, the dismantling is a time-consuming step due to the regular voltage checks of battery components. The battery components are also sorted depending on battery chemistry, to enable batch sequencing treatment in the next steps. As part of a consortium meeting, the CIRPASS team had the opportunity to visit the Pollini Group's vehicle dismantling facility in Italy, and we witnessed the time-consuming process of dismantling a battery pack (cf. Figure 11).

Figure 11 – Disassembly of a battery pack at Pollini Group's vehicle dismantling facility in Italy

2. **Pre-treatment phase -** this involves activities to optimize feedstock for refinement in the main treatment phase:
   a. **Mechanical processing** typically involves mechanical shredding under specific environmental conditions (e.g. nitrogen gas with low oxygen) to avoid inflammation. Components are crushed into pieces a few centimeters in diameter. The outcome is a mix of plastic, metals (copper and aluminum) and black mass, which are further separated into various material categories in order that these can be efficiently recycled.
   b. **Thermal pre-treatment** is used to treat either the battery cells or the black mass output from the shredding. This is commonly done through a pyrolysis process. The aim is to avoid contamination later in the recycling process and, importantly, to liberate the active materials in the electrode.
3. **Main treatment phase** – this includes activities to separate the shredded materials and refine them into secondary raw materials. There are two common processes:

a. **Pyrometallurgy.** This is a well-established industrial process for metal extraction and purification. Metal extraction is performed by heating the shredded battery materials and black mass at high temperature, producing a metallic alloy, slag and gases. Additional processes of the alloy and slag (such as hydrometallurgy) are required to refine them into secondary raw materials.
b. **Hydrometallurgy.** This enables recovery of metals via chemical processes.

Pyrometallurgy can accept both intact cells/modules/packs and black mass, affording flexibility in the choice of pre-treatment method. In contrast, hydrometallurgy can only accept black mass or metal alloys, meaning that mechanical shredding and/or pyrometallurgy are essential.

When we discussed these processes with battery recyclers, we identified the following **current data gaps**:

- **Discharge status.** An important part of the recycling process is the discharge of batteries. In order to carry out a deep discharge of batteries, which makes the recycling process as safe and time efficient as possible, recycling operators should be given access to parts of the battery management system (BMS), or provided with alternative ways to access information on the state of discharge.
- **Dismantling** is essentially a labor-intensive and time-consuming process due to the high variance of battery pack designs. The wide range of battery models and chemical compositions available on the market, as well as the lack of access to dismantling manuals, necessitate a manual disassembly and sorting process carried out by trained technicians.
- **Information on battery composition.** As mentioned previously, battery chemistries vary from one EV application to another and are still evolving. Such information is essential to ensure high process efficiency and thus high recovery rates of valuable materials. Today, recyclers obtain this information either from publicly available documents, such as MDSD (Material Safety Data Sheets), or from waste battery sellers (especially for pre-consumer waste) and sampling, which typically involves paying a fee.

To fill the current data gaps, the recycling companies are building their own IT system in which they identify the used batteries with their characteristics (composition, dismantling instructions, etc.) based on regular sample tests. Access to the attributes of the battery's passport data could fill in these gaps and improve several stages in the recycling process.

4.1.5.2 Potential improvements made possible by the use of a DPP

The potential improvements of the battery recycling process enabled through the battery passport are summarized in Table 4. The potential improvements arise mainly due to information availability in the pre-treatment steps.

Table 4 – Potential improvement of battery recycling process enabled by a DPP

DPP data attributes	**Required per Battery Regulation?** Yes/No (granularity level[27])	Potential improvements
Unique identification and QR code	Yes (Item)	- Eliminate the need to build an internal identification system for traceability
Battery composition: - Battery chemistry - Battery weight - Name and weight of cathode, anode and electrolyte materials	Yes - (Model) - (Model) - (Item)	- Eliminate the need for sampling, pre-analysis, or manual information exchanges. - Improve "process stability" for the treatment phase through effective sorting, leading to more homogenous feed inputs. This also helps to achieve maximum material recovery of the process, as losses are reduced. - Facilitate intermediate output specification (black mass) and mass balance measurement.
Dismantling information, including: - Exploded diagrams of the battery system/pack showing the location of battery cells - Disassembly sequences - Type and number of fastening techniques to be unlocked - Tools required for disassembly - Warnings if risk of damaging parts exists - Number of cells used and layout	Yes (Model)	- Optimize battery dismantling process. Instructions at the model-based level is sufficient from the recycler perspective. The more this is presented in a graphical form, the better, as this will be used by workers on-site and for their training. - Possibility to automate the battery dismantling process. This requires machine-readable format and standardized methods to document disassembly processes, enabling the set-up of automated dismantling equipment. In addition, it is important to note that the disassembly sequence depends on the technology used for disassembly, so a disassembly sequence for a manual operation will be different from an automated disassembly sequence (by a robotic cell for example). The exploded diagram and fastening technique are used to derive the disassembly sequence according to the technology used.
State of battery discharge (including status of deactivation) in addition to the state of charge[28] (SOC)	No (item)	- Improve operational safety for the workers dealing with storage and pre-processing (e.g. it can improve process efficiency when no deactivation is required, and upfront sorting of the batteries can be undertaken).

[27] Model versus individual battery (i.e. item).
[28] State of Charge is an information requirement in the EU Battery Regulation at the item level.

4.1.5.3 Benefits and barriers

Information made available via the battery passport (detailed composition, dismantling information) leads to the following benefits.

- **Economic**
  Decreasing pre-treatment costs, while improving material recovery rates, increases the overall business case for recycling. The Battery Pass consortium estimated a potential increase of profitability up to 20%.
    - **Increase in material recovery rates** - due to process stability, enabling operators to reach the maximum material recovery of the process, higher quality (e.g. purity) and to reduce process losses.
    - **Reduction of sampling costs**
    - **Reduction of dismantling costs** - which can be further reduced through automated dismantling process
    - **Reduction of treatment costs**
      For example, the turn-around time until secondary material is available is reduced, as sampling and dismantling processes can be optimized. The improved feed-in process enables optimization of the process parameters and prevention of additional processing steps, which would be required to remove contaminants.
- **Qualitative**
    - **Improvement of worker safety** dealing with storage and deactivation of the battery.

It is important to note that the economic feasibility of battery recycling processes is currently determined by the potential to recover valuable metals, such as cobalt, manganese and nickel[29]. NCA and NMC batteries are the most economically attractive to recycle, as they contain more cobalt and nickel[30]. The current market trends show that future battery generations will use lower amounts of these critical materials (e.g. increase of LFP batteries), which will reduce the overall value for recyclers and, therefore, may pose challenges for the financial viability of the recycling processes. For example, based on average market values in 2023, LFP cells were 32% cheaper than NMC cells[31]. Therefore, economy of scale and industrialization (through automatization) will be key elements to enable a cost-effective business model for battery recycling.

4.1.6 The perspective of automotive OEMs and battery producers

As part of the stakeholder consultation, we also discussed the benefits and barriers perceived by battery DPP creators. The main insights obtained are summarized in the form of actionable recommendations.

- **Provide further guidance on the economic operator responsible for battery DPP creation**
    - Depending on the types of batteries and their application, automotive OEMs or battery producers will be responsible for creating the DPP, meaning:
        - generation of a unique identifier for each battery, which is linked to the QR code provided on the battery, in order to make the battery passport accessible (EU Battery Regulation, Articles 65(3), 13(5) and (6));

[29] 'Accelerating Policy Action for Safe and Green Electric Vehicle Battery Recycling', World Economic Forum, Jun. 2023. https://www3.weforum.org/docs/WEF_Safe_Green_EV_Battery_Recycling_2023.pdf

[30] 'Material and Resource Requirements for the Energy Transition', Energy Transition Commission, July 2023. https://www.energy-transitions.org/publications/material-and-resource-energy-transition/

[31] BloombergNEF (2023) Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh. Available online via https://about.bnef.com/blog/lithium-ion-battery-pack-prices-hit-record-low-of-139-kwh/#:~:text=These%20packs%20and%20cells%20had,(NMC)%20cells%20in%202023

- ensuring that the information in the battery passport is accurate, complete and up to date (EU Battery Regulation, Article 65(4)); and
- storing of the data included in the battery passport (EU Battery Regulation, Article 65a(c)).

- Regarding the question of who shall be responsible for DPP creation, the text within the Battery Regulation is clear: the responsibility lies with the economic operator making the battery available or placing it on the market, including on-line placing on the market, or putting it into service (EU Battery Regulation, Article 2(19)). However, when we discussed this with external stakeholders, it appears that the interpretation for EV batteries is still subject to debate. The Battery Pass consortium provided some guidance on its interpretation for the different types of batteries[32]. To ensure consistent implementation of the Battery DPP, we strongly recommend the development of guidance documents outlining good practice on how to fulfil the obligations, similar to what is done for other EU regulations (e.g. REACH guidance documents[33]).

- **Ensure the harmonization of DPP data assessment methods to facilitate data collection from the supply chain**
  - To collect data from the supply chain and facilitate compliance with laws and regulations (e.g. recycled content, report on declarable substances, etc.), all global automotive OEMs are using the IMDS system (International Material Data System). Established in 2000, around 16 billion euros have been invested to develop and maintain the system, and to increase the data input quality. Nevertheless, even where contractual terms require the delivery of product information with the supply of parts, OEMs face difficulties to obtain reliable data.
  - Automotive OEMs and battery manufacturers see the potential benefit of DPPs as an enabler to facilitate data collection from the supply chain and as a means to communicate more transparently about the sustainability of their products (e.g. recycled content, carbon footprint, due diligence report). For example, there is a high interest in product carbon footprint to facilitate reporting of CO2 emissions at corporate level, and compliance with the EU Corporate Sustainability Reporting Directive (CSRD)[34].
  - To unlock this potential benefit, DPP data assessment methods must be harmonized across product categories, to facilitate the data reporting of intermediate product manufacturers supplying multiple sectors.

- **Develop an incentive mechanism to ensure DPP data sharing with high quality**
  - There is an increasing economic incentive for automotive OEMs and battery producers to collaborate more closely with life extension actors or end-of-life actors in order to fully capture the value of the battery through 2nd life application and to ensure the stability of their supply chains through use of locally recycled materials. This is illustrated by strategic partnerships established between value chain actors or by vertical integration[35]. For example, in 2021, Volkswagen commissioned a pilot recycling plant in Salzgitter (Germany), which can process 3,000 batteries a year and aims to achieve a recycling rate of 90%. In 2023, Mercedes-Benz agreed to cooperate with CATL subsidiary Brunp, based in China, to recycle electric car batteries. General Motors (GM) has entered into partnerships with Li-

32 https://thebatterypass.eu/assets/images/content-guidance/pdf/2023_Battery_Passport_Content_Guidance.pdf

33 https://echa.europa.eu/guidance-documents/guidance-on-reach

34 https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en

35 See https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-recycling-takes-the-drivers-seat and https://www.adlittle.com/en/insights/viewpoints/european-battery-recycling-emerging-cross-industry-convergence .

Cycle and Cirba Solutions. The development of battery swapping stations could also become a game changer for EV battery management processes currently owned by automotive OEMs. For example, the global battery manufacturer CATL has offered its battery-as-a-service model in China since 2022 and in Europe through its partner NIO Power, since 2023.

- According to Annex XIII of the EU Battery Regulation, detailed composition (including materials used in the cathode, anode and electrolyte) “shall be made accessible only to interested persons and the Commission”. Due to the close collaboration between value chain actors, battery manufacturers see high risk of disclosing confidential information (detailed composition of electrolyte and cathode) to competition, since other battery manufacturers also run recycling plants. The current uncertainty on the mechanism to access DPP data and who will be “interested persons” is seen as a key issue for battery DPP deployment and as a barrier to data quality.
- Given the added costs for DPP creators involved in developing the infrastructure to store and maintain product data, as well as enabling data access by third parties, it is important to consider an incentive mechanism as part of the DPP system to ensure access to accurate data.

4.2 Electronics

Today, electronics have become an important part of our daily life. By supporting the deployment of digital technologies, they are changing peoples' lives - from the way we communicate to how we live and work. This change is also accompanied with a rapid increase in demand for complex electronic equipment, along with increased demand for the critical raw materials which are currently used at an exponential and unsustainable rate. This high demand, coupled with short product lifecycles, has also resulted in the fastest growing waste stream in the EU (and the world), less than half of which is recycled in the EU. As part of the Circular Economy Action Plan, the European Commission has identified electronics and ICT as one of the priority sectors for action, including measures to promote longer product lifetimes and repairability, and to encourage the take-back of electronic products for recycling.

ICT products, other electronics and energy-related products are indeed mentioned among the envisaged priority product groups of the Commission's first working plan for the design of ESPR Delegated Acts. However, the DRAFT ESPR also mentions in Article 8(4) that the Commission is authorized to exempt product groups from the requirement to have a DPP where other Union law includes a system for the digital provision of information related to the ESPR objectives. Because this is applicable to the EPREL registry[36] (European Product Registry for Energy Labelling), electronics will probably not be among the first sectors for Delegated Acts in the short term. However, the ESPR is still relevant for electronics through its general push for circularity and product data transparency. With this perspective, the increased availability of data is expected to reduce the costs of circular business models that support the extension of the life of electronic products and facilitate the recovery of critical materials.

This section first defines the product categories covered by the electronics sector in line with legislation and the potential content of a DPP. We then provide a brief overview of the main characteristics of the electronics value chain including the current circular economy actions. Third, we describe two DPP use cases: the refurbishment of smartphones and the recycling of small consumer electronics at the end of their life. Finally, we summarize the feedback from electronics OEMs and distributors on the creation and use of DPPs.

To assess qualitatively the DPP use cases, we consulted a series of external expert stakeholders[37] involved in the electronics value chain.

4.2.1 Electrical and Electronic Equipment (EEE)

As part of the Circular Economy Action Plan[38], electronics and ICT are considered as one of the key value chains prioritized for action by the EU Commission, but there is currently no specific definition of the product categories to be considered in this value chain. Electrical and electronic equipment (EEE) encompasses a large spectrum of products that vary in size, weight and material

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:98:FIN

[36] Since 1st January 2019, suppliers (manufacturers, importers or authorised representatives established in the EU) must register their products in the European Product Registry for Energy Labelling (EPREL). The database primarily provides information on a product's energy use. In addition, it also provides information about its possible water consumption, noise emission, extension of the warranty, availability of spare parts, duration, and product support.

[37] Apple, Siemens, Dell, Miele, Rockwell Automation, AB S.A., Refurbed, Rebuy, BackMarket, Recupel, Treee, Stena Recycling.

[38]

composition. It includes devices such as mobile phones, computers, televisions, fridges, household appliances and lamps.

To describe the type of products considered as part of the electronics sector, we decided to use the Ecodesign Directive 2009/125/EC[39] as a baseline. This directive establishes a framework to set mandatory ecodesign requirements for energy-using and energy-related products sold in the EU. The ecodesign requirements for individual product groups are created under this directive in a process coordinated by the European Commission. The EU legislation on ecodesign is applicable to 32 product groups (which include tires) and 16 of these product groups require an energy label. The following table provides an overview the product categories that can be considered part of the electronics sector, illustrating the wide spectrum of products.

Table 5 - List of product categories covered by the EU Ecodesign Directive 2009/125/EC

Categories	Product categories
Lighting	Lighting
Heaters	Solid fuel local space heaters
	Space and water heaters
	Solid fuel boilers
	Air heating and cooling products
Refrigeration	Fridges and freezers
	Professional refrigerators
	Refrigerators with a direct sales function
Vacuum cleaners	Vacuum cleaners
Washing machines and driers	Washing machines
	Tumble driers
Air conditioners and fans	Air conditioners and comfort fans
	Industrial fans
	Ventilation units
	Air heating and cooling products
Electronic displays and TV boxes	Televisions
	Set-top boxes
Kitchen appliances	Cooking appliances
	Dishwashers
Pumps	Water pumps
	Circulators
Transformers and converters	Power transformers
	External power supplies

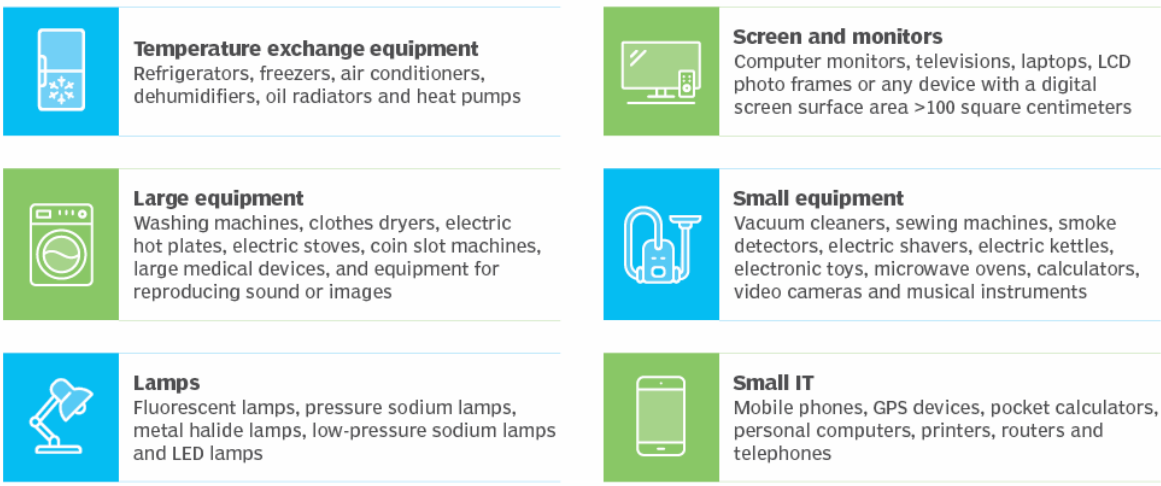
[39] https://eur-lex.europa.eu/legal-content/FR/ALL/?uri=celex:32009L0125

Computers and servers	Computers and small servers Servers and data storage products
Mobile phones, cordless phones and tablets	Mobile phones, cordless phones and tablets
Imaging equipment	Imaging Equipment
Game consoles	Game consoles
Electric motors	Electric motors
Off mode, standby and networked standby	Off mode, standby and networked standby Including also motor-operated building elements, motor-operated adjustable furniture and products using a low-voltage external power supply (LV-EPS)
Welding equipment	Welding equipment

Note: Information on energy savings, energy labelling and ecodesign requirements can be found on each product by clicking on the hyperlink.

It is important to note that the categorization approach adopted for end-of-life treatment is very different and is based on the WEEE Directive 2012/19/EU[40]. The WEEE Directive sets requirements and targets to improve the collection and treatment of WEEE which stands for Waste of Electrical and Electronic Equipment. This directive also provides a harmonized description of EEE waste in its Annex III, which are classified into six product categories (see details in Figure 12). The classification has been designed to facilitate the treatment of EEE at the end-of-life, considering aspects such as product size and content of hazardous substances.

Figure 12 - Product categories according to the WEEE directive



Source: https://www.techtarget.com/searchdatacenter/definition/Waste-Electrical-and-Electronic-Equipment-Regulation-WEEE

[40] https://eur-lex.europa.eu/eli/dir/2012/19/2018-07-04.

In terms of **product composition**, complex EEE can contain up to 60 elements from the periodic table. Common materials used in EEE include:

- **Precious metals** such as copper, gold, silver.
- **Critical raw materials[41] (CRM)** (including rare-earth elements) - for example, gallium and silicon metal used for integrated circuits, neodymium and dysprosium for magnets in small motors and hard drives, and tantalum for capacitors.
- **Plastics -** especially engineering plastics such as Acrylonitrile Butadiene Styrene (ABS), Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) and High Impact Polystyrene (HIPS).

Figure 13 presents the average composition of four typical EEE products. From the composition graphs, it can be concluded that the most valuable materials and components are used in high-tech devices such as smartphones, when compared to appliance products such as vacuum cleaners and washing machines.

Figure 13 - Average composition of smartphones, liquid crystal display (LCD) televisions, vacuum cleaners and washing machines, per cent by weight.

[41] The list of raw materials considered as critical by the EU Commission has been revised several times since 2011. The most recent list is available online via this link https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en.

Source: Bacher, J., Dams, Y., Duhoux, T., Deng, Y., Teittinen, T., & Mortensen, L. F. (2020). Electronic products and obsolescence in a circular economy. European Topic Centre Waste and Materials in a Green Economy. https://www.eionet.europa.eu/etcs/etc-wmge/products/electronics-and-obsolescence-in-a-circular-economy

4.2.2 Digital Product Passport

For the reasons explained above, there is currently no indication of the content of the Digital Product Passport for electronics or which product categories may be prioritized for a DPP in the initial stages. Until the publication of the DRAFT ESPR, the EU product ecodesign approach has mainly focused on promoting:

- safe products via regulations on hazardous substances such as REACH and RoHS[42] and;
- energy-efficiency during use via Energy Labelling[43] and European Product Registry for Energy Labelling (EPREL) database.

Aspects related to resource efficiency and lifetime extension aspects (e.g. recycled content, recyclability, repairability, spare parts, etc.) have been only considered to a limited extent during the last few years. For example, ecodesign requirements to further enhance reparability and recyclability were defined for 10 product categories in 2019 and only started to apply in 2021[44]. As the approach to define ecodesign requirements has been structured around the 31 product categories, we may expect that, if applicable, the definition of DPP information requirements by Delegated Acts will follow a similar path with some horizontal data attributes.

An initial set of information requirements for the electronics sector (see Table 6) was proposed in an earlier report, by extracting requirements from existing and upcoming legislative texts as well as those used in a large number of currently proposed DPP-related initiatives (see report D2.1 “Deriving an initial set of information requirements to serve as a basis for future discussions[5]. The list of potential information requirements was used as a baseline when exploring the potential benefits of the DPP in the selected use cases. In addition, whereas several initiatives are working on the development of DPPs for the electronics sector [10]), there is currently no solution implemented beyond prototyping and piloting.

Table 6 - Summary of findings on current data used in the electronics sector in initiatives (U) or in legislation (M)

Information Categories	DPP data attributes	Mandatory by legislation (M) / Used by DPP-related initiatives (U)
Functional and technical specifications	Product information sheet on energy consumption & performance	M
	Technical documentation with product-model specific information e.g. test results, measurement method, etc. (Energy Labelling Regulation)	M
	CE-marking	M
	Disposal, return and collection scheme information	M

[42] “RoHS” Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment. The RoHS Directive identifies 10 restricted substances, including lead, cadmium and mercury. As with the WEEE Directive, the RoHS Directive seeks to protect the environment and public health.
[43] “Energy Labelling” Regulation (EU) 2017/1369 https://eur-lex.europa.eu/eli/reg/2017/1369/oj .
[44] https://energy.ec.europa.eu/topics/energy-efficiency/energy-label-and-ecodesign/regulation-laying-down-ecodesign-requirements-1-october-2019_en

Material and composition information	Information on different materials and location of dangerous substances and mixtures (WEEE)	M
	Substances of concern: name, location within the product, concentration at the level of the product, main components or spare parts	M
	Hazardous substances (REACH, POP, CLP, Ecodesign, WEEE)	M
	Individual material declaration	U
	Full material composition	U
	Recycled content	U
	Recycling oriented information	U
Product design and service	Use, repair information (maintenance, spare parts, updates)	M
	Repair information incl. disassembly instructions, component map, etc. (Ecodesign)	M
	Disassembly instructions (WEEE)	M
	Resale options, end-of-life options, service availability for waste handling	U
	Instructions for safe use	M
	User manuals, instructions, warnings or safety information	M
	Information relevant for disassembly	M
Usage history	Usage data (purchase date, use cycles, etc.)	U
Repair and reuse history	Repair data (date, exchanged parts, costs, images)	U
Indicators	Circularity indicator (repairability, reuse, recycling index), environmental and social impact indicator, Product Environmental Footprint, Life Cycle Assessment	U / M[45]
Certification	Responsibility supply chain certifications	U

Note: product identification and company information are not listed in this table but are referred to in report D2.1 "Deriving an initial set of information requirements to serve as a basis for future discussion"

4.2.3 Electronics value chain and circular economy actions

The electronics value chain is complex, highly fragmented and globally distributed. It is characterized by a high number of hardware components, interchangeable parts, many unique

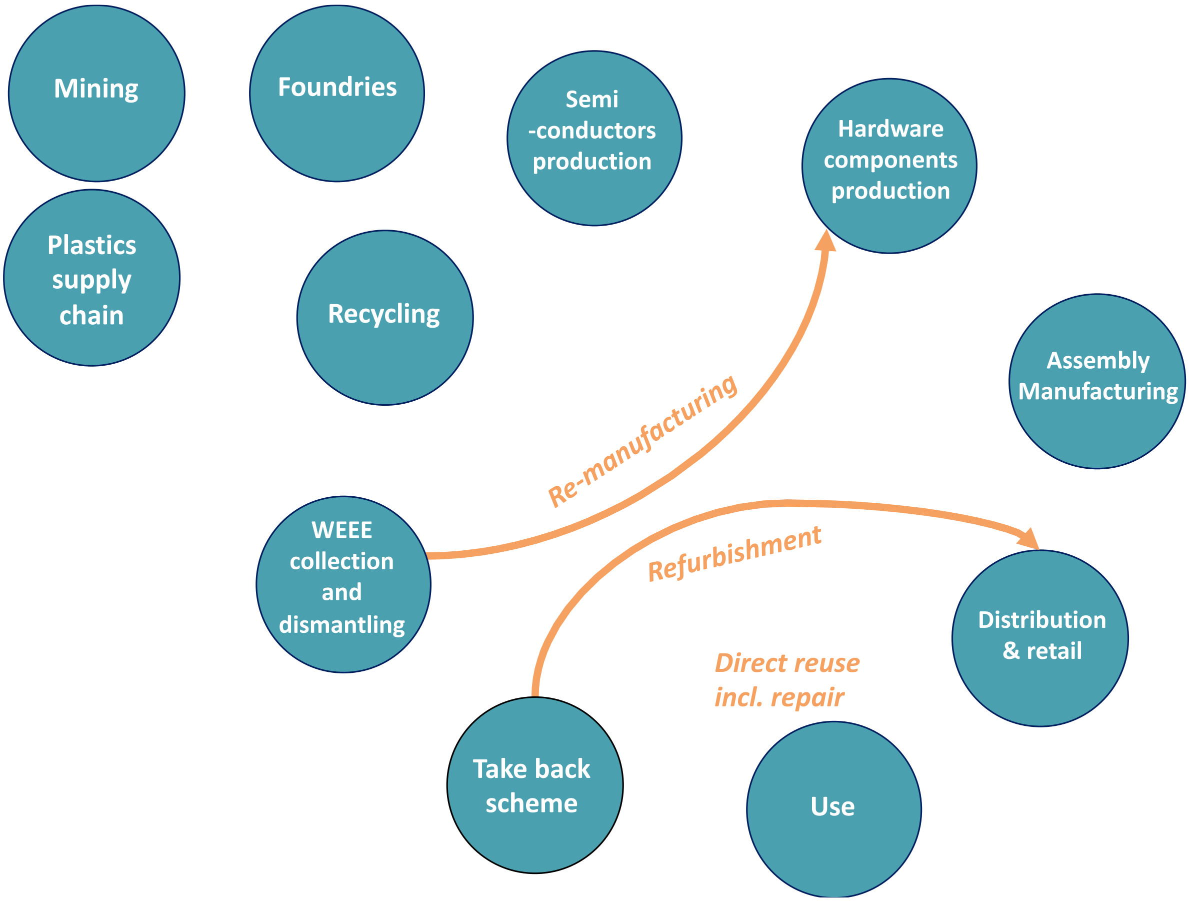
[45] For smartphones and tablets, additional ecodesign requirements and information related to the repairability on the Energy Labelling will become mandatory by June 2025. For example, obligation for producers to make critical spare parts available to repairers within 5-10 working days, and until 7 years after the end of sales of the product model on the EU market ; durability of batteries – batteries should withstand at least 800 cycles of charge and discharge while retaining at least 80% of their initial capacity. For more details, see https://energy-efficient-products.ec.europa.eu/ecodesign-and-energy-label/product-list/smartphones-and-tablets_en.

products, and software operating systems. To illustrate this, we describe below the key steps of the electronics value chain (see Figure 14).

Firstly, the value chain commences with the mining and extraction of raw materials to provide inputs to foundries for semiconductor components. China is one of the world's largest suppliers of raw materials for electronic products. Secondly and thirdly, the next steps in the value chain are the manufacturing of hardware components and assembly of these in devices. Both of these processes take place mostly outside the EU, and specifically in Asia. China, South Korea, Malaysia, Singapore, and Taiwan are the main economies involved in these value chain steps. The electronic OEMs and brands (e.g. Apple, Samsung, Dell, Siemens, etc.) are typically responsible for the design of new products, supply chain management (including component suppliers and manufacturing assembly via third parties) and the marketing of new products. For example, for the iPhone, Apple buys many of the hardware components such as memory chips, modems, camera modules, microphones, liquid crystal display, etc. from more than 200 suppliers and sells them to one of its contracted manufacturing assembly companies based in China[46]. In addition to the hardware manufacturing, electronic equipment requires software to operate and control the device, which typically involves other actors in the value chain. Then, OEMs and brands sell the electronic to customers or consumers via their own distribution channels and/or sells them through various physical and online channels (distributors, retailers, telecommunication companies). Customers or consumers use the EEE until they decide to upgrade or stop using them, at which point they reach the end of their first use life.

[46] Barboza D. An iPhone's Journey, From the Factory Floor to the Retail Store. The New York Times, 29/12/2016. https://www.nytimes.com/2016/12/29/technology/iphone-china-apple-stores.html

Figure 14 - Electronics value chain and circular economy actions



From that point, EEE can enter **several circular economy loops** to retain and optimize their intrinsic value through reuse and refurbishment, remanufacturing and finally recycling.

- ***Product lifetime extension***

  Circular business models such as product repair and refurbishment, second-hand market and rental services support the lifetime extension of EEE. While the initial product design is important (e.g. design with higher quality materials, design for disassembly and upgradability), buy-in from consumers and availability of efficient reverse logistics infrastructure are also necessary to enable the extension of product lifetime. For example, at present, there are limited incentives to encourage consumers to return their mobile phone once they no longer use them, which is a key challenge as most used smartphones remain unused in households. Some good practices are emerging, including offering discounts for new phones when the old one is returned, or providing other forms of financial compensation.

- ***Harvesting hardware components and recovery of high value materials***

  At final end of life, the residual value of EEE can be extracted by harvesting hardware components and reusing them in other electronic products (remanufacturing[47]) and by recovering highly valuable materials. The end-of-life process is typically structured in the three main steps of collection, disassembly and recycling. In the EU, dedicated systems are in place to collect and transport WEEE for the purpose of re-use, recycling and recovery. During the collection process, WEEE is funneled from local collection points and collection facilities (e.g. retailers or municipalities), sometimes via sorting centers, to treatment operators.

The electronics sector has a **significant environmental impact** in terms of resources consumption, GHG emissions and electronic waste (e-waste), which are all increasing vastly due to the rapid growth in sales worldwide. Electrical and electronic equipment is the fastest growing waste stream in the EU, with current annual growth rates of 3-5%. Europe produces the most e-waste per capita worldwide with around 11kg per person/year[48]. In addition, it is estimated that less than 50% of electronic waste is recycled in the EU, resulting in lost value in raw materials of ca. €13 billion/year (e.g. gold, tungsten, gallium, tantalum, silicon metals)[49]. This value is lost when fully or partially functional products are discarded because they are not reparable, the battery cannot be replaced, the software is no longer supported, or materials incorporated in devices are not recovered.

ICT devices (smartphones, tablets and laptops) are of particular concern due to the increase in sales volumes, their high production emissions, and their intensive use of critical and valuable raw materials. Around 80% of a smartphone's lifetime GHG emissions results from its production, transport and sale, rather than its actual use[49]. Increasing the lifespan of all smartphones in the EU by 1 year would reduce emissions equivalent to taking 1 million cars off the roads (in emissions)[49]. Furthermore, according to the Eurobarometer[50], about two in three Europeans would like to keep using their current digital devices for longer, providing its performance is not significantly affected.

To address these environmental challenges, the European Commission launched the '**Circular Electronics Initiative'** (CEI)[51] with the objectives to 1) extend the lifetime of electronic devices 2) to prevent premature obsolescence and 3) to promote repair, recycling and efficient use of resources. CEI includes, among others, the following actions:

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https://circulareconomy.europa.eu/platform/sites/default/files/cei_260521kl_002.pdf

https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-circular-electronics

[47] Common EEE remanufacturing practices include printers, toner cartridges, ECUs (Engine Control Units) and electric motors and drives. More examples are available on this website of European Remanufacturing Network (see https://www.remanufacturing.eu/case-study-tool.php).

[48] Eurostat for the year 2021. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics_-_electrical_and_electronic_equipment&oldid=556612#Electrical_and_electronic_equipment_.28EEE.29_put_on_the_market_and_WEEE_processed_in_the_EU

[49] Lorz (2021) Insights about the EU Circular Electronics Initiative and take-back study.

[50] Special Eurobarometer 503, January 2020.

[51]

- regulatory measures for electronics and ICT including mobile phones, tablets and laptops under the Ecodesign Directive, so that devices are designed for energy efficiency and durability, reparability, upgradability, maintenance, reuse and recycling;
- implementation of the 'right to repair', including a right to update obsolete software;
- EU-wide take back schemes to return or sell old ICT devices (mobile phones, tablets, etc.);
- review of EU rules on the restriction of hazardous substances in electrical and electronic equipment.

When considering the current trends and challenges of the electronics sector, **smartphone refurbishment and recycling of small consumer electronics plays a crucial role** in enhancing the circularity of the electronics value chain.

- The life extension of electronic systems, particularly by smartphone refurbishment, is a viable solution for maintaining and optimizing the intrinsic value of EEE. In some secondary markets, sales of refurbished smartphones have begun to outpace sales of new smartphones. However, there are concerns over the resulting reliability and, in some cases, the safety of such products.
- E-waste contains a complex mixture of materials, some of which are hazardous. These can cause major environmental and health problems if the discarded devices are not managed properly. Small consumer electronics (smartphones and LCD screen) also contain rare and expensive resources, including critical raw materials. Improving the collection, treatment and recycling of electronic devices at the end of their life can increase resource efficiency and contribute to the security of supply for critical raw materials, ultimately enhancing the EU's strategic autonomy.

Therefore, when discussing DPP use cases with external stakeholders, we focused on two DPP use cases:

- **DPP use case 3** describes the potential opportunity for the DPP to facilitate the evaluation of the remaining value of smartphones, and to support the development of a reliable and trustworthy refurbishment process.
- **DPP use case 4** describes how the DPP can provide potential benefits to electronics recyclers, increasing the recovery of valuable materials.

4.2.4 DPP use case 3: Increase volume of refurbished smartphones by improving the quality and transparency of the refurbishment process

4.2.4.1 Current situation

Refurbishment refers to the "actions carried out to prepare, clean, test, service and, where necessary, repair an object that is waste, in order to restore its performance or functionality within the intended use and range of performance originally conceived at the design stage at the time of its placing on the market" (Draft ESPR, Article 2 (18)). The smartphone refurbishment market is currently worth around €5.2 billion in Europe. Second-hand smartphones represent 10% of total smartphone sales in some countries (France, Germany) with an expected annual growth rate of around 10% in the coming years[52]. The refurbished mobile phone market has experienced extraordinary growth over the last decade due to a combination of several factors including, among others, rising costs of higher-end smartphones, consumer search for more budget-friendly choices, growing environmental awareness and increased acceptance of refurbished devices. As a consequence, aside from their new product sales, many electronics OEMs have seen an opportunity for another revenue stream and now sell their refurbished devices directly to consumers.

[52] https://www.eurefas.com/refurbishment_industry/

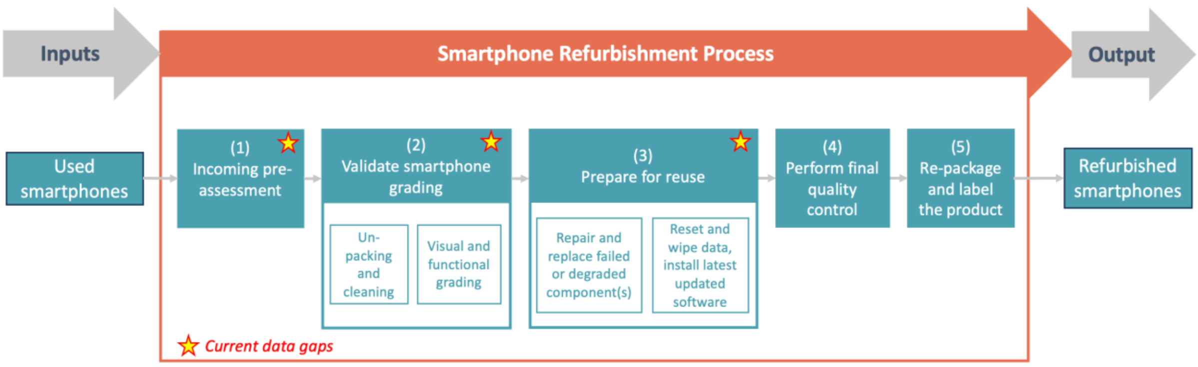
Online marketplaces have played a key role in the development of the refurbishment market by giving professional refurbishers (who are generally SMEs) access to a wider market and by channeling the supply of used smartphones. They act as an interface between buyers of refurbished smartphones, sellers of used devices and professional refurbishers. Although they do not handle any physical goods, they manage the communication between these actors and act as guarantors of quality and trust in refurbished devices by establishing a list of requirements for refurbishment processes and verifying that they are met.

The depth of refurbishment processes undertaken on used smartphones for resale has been found to vary depending upon the standards of the organization performing the refurbishment[53]. From the discussion we had with interviewed companies, some refurbishers may simply perform basic functional tests and device cleaning while others may engage in additional processing, such as battery and/or screen replacement and performance testing. There are two typical refurbishment routes that mobile phones can enter:

- ***OEM refurbishment process***. Used devices are returned by customers, either directly to the manufacturers or through retailers who have a direct agreement with the OEM (e.g. via trade-in program).
- ***Third-party non-OEM refurbishment process.*** This route includes a wide variety of origins and actors.
  The used devices may be purchased by refurbishers or online marketplaces directly from consumers, through websites or retail locations, collected from non-profit organizations as either working or non-working devices, or from a variety of smartphone insurance programs. This second refurbishment route is of particular interest for the DPP as third-party refurbishers face challenges to access information on the original device.

Taking into account this wide variability in approach, we summarize in Figure 15the main steps of a typical refurbishment process for a mobile phone. Current data gaps are also highlighted. Some steps may be handled by the same actor, or these may be subcontracted to others. For example, some online marketplaces (e.g. ReBuy) also operate the grading process and rely on a network of partners to repair the used smartphones when required.

Figure 15 - Overview of smartphone refurbishment process and current data gaps



1) **Pre-assess incoming devices**
   Online marketplaces, electronics OEMs or refurbishers typically offer the possibility for their customers (mostly end-consumers) to resell their used smartphones directly or via trade-in programmes. After answering a brief questionnaire, the customer receives a proposed selling

[53] D. A. Hazelwood and M. G. Pecht, "Life Extension of Electronic Products: A Case Study of Smartphones," in IEEE Access, vol. 9, pp. 144726-144739, 2021, doi: 10.1109/ACCESS.2021.3121733.

price and an associated grading of the device. If accepted, the customer ships the used smartphone to the refurbisher. Shipping costs are often included in the selling price.

2) **Validate smartphone grading**
   The grading process aims to validate the price to buy the used smartphone and associated grading, based on questionnaire inputs provided previously, and to verify if some repairs are required. Two aspects are evaluated during the process: aesthetic and functional grading whose rating (typically A to D) is based on the requirements of the refurbishment organization or established by the online marketplace. The grading process generally includes the following activities:
   - **Unpacking** and assignment of internal unique ID and QR codes for internal traceability.
   - **Cleaning** - which is done manually by trained professionals.
   - **Visual grading** - based on a physical inspection by a trained professional or by an optical testing machine. A rating level is assigned based on the identified scratches or other aesthetic degradations.
   - **Functional grading**. Such a step tests the device's functionality and identifies failed components or degraded components that need to be replaced (e.g. battery with a low state of health). This step is generally automated by robots which check typical functions such as microphone, speakers, the camera function, screen, bluetooth, etc.

   At the end of this process, the refurbisher can confirm to the seller the grading of the used smartphone. The grading process must be as efficient as possible so the seller of the used phone can be paid as soon as the smartphone grading is validated. The refurbishers interviewed told us that less than 5% of the received smartphones are rejected at this stage, and these are either sent back to the seller or dispatched for recycling (if the customer does not want to take it back).
3) **Prepare for reuse**
   - **Repair and replace failed or degraded component(s)**
     Failed components which were identified in the previous step are replaced. Some refurbishers may perform the replacement of selected parts, such as battery, screen replacement, casing, etc.
   - **Reset and wipe data, install latest updated software**
4) **Perform final quality control**
   This step is typically undertaken by trained professionals who perform a series of tests (visual and functional) to validate conformity with quality requirements.
5) **Re-package and label the product**
6) **Product enters the refurbished device marketplace**

During the interviews with representatives of online marketplaces and refurbishers, we identified the following **current data gaps and challenges**:

- **Lack of data on smartphone state of health and repair history** (e.g. replacement of components such as battery or screen, etc.)
  Today, when the refurbishers receive the used smartphones, it is an “electronic box without any information on its history”. Although functional tests can provide an evaluation of the performance at the present time, the degradation of electronic device performance is not a linear phenomenon (as discussed for batteries in section 4.1.4.1. For example, the replacement of the smartphone screen during its first life can give an indication of the history of the smartphone, either the presence of stressed events (e.g. impact on the screen or the smartphone being dropped) or a component fault. The more historic information is available, the easier it is to assess the state of health of the smartphone, its remaining useful life and potential risk of failure.
- **Lack of transparency on the refurbishment process**

The number of refurbishers who supply refurbished devices on online marketplaces can be very high, more than 100 suppliers for some platforms. The name of the refurbisher is generally not visible for the customer who buys the refurbished device. To ensure a level of quality and trust by their customers, online marketplaces have established a list of requirements (e.g. battery state of health >85%, memory erased) that each refurbisher must comply with in order to sell products on their marketplace, and grading criteria to evaluate the condition of the used smartphones. However, the lack of transparency in refurbishment operations makes it difficult for marketplaces to enforce and verify compliance with their process requirements. They usually carry out spot checks and mystery shopping as a form of quality assurance. They also work on data analysis to identify abnormal levels of device returns or quality complaints.

- **Limited access to repair instructions and part pairing**
  For most independent repairers, the best source of repair information is their internal database or repairer community platform, such as IFIXIT. Having access to the list of spare parts, disassembly and repair instructions are important to improve the efficiency of repair operations and to reduce the risk of failure. In addition, knowledge of the state of health of the used device (e.g. battery state of health) can improve the accuracy of the refurbishment process and cost-efficiency (i.e. greater clarity on whether a component needs to be replaced or not). Finally, all interviewed companies shared concerns about part pairing[54], which is an increasingly common practice used by electronic OEMs to control who can perform certain types of repairs. Only OEM authorized or certified repairers (who pay an annual license fee) can perform certain repair operations without affecting the functionalities of the smartphone, which creates an important barrier for independent repairers[55]. The EU law Right to Repair which was approved in February 2024 will contribute to reducing some of the barriers faced by repairers (e.g. easy access critical spare parts, non-discriminatory access to any software or firmware needed for the replacement of components, etc.).
- **Lack of standardized requirements for smartphone refurbishment and grading criteria**
  All refurbished phones are given a grade that reflects their condition. There is currently no harmonized standard for the grading of refurbished smartphones. This creates a challenge for refurbishers who sell devices to different marketplaces and for customers who are not able to compare the refurbished offering. To reduce the administrative burden and to improve quality, standards need to be developed on the requirements for and performance of refurbished smartphones.

4.2.4.2 Potential improvements made possible by the use of a DPP

The potential improvements to the refurbishment process enabled through the DPP are summarized in the Table 7. The potential improvements arise mainly due to information availability when assessing the used smartphone and repairing the failed or degraded components.

https://repair.eu/news/part-pairing-a-major-threat-to-independent-repair/

[54] Part pairing is made possible by serialization of spare parts: some parts have a unique serial number, which is paired by manufacturers to an individual unit of a device using software. If any of these parts need replacing during a repair, they might not be accepted, or lose some of their functionality unless remotely paired to the device again via software by the manufacturer (e.g. touch screen functionality after the screen replacement).

[55] Chloé Mikolajczak. *Part pairing: a major threat to independent repair*. Repair.eu, 06/08/2021. Available online via

Table 7 - Potential Improvement of smartphone refurbishment process enabled by a DPP

DPP data attributes	Level of granularity	Potential Improvements
Unique identification and data carrier	Item	- Eliminate the need to build an internal identification system for traceability.
Product and manufacturer information - Trade name - Model reference - Name or trademark of producer or importer - Functional and technical specifications	Model	- Streamlining of product data, from the person selling the used smartphone to the refurbisher/marketplace

Information on the state of health and the repair history
- Date of manufacture
- Dates of first commercialization and resale
- Repair events history:
  - List of original parts
  - Component(s) which were repaired/replaced and reason for replacement.
- Battery state of health
	Item	- Improve the accuracy of the assessment of grading criteria, remaining useful lifetime, safety and failure risks.

Repair and disassembly information
- Repair instructions
- Spare parts availability
- Disassembly information
  - Exploded diagrams of the smartphone showing the location of hardware components
  - Disassembly sequences
  - Type and number of fastening techniques to be unlocked
  - Tools required for disassembly
	Model	- Improve the efficiency of the repair process

Information on refurbishment operations
  - Refurbisher operator name
  - Repair history events including date of refurbishment, component(s) that was replaced, data wiping status
  - Report of grading test
	Item	- Facilitate quality control for marketplaces and the implementation of quality management system for refurbishers.
		- This requires repairers and refurbishers to provide data in the DPP.

4.2.4.3 Benefits and barriers

Information made available via the Digital Product Passport (state of health, repair history, disassembly and repair information) leads to the following benefits.

- **Economic**
  - Reduction of costs for quality control thanks to the improved transparency of the refurbishment process.
  - Reduction of repair costs thanks to the improved access to spare parts and repair instructions, especially for independent repairers.
- **Qualitative**
  - Increased trust and transparency for customers (e.g. knowing that the battery has been replaced).
  - Reduction of the risk of failure.

The companies interviewed placed particular emphasis on the importance of quality and trust as key factors to increase the market share for refurbished goods. The DPP could lead to an increased volume of refurbished smartphones, as it supports both improved transparency and economic competitiveness. However, to unlock the full potential of these opportunities, data related to the repair history also needs to be added to the DPP, requiring repairers and refurbishers to also provide inputs to the DPP. As most of these companies are SMEs with limited IT resources and capabilities, there is a shared concern about their active contribution to the DPP. In addition, boosting the return of smartphones instead of leaving them unused in households is a key challenge for the refurbishment market. There is currently not enough supply to meet the demand for refurbished devices and there are limited incentives to encourage consumers to return their smartphones[56]. Several approaches are being developed including trade-in programmes, subscription models (e.g. leasing smartphone via a telecommunication contract), etc. Establishing harmonized take-back schemes at EU level are important to meet the increasing demand for refurbished devices.

4.2.5 DPP use case 4: Increase recovery rate of critical raw materials of small electronics equipment

4.2.5.1 Current situation

Companies selling electrical and electronic goods in the European Union must conform to the EU legislation for Electrical and Electronic Equipment (EEE), and in particular with the WEEE Directive which sets out the responsibilities of EEE producers and requirements for the collection and recycling of their products at the end of their lifecycle. WEEE requirements include, among others,

- Registration and reporting to national authorities on volumes of EEE placed on the market;
- Organizing and/or financing the collection, treatment, recycling and recovery of WEEE and the provision of specific information to recycling companies.

As for any EU directive, each Member State is responsible for the implementation of measures to conform with the obligations and the objectives. Therefore, the practical implementation of the WEEE Directive varies across the EU from country to country, with procedures and costs differing.

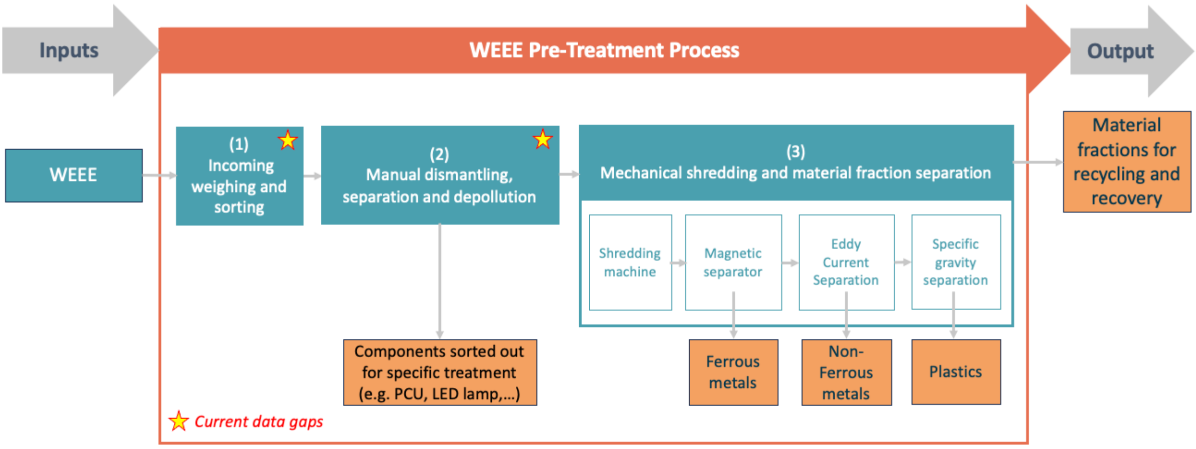
The WEEE recycling process involves a cascade of specialized treatment operators forming a chain of treatment activities which can be summarized in three main phases. While Phase 1 and Phase 2 occur at a regional level, interim fractions (e.g. plastic or ferrous fractions) are generally processed by downstream operators, which may be situated in other countries.

[56] https://www.foxway.com/en/articles/a-circular-tech-approach-what-if-95-of-devices-were-reused/

1) **WEEE Collection**
   - Dedicated systems are in place to collect WEEE locally in collection points at retailers or other highly frequented locations, as well as at the waste collection facilities of municipalities.
2) **Pre-treatment phase**
   - As EEE products contain a wide variety of metals, metal-alloys, plastics, glass and other materials including hazardous substances, the pre-treatment process steps aim to liberate materials or components that contain hazardous substances and separate the other materials for further processing.
   - Since the composition of products varies between the types of EEE, different materials are targeted and different treatment technologies are used during the recycling. For example, recycling a laptop requires a completely different approach than recycling a washing machine or a refrigerator.
   - This phase involves the steps of sorting, manual dismantling and depollution, mechanical shredding, and separation into material fractions (ferrous, non-ferrous, plastics, etc.).
3) **Main treatment phase**
   - This phase aims to refine and process the interim material fractions from Phase 2, in order to recover high quality secondary materials.

As products will be totally dismantled in the pre-treatment phase, the link to the associated DPP shall cease to exist at this step. So, we focused our analysis on this phase to evaluate the potential benefits of a DPP. As part of a consortium meeting, the CIRPASS team had the opportunity to visit a pre-treatment facility of Treee in Italy (https://www.treee.it) which provided great insights in relation to the current treatment process. Figure 16 illustrates the main steps of the pre-treatment phase are described in the following.

Figure 16 - Pre-treatment process of WEEE and current data gaps



1) **Incoming sorting**

   Recycling operators usually sign multi-year contracts with municipalities to process e-waste within a recycling center. The first step of the pre-treatment phase consists of sorting the WEEE per waste category (as described in Figure 12), as each waste category follows a specific treatment process. Some e-waste is already pre-sorted at the collection site such as large equipment (e.g. washing machines, electronic stoves, etc.) lamps (LED lamps), screens and monitors. Small equipment (e.g. microwaves, electric shavers, vacuum cleaners, coffee machines, etc.) and small IT and telecommunication devices (smartphones, printers, laptops, etc.) are often all mixed together and arrive in bulk at the pre-treatment facility (cf. Figure 17).

This inflow of e-waste is weighed, placed on a conveyor belt and sorted manually by trained workers. They also filter out the products that contain a battery, as these contain highly inflammable substances and hazardous substances.

Figure 17 – Incoming of e-waste at a pre-treatment facility of Treee in Italy

2) Manual dismantling, separation and depollution

- The second step of the process aims to separate the main components and sort out the hazardous parts in order to optimize the recovery of materials in the next step.
- WEEE contains substances of concern which can be hazardous, for example mercury, polychlorinated biphenyls, cadmium, volatile fluorocarbons, some brominated flame retardants, etc. According to the WEEE Directive (Annex VII), materials and components that contain hazardous substances require dedicated handling and treatment to avoid environmental pollution and the associated health and safety risks. These materials and components are removed in a process that is called “depollution”. For example, batteries contain metals such as lead, mercury and cadmium and, in general, Printed Circuit Boards (PCBs) contain cadmium and lead.
- The dismantling of e-waste is undertaken manually by trained professionals. As this task can be very time-consuming, it must be as efficient as possible, and the level of material separation undertaken is determined by the potential for material recovery and the value of these materials. For example, the dismantling of an LCD (Light Crystal Display) leads to the separation of the following parts, which are sorted based on their respective next treatment (cf. Figure 18). The dismantling process of an LCD should take a maximum of three minutes, as after that time profitability is compromised. Workers are therefore under a great deal of pressure.
  - Processed by external recycling operators:
    - LCD foot
    - Cables
    - PCBs
    - PMMA (Polymethyl methacrylate) which is the transparent and rigid thermoplastic used for the screen display layer)
    - LED backlighting lamps or for older LCD screens, mercury backlighting lamps (which are hazardous components, so they are manually extracted using an abatement system to avoid toxic dispersions)
  - Sent to the mechanical shredding step
    - Housing plastics

    - LCD “sandwich”
    - LCD Metal frame
- Some components of e-waste (e.g. RAM memory) with high reuse potential are tested and, if they work, the treatment operators resell them to market brokers. But the percentage of reuse usually represents less than 1% of the total incoming stream of end of life products.

Figure 18 - Dismantling operation of LCD screen at a pre-treatment facility of Treee in Italy

3) Mechanical shredding and material fraction separation

- The parts sorted in step 2 are then shredded mechanically. For small WEEE equipment, on average 85-95% of the total mass fraction of the incoming stream is shredded mechanically.
- Shredded materials are further processed, usually by magnetic separator and Eddy Current Separation machines, to achieve three distinct material fractions:
    - Ferrous metals
    - Non-ferrous metals (copper, aluminum, etc.)
    - Mixed shredded plastics
- These material fractions are weighed and then shipped to recycling operators to recover the individual materials. The recovery rate is highly dependent on the recycling technology and process used (e.g. smelting, pyrometallurgy, hydrometallurgy, etc.), but the composition of the material fractions will also affect the recycling performance[57].

When we discussed WEEE with pre-treatment operators, we identified the following **current data gaps and challenges**:

- **Challenge to identify the hazardous waste and product containing battery**
    - Pre-treatment operations involve a number of manual tasks undertaken by trained workers, which increases the risk of exposure to hazardous substances. Sorting incoming e-waste, in particular identifying products containing batteries, is very challenging. The constant evolution of product design and material composition, combined with the time

[57] Van Yken, Jonovan, Naomi J. Boxall, Ka Yu Cheng, Aleksandar N. Nikoloski, Navid R. Moheimani, and Anna H. Kaksonen. 2021. "E-Waste Recycling and Resource Recovery: A Review on Technologies, Barriers and Enablers with a Focus on Oceania" Metals 11, no. 8: 1313. https://doi.org/10.3390/met11081313

lag of several years between the first commercialization of products and their end-of-life, makes the task even more challenging.
- To address this challenge, one of the companies we interviewed is currently working on an optical solution with image recognition to automate this task as far as possible.

- **No visibility of the potential value of components or materials recovery**
  - WEEE treatment operators have very little visibility over the future value they can recover from the incoming stream of WEEE as this can fluctuate considerably depending on the types of WEEE being disposed of. The contract with municipalities is typically based on the mass of waste inflow to be treated, without any knowledge of the material composition. In addition, the economic viability also varies depending on market prices of the materials, which can fluctuate significantly.
  - The potential recovery of materials in WEEE can vary significantly depending on the granularity level of dismantling and on the recycling technology used. For example, the analysis of three different recycling routes for the Fairphone 2 revealed some great insights on the recycling rates of individual materials that can be achieved[58]:
    - Recovery of materials such as gold, copper, silver, cobalt, nickel, palladium, platinum, gallium, indium and zinc can vary between 80% to 98%.
    - Tungsten and tantalum are very difficult to recover unless the parts containing them are removed and processed separately.
  - Information on the material composition could lead to a more selective dismantling of WEEE parts and higher material recovery rates.
- **No harmonized reporting of WEEE between EU Member States**
  - The WEEE Directive (Annex V) sets recycling and recovery targets for different WEEE categories, but as mentioned previously, the WEEE Directive allows for varied implementation approaches by Member States, creating challenges for e-manufacturers and e-waste handling operators[59].
  - Producers and importers report on the amount of EEE which was put on the market, and treatment operators on the amount of WEEE treated. The reported amounts provide information on how the recycling and recovery targets were met.
  - However, the methodology for calculating recycling and recovery rates is complex and is not uniform across Europe, resulting in reported rates that cannot be compared[60].
    The WEEE Directive requires treatment facilities to report and record incoming WEEE and treated streams that leave the facilities. But treatment and recycling consist generally of a cascade of treatment operations within the same country or in another country, both inside or outside of Europe.
  - To provide a verifiable and accurate basis for the calculation of the recycling and recovery rates, the first treatment operator should monitor downstream fractions within the chain of treatment activities, which is not often done in practice. For example, one of the companies interviewed explained to us that treatment operators use different calculation approaches, leading to totally different recycling rates:

[58] https://www.fairphone.com/en/2017/02/27/recyclable-fairphone-2/

[59] Andersen, T. A comparative study of national variations of the European WEEE directive: manufacturer's view. Environ Sci Pollut Res 29, 19920–19939 (2022). https://doi.org/10.1007/s11356-021-13206-z

[60] CENCENELEC (2017) European Standards for Waste Electrical and Electronic Equipment (WEEE). Available online via https://www.cencenelec.eu/media/CEN-CENELEC/AreasOfWork/CEN-CENELEC_Topics/Environment%20and%20Sustainability/Quicklinks%20General/Documentation%20and%20Materials/weee-brochure.pdf

  - Some consider that the incoming mass fraction shipped to the smelter is 100% recycled.
  - Others report the actual outcome of the smelting process in mass fraction, e.g. 75% recycled, 19% energy recovery, 6% landfilling.
- Increased transparency on the mass flows of EEE and WEEE will facilitate the establishment of a consolidated and common reporting framework in EU[61].

4.2.5.2 Potential improvements made possible by the use of a DPP

The potential for improvements to the WEEE treatment process enabled through the DPP are summarized in the Table 8.

Table 8 - Potential Improvement of the treatment process of WEEE enabled by a DPP

DPP data attributes	Level of granularity	Potential Improvements
Unique identification and data carrier	Item	- Automate the incoming sorting process - This requires remote-readable data carriers (e.g. RFID, NFC, etc.) , especially for small IT and electronic equipment which arrive in bulk.
Product mass Product category	Model	- Facilitate the reporting of WEEE and data analytics on treatment flows
Product and manufacturer information - Trade name - Model reference - Name or trademark of producer or importer - Date of manufacture - Date of first commercialization	Model	- Facilitate feedback to OEM manufacturers to improve product design - Some OEMs already contact WEEE treatment operators to get information on their products (which were collected) to better understand their useful lifetime and the potential failure of components (e.g. model, date of manufacture, presence of degraded components, etc.).
Product Composition (Material content per parts)	Model	- Enable selective dismantling to increase material recycling rate. - This requires modular products designed for ease of disassembly, which is currently not the case for many products. This aspect is discussed in section 0.
Information on hazardous substances - Contains battery – Yes/No - Contains hazardous substances + Location of hazardous substances (parts/components) - Material content that requires selective treatment (according to WEEE)	Model (except if variations exist between items)	- Improve the process to identify and sort out the parts containing hazardous substances - Possibility to partly automate the process if remote-readable data carriers are applied.

[61] Magalini F., Wang f., Huisman J., Kuehr R., Baldé K., van Straalen V., Hestin M., Lecerf L., Sayman U. Akpulat O. (2014) STUDY ON COLLECTION RATES OF WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE).

4.2.5.3 Benefits and barriers

Information made available via the Digital Product Passport leads to the following potential benefits.

- **Economic**
  - Reduced pre-treatment costs thanks to automation of pre-sorting
  - Increase in material recovery rates thanks to selective dismantling and sorting of parts with high value materials
- **Qualitative**
  - Improvement of workers safety
  - Improved treatment of hazardous substances contained in WEEE
  - Increased transparency on WEEE flows

However, we identified several barriers that can undermine the potential benefits of the DPP.

- **Products are not designed for easy disassembly and with limited modularity, limiting the potential recovery of materials.**
  - The economic viability of WEEE pre-treatment operators is highly dependent on the efficiency of the dismantling and on the value of components or materials that can be recovered. For example, the intrinsic value of a used smartphone weighing 90 grams is estimated by the United Nations University to be only €2, while the average selling price for a used smartphone was €118 in 2017[62].
  - The collection rates of WEEE in EU is still very low, around 40%. Although EU reporting on WEEE indicates high recycling rates (around 80%), it is important to emphasize that there are large variations between the recovery rates of individual materials. For example, the recovery percentage of precious and rare earth materials such cobalt, antimony, tantalum, silver, gold and platinum (which are mainly present in small IT and electronics equipment, but in limited concentrations) does not exceed 1%[63].
  - Dismantling of WEEE is a key necessary step to improve the recovery rate of materials and to sort out parts containing hazardous substances. But it is also the most expensive step of WEEE pre-treatment, which affects its profitability. Dismantling trials in the EU Project Critical Raw Material (CRM) Closed Loop Recovery[64] illustrated how difficult and time-consuming it is, especially for smaller items such as laptops and smartphones. For example, it is difficult to chemically separate components containing high value elements from circuit boards due to the variety of fixings and issues with large metal pieces such as heat sinks (temperature regulators). As illustrated by a study on the recyclability of Fairphone 2[58], modular construction improves the recovery of minor high-value elements such as gold, especially if these are well concentrated on specific components of the smartphone.
  - Modular construction and design for disassembly are important enablers to fully capture the benefits of the DPP and to increase the recycling rate of critical raw materials in WEEE.

https://single-market-economy.ec.europa.eu/sectors/raw-materials/eip/raw-materials-commitment/critical-raw-material-closed-loop-recovery_en

[62] Baldé, C. P., V. Forti, V. Gray, R. Kuehr and P. Stegmann (2017), "The Global E-waste Monitor 2017", United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA)

[63] Data for 2011 based on Binnemans, Koen; Jones, Peter Tom; Blanpain, Bart; Van Gerven, Tom; Yang Yongxiang, Walton, Allan; Buchert, Matthias. "Recycling of rare earths: a critical review," Journal of Cleaner Production, 51, 15 July 2013, pp. 1-22.

[64]

- **Time lag and transition period.**
    - EEE includes a large variety of product categories. It is likely that the implementation of DPP in the electronics sector will be spread over several years as Delegated Acts are put in place. In addition, there will be a time lag between the commercialization of the first products with a DPP and their end of life. Therefore, WEEE treatment operators are likely to wait before investing in technologies that automatically read DPP data and pre-sort electronics products.
    - As products reach the end of life status, a mechanism may need to be put in place to deactivate the DPP. Treatment operators are best placed to play this role. However, this transition period also creates uncertainties on the active contribution of the WEEE treatment operators to the DPP ecosystem.

4.2.6 Perspective from electronic OEMs and distributors

As part of the stakeholder consultation, we also discussed the benefits and barriers perceived by DPP creators (electronic OEMs) and distributors. The main insights are summarized in the form of actionable recommendations.

- **Enable the possibility to add non-mandatory information to the DPP**
    - Electronic OEMs perceive the DPP as a major opportunity to streamline all product related information and to make this accessible in a single digital location.
    - Having a standardized and harmonized set of data attributes at EU level would also reduce the complexity of dealing with national requirements on sustainability and circularity aspects (e.g. repairability index and environmental qualities datasheet in France[65]). This is currently a challenge for electronic OEMs that need to adapt their product datasets and website interface depending on the country, to ensure that all mandatory information is accessible by customers.
    - Electronic OEMs also see the DPP as an enabler to reduce the need for paper documents and packaging (and thus the associated costs) thanks to the digitalization of these documents (e.g. instructions manual, declaration of conformity, etc.).
    - Ensuring access to accurate product data by downstream actors such as distributors, retailers and users is also a key challenge for electronic OEMs due to the multiplicity of distribution channels. OEMs see the DPP with its unique product ID and data carrier on the product (e.g. QR Code) as a means of accessing the "single source of truth", limiting the effort and errors involved in transferring data down the value chain.
    - To unlock these benefits, it is important to enable the possibility to add non-mandatory information to the DPP.

- **Ensure interoperability with existing reporting databases (i.e. SCIP and EPREL) to avoid duplication of efforts**
    - Suppliers (importers or manufacturers) of electronic devices are required to register their products on the ECHA SCIP database and on the EPREL database, before they can be sold on the EU market.
        - The SCIP database has been introduced as part of the Waste Framework Directive and applies to all products sold on the EU market. To comply with the REACH regulation, the economic actor must register its products to notify actors of the presence of Substances of Very High Concerns (SVHC) above the specified concentration

[65] Following the new French law AGEC (loi relative à la lutte contre le gaspillage et à l'économie circulaire du 10 février 2020), the manufacturers of electronic products concerned by the law have the obligation to publish a product sheet on their website or on a dedicated web page presenting the environmental qualities and characteristics of the product models. It includes also a reparability index.

thresholds. Each entry in SCIP database has a unique ID generated by the SCIP system, which does not correspond to the equivalent unique product identifier required for the DPP.
    - Since 2019, all energy consumption-relevant products that are included in the EU Energy Labelling Regulation 2017/1369 should be registered in the European Product Registry for Energy Labelling (EPREL) database. The registration is done at the model level.
- Both SCIP and EPREL are EU centralized databases, while the DPP data will be managed in a decentralized system. DPP information requirements and the associated format should be defined to ensure interoperability between the systems. To avoid the duplication of efforts to collect and submit product information, some stakeholders consulted recommended that the DPP system should allow operators to reference and make links to these existing EU databases for specific information requirements. The horizontal interoperability between systems and sectors might be integrated at a later implementation stage or transition phase.

- **Exploit semantic interoperability to potentialize standardized data models and machine-readable formats to facilitate data exchange**
    - There is currently no unique and standardized data model which is commonly used to document and exchange product data e.g. covering functional, compliance and circularity attributes, neither in the electronics sector nor within each value chain stage such as repair. Therefore, data exchange within a value chain stage, but also between the stages, requires specific data mappings and APIs (Application Programming Interface) on a case-by-case basis. Since a unique and standardized data model will never exist, semantic interoperability should be exploited and promoted.
    - We learnt from discussions with large EU-based distributors that collecting and maintaining product data from electronic manufacturers is a challenge and, in most cases, it is very difficult to compare the product data between manufacturers due to lack of standardization. To address this challenge, they are currently discussing with several industry actors the development of a B2B data exchange platform. As DPP data are made available in machine readable format, they see a clear opportunity to reduce the current administrative burden to collect product data. In addition, distributors clearly see the value of the DPP for their customers in supporting:
        - product comparison and green procurement;
        - product-as-a-service business models. Having access to standardized data for the products such as estimated product life length, spare parts availability, expected battery life, etc. will facilitate the evaluation of Total Cost of Ownership and residual value.
    - The recently published standard IEC 63278 is a promising candidate to serve as a baseline to define a standardized data model. The standard defines the structure of a digital representation of an asset, called Asset Administration Shell (AAS). The AAS approach has been developed by the German associations VDMA, ZVEI and Bitkom with the help of around 20 companies.

- **Allow other stakeholders to input at serial number level (repairers and refurbishers) within a model-level database**
    - For the electronics OEMs, there is a shared concern about the granularity level at which the data should be provided in the DPP. Providing all product data in the DPP at item level may not create added value downstream in the value chain. For example, spare parts availability and disassembly related information (tools, fasteners, sequence, etc.) are already provided at the model level by many electronic manufacturers. Similar to the

battery DPP, the Delegated Act may define information requirements that should be provided at the model level and others at the item level.
- The DPP system should be designed to allow stakeholders to input use phase data at the item level and link this data to the original DPP created at the model level.

4.3 Textile

The textile sector is economically a very important industrial sector for Europe, employing around 1.66 million people in 2018, but one of its greatest challenges is its environmental footprint throughout the value chain. The EU is the world's second-largest importer of textiles (including fibers and fabrics) and clothing, reaching a combined value of 125 billion dollars, a figure that is doubled when intra-EU trade is included according to the Circular Economy Perspectives in the EU Textile Sector report[66]. The industry is dominated by micro-companies and SME's, with only 0.2 % of textile companies with more than 250 employees. 67% of companies produce garments and 33% produce other textiles and semi-finished products[67].

Households are the main consumers of clothing and household textiles. Between 2000 and 2018, consumption increased by 14 % and 17 % respectively, which corresponds to 5.4 million tons of textiles in 2018, of which 4.4 million tons (81 %) are clothing. Today, more than 15 kilograms of textile waste are produced per person per year in Europe. The largest source of textile waste is discarded clothing and home textiles, which account for around 85% of all textile waste[68]. Although a large proportion of this waste is collected for reuse or recycling, the majority of textiles that could be reused are exported outside Europe.

Textile as a product category is therefore considered a priority sector in the CIRPASS study. Contrary to the Battery and Electronics cases covered in 4.1 and 4.2, there is currently almost no sectorial legislation addressing the environmental performance of textiles. There is also currently no regulation in force requiring a Digital Product Passport for textile products, even though this product category is set as a priority for the issuing of a delegated act under the ESPR.

In this section, we first describe what type of fabrics are included in the textile product category and review the applicable regulations and labelling that relate to the DPP. We then provide an overview of the different steps in the value chain and circular economy actions already put in place. Then, we describe two DPP use cases, respectively:

- **DPP use case 5:** Improving the efficiency of textile product sorting to favor reuse and increase sales of second-hand textile over recycling.
- **DPP use case 6:** Increasing the value created in reselling second-hand garments on online platforms.

Finally, we summarize the feedback from brands, e-platforms, and recycling companies on the DPPs creation and use. We also provide perspectives on the development and implementation of a DPP for Textiles. Throughout this process, we consulted a series of external expert stakeholders involved in the textile value chain[69].

[66] Köhler, A., Watson, D., Trzepacz, S., Löw, C., Liu, R., Danneck, J., Konstantas, A., Donatello, S. and Faraca, G., Circular Economy Perspectives in the EU Textile sector, EUR 30734 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-38646-9, doi:10.2760/858144, JRC125110.

[67] Based on Euratex data for the year 2020.

[68] McKinsey & Company (2022) Scaling textile recycling in Europe–turning waste into value.

[69] Decathlon, Eon Group, Resortec, Cent Neuf, Nicole Kösegi (ex Boer group), Atma, TrustTrace, Aquafil, Vretena, NHST Studio – Letsbehonest, Texon.

4.3.1 Textile category

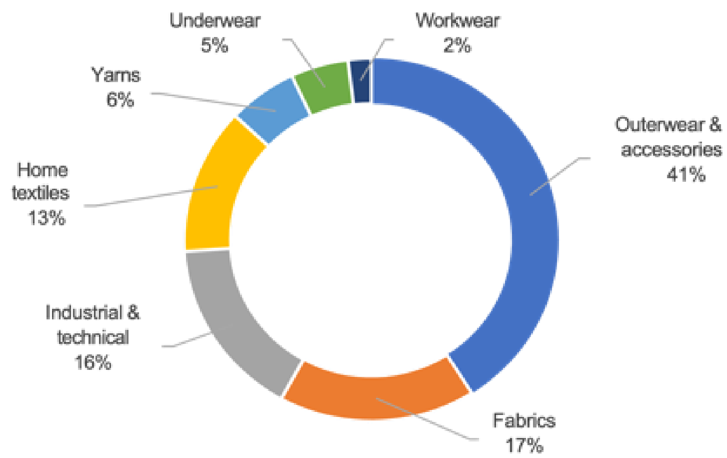
Textile products are commonly defined as products containing at least 80% by weight of textile fibers. According to the EU Textile Strategy[70], the following products are included in the textile product category:

- Apparel
- Footwear
- Home/interior textiles (e.g. bedlinen, towels, tablecloths, curtains etc.) consumed by households or by government or businesses (e.g. uniforms and workwear, hotel bedlinen and towels, restaurant napkins and dish towels)
- Technical textiles meant for consumers (e.g. truck covers, cleaning products) or for industry (automotive, construction, medical, agriculture, etc.)

Figure 19 shows the breakdown of European production of textiles by product type. The following products for which textile is not the dominant component are excluded from the textile group:

- Upholstery
- Carpets
- Duvets
- Pillows
- Leather

Figure 19 - Breakdown of European production by broad product type



Source: derived from Euratex (2020).

4.3.2 Applicable regulations and labelling

Two regulations currently apply to textile products with regard to their environmental performance and another will come into force in January 2025.

1. **The REACH regulation** is related to the protection of human health and the environment from the risks that can be posed by chemicals.

   Like most products sold or manufactured in Europe, textile products need to comply with the REACH regulation related to substance restrictions (Annex XVII) and notification obligations (SVHC Candidate List). Among these substances, one can find:

[70] Directorate-General for Environment (2022) EU Strategy for Sustainable and Circular Textiles. Available online via https://environment.ec.europa.eu/publications/textiles-strategy_en.

- Aromatic amines (from azo dyes, used to provide vibrant colors to textiles)
- Formaldehyde (used to increase colorfastness and anti-wrinkle of the textiles)
- Phthalates (might be found in plastic parts of the clothing or textiles, used to improve brightness)
- Pentachlorophenol (PCP) (used as preservatives in the textiles)
- Organotin compounds (used for anti-microbial function and to prevent unpleasant odors caused by sweat)
- Alkylphenol ethoxylates (APEOs) (used as a surfactant)
- Perfluorooctanoic acid (used for fluoropolymers based waterproof membranes) and specific flame retardants.

2. **The Textile Labeling and Fiber Composition Regulation((EU) 1007/2011)** lays down the conditions and rules for the labelling and marking of textile products and rules on textile fiber names. It requires the provision of information on fiber composition, but not on the producer or importer, nor on the presence of regulated substances:
    - Fiber composition (e.g. 100% Polyester)
    - Non-textile parts of animal origin must be clearly specified (such as fur or leather)
    - The label should not contain abbreviations with the exception of mechanized processing codes.

3. **The EU Waste Framework Directive** has been amended in July 2023 with a focus on textiles waste. Member States are required to set up separate collection of textiles by 1 January 2025. In addition, the Commission is proposing to introduce mandatory and harmonized Extended Producer Responsibility (EPR) schemes for textiles in all EU Member States.

In parallel, the **EU Green procurement of textiles**[71] provides guidance on purchasing criteria for textiles, which focuses on the most significant environmental impacts along the life cycle of textile products:

- Fiber sourcing (e.g. traceability on fiber source, content and production, organic cotton content, recycled content)
- Chemical restrictions (REACH)
- Durability and lifespan extension (e.g. dimensional stability, color fastness, availability of spare parts such as buttons or fasteners)
- Energy conservation during use (e.g. wash temperature)
- Design for reuse and recycling (e.g. dismantling of logos)

It also includes certain guidelines on purchasing criteria for maintenance services, such as:

- The implementation of procedures and asset management systems allowing for data and feedback from end users on the condition and lifespan of the textiles to be collected.
- The management of services to repair and maintain garments.

Although it is not mandatory to use any of these criteria, they do give some indication of the information currently provided by textile manufacturers or brand owners that could be included in a DPP.

Ecolabels are voluntary marketing tools that aim to inform customers about product environmental performance in a simplified manner and typically an eco-labelled product is associated with a good environmental performance. An example of such label is the Circular Design Criteria from circular.fashion, the only label that really evaluates recyclability. Some ecolabels such as the **EU Ecolabel** or **Blue Angel** refer to recycled content, but only for polyester and nylon, and not for natural fibers like cotton. Additionally, and with no difference between pre- and post-consumer waste, the

71 https://circabc.europa.eu/ui/group/44278090-3fae-4515-bcc2-44fd57c1d0d1/library/e9bfd88e-f2f7-4545-aa8a-87e731d132ad/details

Nordic Swan refers to wood input for cellulose based materials such as viscose. Figure 20 summarizes circular economy related requirements for major ecolabels.

Figure 20 - Circular Economy relevant criteria for ecolabels

Circular economy relevant criteria	EU Ecolabel	Nordic Swan	Blue Angel	GOTS	Oekotex 100	Bluesign
Requirements/ points for recycled content	✓✓ (polyester and nylon)	✓ (wood inputs)	✓✓ (polyester and nylon)			
Quality and durability requirements	✓		✓	✓		
Requirements for ease of dismantling and repair						
Requirements for recycling of production waste		✓✓				
Restrictions on residual chemicals in product	✓	✓✓	✓✓	✓✓	✓	✓✓

Source: Circular Economy Perspectives in the EU Textile Sector

4.3.3 Digital product passport – ESPR delegated act

The publication of the DRAFT ESPR in March 2022 introduced the creation of Digital Product Passports for all product categories, in order to increase transparency, both for supply chain businesses and for the general public, and to increase efficiencies in terms of information transfer. It specifies the minimum information that should be common to all product categories and confirms that information relating to different product category shall be specified in delegated acts. The DPP shall include information on specific voluntary labels applicable to the product and indicate whether an EU Ecolabel has been awarded to the product in line with Regulation (EC) No 66/2010[72].

A preliminary study on new product priorities for the ESPR was published in 2023 by the Joint Research Centre (JRC) Science for Policy Report[73]. Textiles (and footwear) scored the highest among all product groups in terms of their impact on water, waste generation, climate change and energy consumption, taking into account material sourcing, production (even if mainly outside Europe), use and disposal. It is also in this category that a high improvement potential on material efficiency and lifetime was identified. The ESPR compromise text resulting from the trilogues explicitly states that "In the first working plan, the Commission shall prioritise [...] textiles, notably garments and footwear".[74] This is in line with the results of the public consultation on the future ESPR working plan and product priorities which took place early 2023: textiles were the product group that achieved the highest score in this prioritization exercise.[75]

It was therefore suggested that textiles as a product category is a suitable candidate for prioritization under the ESPR, and also confirmed that textiles should move to sustainable and circular

[72] Regulation (EC) No 66/2010 of the European Parliament and of the Council of 25 November 2009 on the EU Ecolabel. http://data.europa.eu/eli/reg/2010/66/oj

[73] European Commission, Joint Research Centre (2023) Ecodesign for Sustainable Products Regulation (ESPR) – preliminary study on new product priorities. Available online via https://susproc.jrc.ec.europa.eu/product-bureau/product-groups/635/documents.

[74] https://www.consilium.europa.eu/media/69109/st16723-en23.pdf

[75] https://susproc.jrc.ec.europa.eu/product-bureau/product-groups/635/home

production, consumption, and business models as set out in the
and the 2021 update of the EU Industrial Strategy[76].

In order to support the fulfilment of these commitments, the European Commission has launched a preparatory study by the Commission's Joint Research Centre.[77] This preparatory study aims to provide a basis on which the Commission can consider the introduction of ecodesign requirements for textile products, including those linked to the DPP, green public procurement criteria and revised EU Ecolabel criteria. This study is expected to conclude by the end of 2024.

EU Strategy for Sustainable and Circular Textiles

Work on a Delegated Act for textiles is expected to start after the conclusion of the preparatory study and will include aspects related to the DPP for textiles. The exact schedule of the DA is not clear yet, adoption could be expected at earliest in 2026. Regarding entry into force, that date will be stated in the Delegated Act and will take into consideration the need for businesses to suitably prepare for compliance with ecodesign requirements, including on aspects related to the DPP

It is believed that the implementation of a DPP for textiles would support the development of more durable products whose lifespan could be extended by repair and reuse by new users, and through recycling to provide new high-quality products at the end of the life cycle. The potential ESPR requirements for the textile category proposed in the preliminary study on new product priorities are shown in Figure 21. In terms of design for durability (reliability, repairability, reusability, upgradeability) or modular design, it could include:

- Resistance to stress or ageing mechanisms
- Minimum durability of function (repellence to oil, water and stain, color fastness, dimensional changes)
- Introduction to repairability or scoring index
- Availability of repair information and maintenance instructions to independent operators and/or end users
- Spare part availability and delivery time
- Disassembly generally or related to tools, fasteners, working environment and skill level
- Number of materials and components used
- Modularity, transformability, detachable/transformable elements

In terms of design for recyclability, it could include:

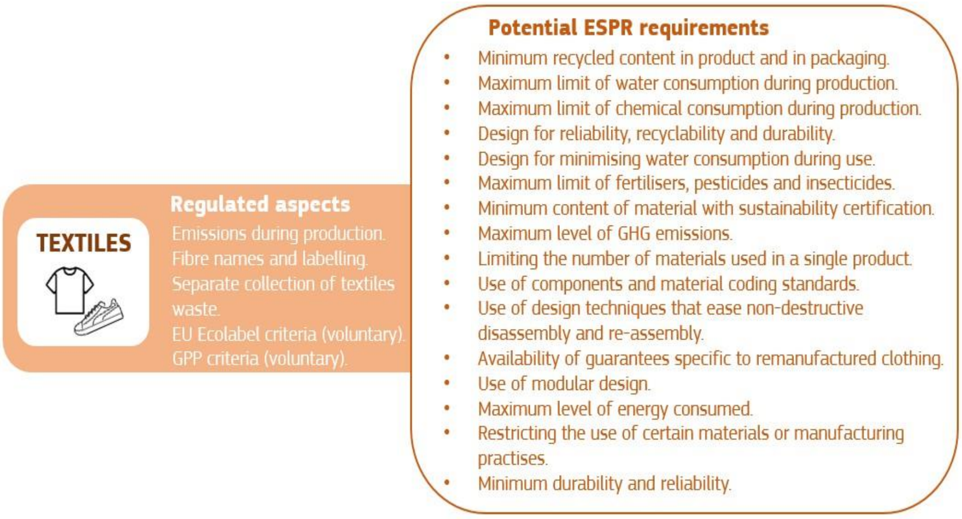
- Ability to easily separate the product into different materials
- Choice of materials and restrictions on substances
- Conditions for access to the product data relevant to recycling including dismantling information

https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:52021DC0350

[76] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe's recovery. Available online via

[77] EC Product Bureau web page on 'Textile products', URL: https://susproc.jrc.ec.europa.eu/product-bureau/product-groups/467/home

Figure 21 - ESPR requirements proposal for the Textile category



Source: European Commission, Joint Research Centre (2023) Ecodesign for Sustainable Products Regulation (ESPR) – preliminary study on new product priorities.

4.3.4 Textile value chain and circular economy actions

Textile value chains start with fiber preparation:

- Natural fibers such as cotton or any other natural cellulosic seed fibers, wool or other keratin fibers
- Synthetic fibers such as polyamide or polyester
- Man-made cellulose fibers such as lyocell, modal or viscose.

The fibers are then spun into yarns before being woven, knitted or bound into fabric. The fabric then undergoes finishing treatments such as bleaching or dying, waterproofing etc. before being cut and assembled into clothing or household textiles. Brands sell their textile products through distribution channels, their own stores or e-commerce.

Textile value chains are often global. The value chain for a typical piece of clothing passes through several countries and even continents. For example, the cotton for a shirt may have been grown in Greece, spun into yarn in Turkey, woven into fabric in India, sewn in Bangladesh and purchased from a retailer in Germany.

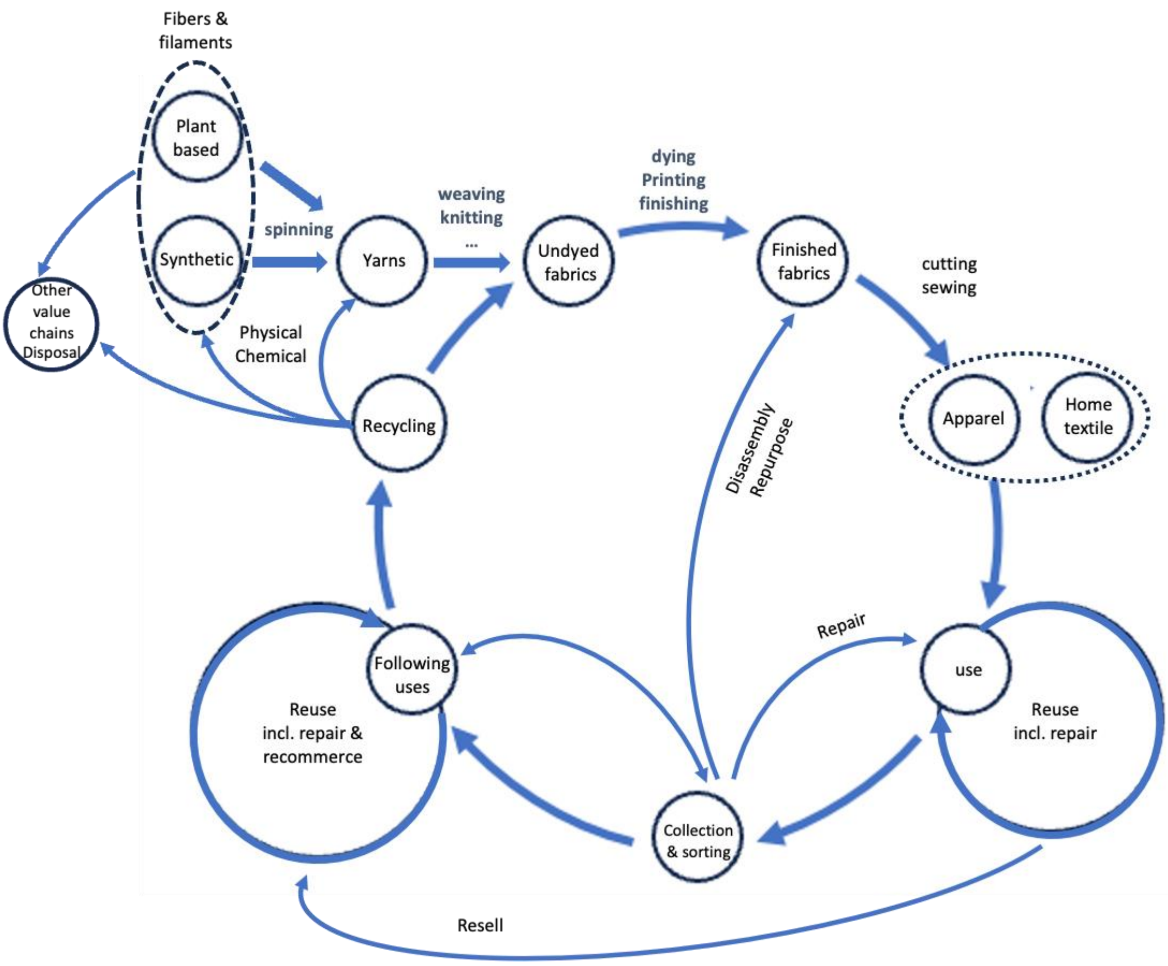
After their use by consumers, textile products were historically managed with municipal waste. However, over the last ten years, new consumer behaviors, new business models in distribution channels and new regulations concerning the collection, sorting and end-of-life management of textile products have considerably altered the end of the linear value chain in favor of greater circularity.

After their first use, there are several ways of **reusing** textile products and **extending** their **lifetime**:

- **Rental** i.e. the textile product is sold as a service. This business model is not totally new but developed largely over the last 10 years, starting in the US with companies like Rent the Runway and expanded quickly into Europe to a point where clothing can now be rented in large department stores like Galeries Lafayette in France.
- **Resale** i.e. the textile product is sold after it has been used to a new costumer as second-hand:
  - directly between customers through multi-sided platforms such as Vestiaire Collective or Vinted
  - by brands that take back their own products from their customers

  - by independent stores, hypermarket or other distribution channels that take back used textiles directly from customers or from collection companies e.g. Carrefour in France or ReTuna in Sweden.
- **Repairs** are carried out either by repair workshops or by brands. Some textiles are also repaired after collection for resale through various distribution channels.
- **Repurpose** into new textile applications, but often downcycled in applications such as wipes for industrial use, insulation, upholstery fill and low-grade non-woven textiles.

Figure 22 - Textile value chain and circular economy actions



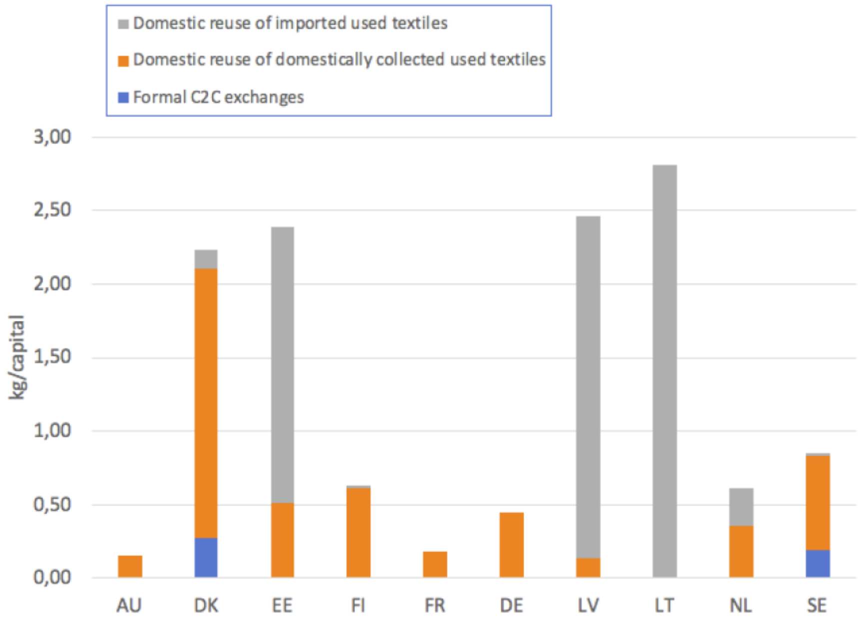
As a result, consumption of second-hand textiles accounts for a significant proportion of total consumption of clothing and home textiles, particularly in the Nordic region e.g. 29% in Latvia and Lithuania, 16% in Estonia and 13% in Denmark. Second-hand textiles can be collected domestically or imported, as shown in Figure 23. The European second-hand clothing market was estimated to be worth €17 billion in 2022 and is expected to grow at a CAGR of 8.4% to reach about €38 billion by 2032[78].

When textiles are not resold via Customer-to-Customer (C2C) platforms, they are generally collected by charities or private collectors through municipal bring banks. Some European countries, such as France and Estonia, already have legal obligations for the separate collection of textile waste. The revised Waste Framework Directive (WFD) will make such collection compulsory for all member states from 2025. It is worth noting that in 2019, even though the French Extended Producer

[78] Future Market Insight (2022) Europe Second-hand Apparel Market Outlook (2022 to 2032).

Responsibility System for textiles has been in place since 2007, only 38% of textiles placed on the market were collected.

Figure 23 - Consumption of second-hand textiles in countries with available data



Source: Circular Economy Perspectives in the EU Textile Sector

In terms of circularity potential if all textiles were collected, the Dutch Department of Public Works (Rijkswaterstaat) estimates that 25% should be reusable, just under 30% would be recyclable, and 40-50% would be categorized as non-reusable and non-recyclable waste. Private collectors target reusable textiles because of their economic value, and it is mainly on non-reusable textile waste that the separate collection obligation laid down in the WFD is focused. One way of increasing the percentage of reusable textiles would be to increase their durability, i.e. their resistance to wear and tear, color fastness, low shrinkage rate, etc. According to the Ellen MacArthur Foundation[79], increasing the shrink and weather resistance of textile articles could double their average lifespan and save 44% of greenhouse gas emissions.

When textiles cannot be reused and are considered as waste, they can be recycled using different technologies. These include mechanical processes, fraying into yarns or fibers; and another is chemical, involving dissolution/precipitation for polymer separation or depolymerization into monomers.

[79] Ellen MacArthur Foundation, A new textiles economy: Redesigning fashion's future, (2017, http://www.ellenmacarthurfoundation.org/publications).

4.3.5 DPP use case 5: Improve the efficiency of textile product sorting to favor textile reuse over recycling and incineration

4.3.5.1 Current situation

Textiles are collected, sorted, and recycled by private waste management companies, who only deal with the end-of-life of textile products, not other waste. It is important to remember that even if a textile product can be sold for reuse after being sorted, it is considered waste as soon as it arrives in a collection container. Within EU Waste Framework Directive, Art. 3(1): 'Waste' means any substance or object which the holder discards or intends or is required to discard.

Textiles are collected using textile containers placed at the doors of charity associations, and on public and private roads, solely at the request of local associations and public structures. Large mobile containers are also available to associations for the collection of larger volumes. The container typically belongs to the textile wholesale collectors, but is managed by associations or municipalities, which can pre-sort textiles it contains if they wish.

When the containers are full, the wholesale textile collector receives a notification inviting them to collect the container and transport the textiles to the sorting facility. Weighing is carried out at the time of collection (on departure and arrival) to determine the weight of donations collected. These containers generally contain a mix of clothing, textile accessories, home textiles (bedding, towels), bags, shoes, sleeping bags, stuffed animals, etc. irrespective of how dirty or reusable they are.

The average weight of a container is around 5 thousand tons and wholesale collectors can sort between a few hundred tons to over a hundred thousand tons per year, depending on the size of the organization.

The collected textiles taken to sorting centers are sorted manually and visually by experienced employees into typically over a hundred product categories and then segregated for reuse on the basis of the following criteria:

- Is the product reusable?
- Is there a market for the product?
- Is the product recyclable?

To determine whether the product can be reused or recycled, sorting operators are trained to assess:

- Condition of the item
- Color
- Peeling
- Stains
- Shape

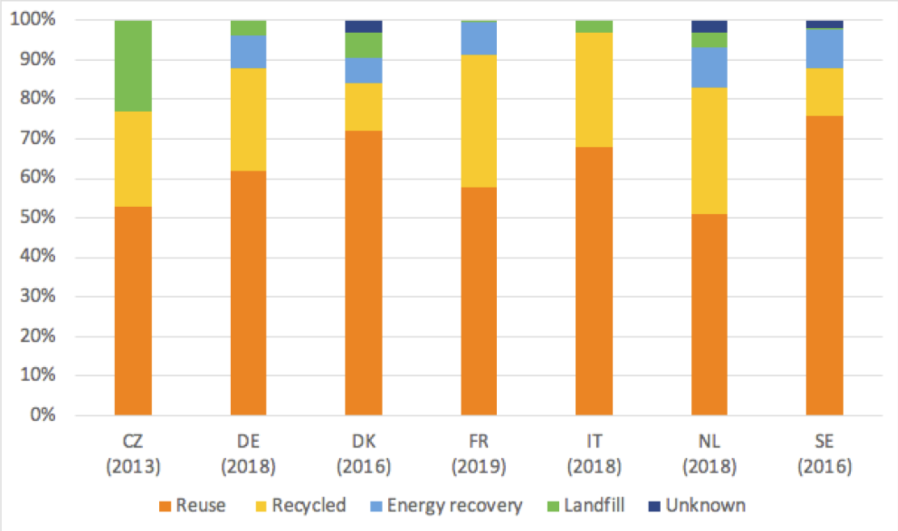
When the product label is still attached to the product, which is not always and even rarely the case, none of its information is reused by sorting professionals. Consequently, the more experienced the sorting staff, the more cost-effective and efficient the process will be.

There are currently no advanced, accurate, and automated fiber sorting and preprocessing technologies to facilitate sorting operations, in particular for reuse markets. It is also unlikely that automation of sorting for functional quality aspects of textiles will be possible in the foreseeable future. After manual sorting, around 50-60% of textiles are labeled as reusable, 35% are recycled and 15% are incinerated, put into landfill, or go to energy recovery[80]. Figure 24 illustrates the composition

[80] Based on inputs from Nicole Kösegli Textile recycling business expert.

of post-consumer textiles in Europe in 2018 in terms of their post-collection treatment. Different sources give slightly different percentages, but orders of magnitude remain the same.

Figure 24 – Global treatment pathways for separately collected post-consumer textiles in countries with available data



*Note that the treatment is global. For example, 71 % of all textiles collected separately in Denmark are reused either within Denmark or on global reuse markets.

Source: Circular Economy Perspectives in the EU Textile Sector

Recyclable textiles are either: cotton from broken jeans, which can be transformed into e.g. industrial cotton wipes; or knitwear, acrylic or polyester, which can be physically or chemically recycled into new raw materials, yarns, or polymers. The value of recyclable textiles averages 10 cents/kg, between e.g. zero and 30cents/kg for cleaning wipes. Given the rise in wool prices over the past 10 years, recyclable wool has the highest value among recyclable materials.

Fiber-to-fiber recycling technologies require a certain level of purity and can only be used for specific fiber compositions. Among the problematic substances one can find is elastane, which is often mixed with another material like cotton or even some dyes (as stated by Aquafil, a yarn producer and recycler of polyamide 6). As a result, even textiles made of recyclable fibers end up in incineration or energy recovery.

When it comes to reusable textiles, it is the demand from the second-hand market that drives sorting and price. 20% of reusable textiles stay in Europe, the majority is exported to Asia (41%) and Africa (46%). The cost of collection for the sorter is then linked to the quality of what is collected. It requires trading expertise to adapt to market demand and the majority of wholesale collector revenues come from sales of reusable textiles. The export market of used textiles has tripled from 2000 to 2019, reaching almost 1,7 million tons, corresponding to about 3.8 kg/person or 25% of textiles consumed each year in the EU[81].

Figure 25 is an illustration of the composition and value in a typical ton of textiles collected in the Nordic countries in 2015. The non-reusable textiles represented 29 % of the weight of collected textiles and less than 4 % of the value.

A company such as the Dutch Boer group has strong collaborations with customers and depending on the country, they sort by type of product their customer is looking for. Sorted items are put together in bales with a typical mix of what a customer might accept, e.g. men's pants in all colors and sizes, men's slim fit shirts, and so on. Each bale is accompanied by the following information:

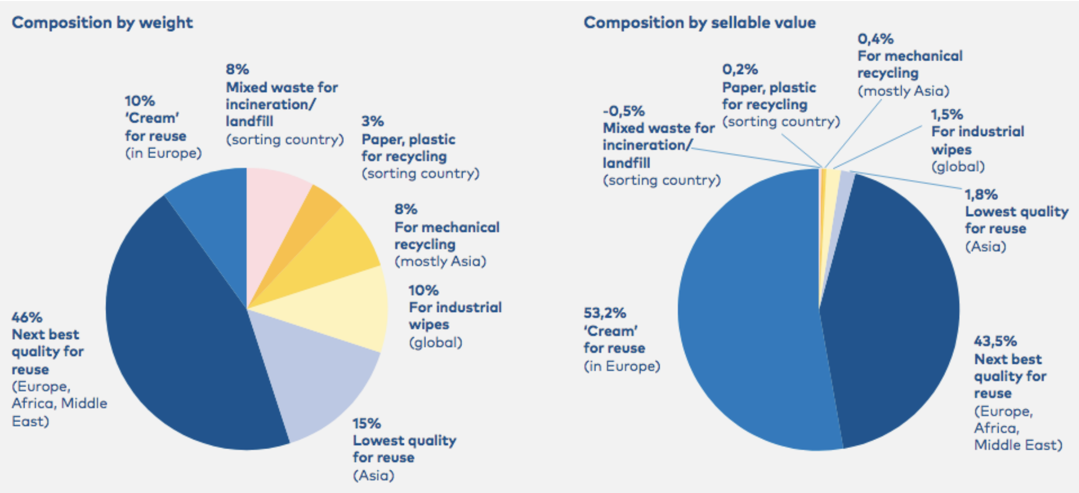
- Sorter name

[81] European Environment Agency (2023) EU export of used textiles in Europe's circular economy.

- Product type
- Weight
- Price

The price is per kilo of textile sold and varies from 30 cents to 5 euros per kg.

Figure 25 -Typical post-sorted composition of collected textile waste in the Nordics in 2015



Source: WRAP UK Report (2017).

4.3.5.2 Potential improvements made possible by the use of a DPP

The current state of sorting and orientation of collected textiles in terms of next treatment, as presented in the previous section, has shown that the highest value is created when textiles are resold on the European market for further use, without modification (with the exception of necessary repairs). It also showed that there is currently no data available to direct textiles to their next treatment beyond visual inspection by qualified personnel. An additional sorting criterion is the demand for the second-hand export market which is based on close cooperation between the wholesaler and his customers. There is also currently no demand for data related to hazardous substances (REACH) from the second-hand market.

It is thought that providing information on product quality (brand, composition, durability) as part of a pre-sorting operation in a sorting facility could help increase the quantity of textiles sorted for reuse in the European market.

With the development of fast fashion, the quality of textiles has dropped, and even if a product has only been worn a little and has kept its shape, color, etc., the quality problem appears when it is used a second time, posing a problem for some European second-hand players. If a DPP were attached to such a product, resellers could specify what they do or do not accept (brand, collection date, composition, size etc.) and buy a certain volume of what is currently exported outside of Europe due to the lack of information. Similarly, if data on durability such as oil and stain repellence, color fastness or dimensional stability, were available, a pre-sorting operation based on a DPP could help select quality products. Data on design for disassembly and availability of spare parts could help avoid products being classified as non-reusable, as products could be repaired, or textile parts reused. The DPP data that could be useful to sorters in identifying higher-value textiles for reuse in Europe are summarized in Table 9. Usage, repair and reuse history and certification are not relevant information for the sorter.

It should be noted, however, that even if such data were to become available for an automated pre-sorting operation, it could not replace the final visual sorting operation, at least based on the currently available technologies. In reality, the highest value of products for reuse is created when products are sorted before being placed in a bring bank. Many brands have now set up a take-back and reward program for their own products which somehow also favor the design of better-quality textile products and reuse of clothing in particular (this is the case for instance for the fast fashion brand H&M). The availability of DPP data would also create value for consumers when products are sold on C2C platforms and this topic will be covered in the second use case analysis.

Table 9 - DPP data supporting textile reuse

Information categories	DPP data attributes	Useful to sorters for reuse	Useful to sorters for recycling
Functional and technical specifications	Minimum durability of function (repellence to oil, water and stain, color fastness, dimensional changes)	x	
Material & composition information	CE marking, fiber composition, other substances	x	x
Product design & service	Brand, description, size, color	x	x
	Hazardous substances		x
	Maintenance and repair information incl. spare parts availability and disassembly map	x	
	Modularity, transformability	x	
Usage history			
Repair and reuse history			
Indicators	Repairability	x	
Certification			x

Additional value could be created for sorters if data were available to facilitate the identification of recyclable textiles, when they cannot be reused, helping to reduce the current quantity of textiles sent for incineration. According to Aquafil, recycler, and manufacturer of polyamide 6 yarns, the presence of hazardous substances (REACH), substances of concern such as dyes, or non-separable materials such as elastane, has a negative impact on textile fiber recycling. The availability of such data in a DPP would facilitate the identification of recyclable textile materials as this information is not accessible through visual inspection only. Consequently, sorters could sell at higher prices if they can guarantee there are no substances of concern for the recyclers.

4.3.5.3 Benefits and barriers

Currently, the majority of used textiles do not even reach the textile collection containers to be sorted, even in countries where separate collection of used textiles is mandatory. Figure 26 illustrates the proportion of used textiles collected compared to new textiles placed on the market. The EU Waste Framework Directive on mandatory separate collection of textiles, due to come into force in 2025, should encourage an increase in the collection of used textiles and, consequently, in the volume of reusable textiles.

Figure 26 - Share of used textiles collected compared to new textiles placed on the market

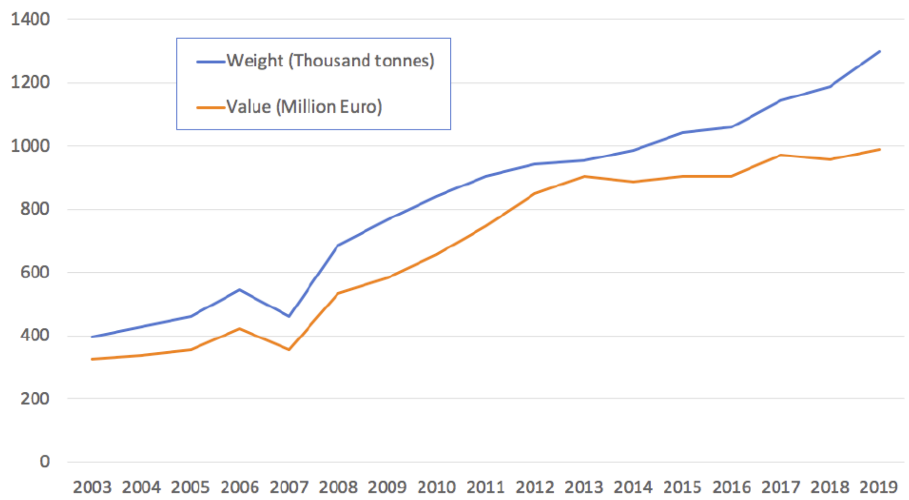
Country code (data year)		AT (2018)	CZ (2013)	DE (2018)	DK (2016)	EE (2018)	FI (2012)	Fla. (2019)	FR (2019)	IT (2018)	LT (2018)	LV (2018)	NL (2018)	SE (2013)
Consumption of new textiles	K-tonnes	---	69	1715	85	16	72	----	648	1383	19	12	305	121
	Kg/ person	---	6.6	20.7	15.0	12.4	13.2	----	9.7	22.8	7.0	6.1	17.7	12.6
Separate collection of used textiles	K-tonnes	38	20	1271	37	4.8	16	55	249	146	2.1	0.5	136	23
	Kg/ person	4.3	1.9	15.3	6.4	3.7	3.0	8.3	3.7	2.4	0.8	0.3	7.9	2.4
Collection rate*	**%**	**---**	**30 %**	**---**	**43 %**	**30 %**	**23 %**	**----**	**38 %**	**11 %**	**11 %**	**4.5 %**	**45 %**	**19 %**

*The collection rate is defined as the total separate collection of used textiles divided by the total quantity of textiles placed on the market.
Note: the figures in this table are not immediately comparable between countries due to differences in methodologies and scope.

Source: Circular Economy Perspectives in the EU Textile Sector

At the same time, European consumer behavior is shifting towards the purchase of more second-hand textile products, particularly clothing, which should create a larger market for sorters. However, it also encourages the development of online platforms for the consumer-to-consumer sale of second-hand textile products and, in addition, not only brands but also major retailers now take back and resell second-hand textiles. Used clothing is increasingly part of a specialized and traded global commodity value chain. The result is a negative impact not on the quantity (thanks to increasing separate collection schemes) but on the value of reusable textiles collected by wholesale collectors as illustrated in Figure 27.

Figure 27 - Growth in exports of used textiles from the EU



Source: Eurostat Comext database EU-27.

Access to DPP data on the composition, quality and recyclability of textile products should make it possible to increase the volume of reusable and recyclable textiles sold on the European market. However, this would require the development of automatic pre-sorting technologies whose return on investment is unknown at this stage, especially as there is still a vast export market that does not require such investment.

There are other barriers to encouraging the use of DPP textile data for better sorting when it becomes available. The first relates to the unique product identifier, which should be accessible via a QR code printed on a physical label or RFID attached to the physical product. When a consumer buys a new textile product, he or she often immediately removes the label, or it often becomes damaged in the wash. If no solution is found to attach a permanent identifier to textile products, the development of new sorting technologies capable of automatically accessing DPP data will make no sense.

The second barrier relates to the pace at which textile manufacturers and brands will implement DPPs for textile products and if the available information will meet the needs of wholesale collectors. As mentioned earlier, the majority of companies in the textile sector are SMEs. Implementing DPP issuance for these companies will require costly investment in digital tools and processes and this will take time. In addition, if major brands start issuing DPPs for more transparency and take back products for resale, we can expect the overall quality of textile products to increase. The result would be a larger market for the reuse of products before they reach the collection containers.

There will, therefore, be a time lag between the implementation of the Waste Directive for the separate collection of textiles and the ability of brands to implement the issuance of DPPs. In this context, wholesale collectors are likely to wait before investing in technologies that automatically read DPP data and pre-sort textile products for re-use.

4.3.6 DPP use case 6: Increasing the value created in reselling secondhand garments on online platforms

4.3.6.1 Current situation

Second-hand clothing sales are increasingly part of a specialized, globally traded value chain, as the second-hand market expands in Europe and around the world. According to the Boston Consulting Group, the global second-hand clothing market was estimated to be worth $40 billion in 2019. This represents just 2% of the total apparel market, but growth forecasts for the next five years are between 15 and 20%.

After a first use, there are several options for selling textiles for a second use. In this section, we briefly describe cases where textiles are sold in retail stores and hypermarkets, and then focus on cases where they are sold online via e-commerce and C2C platforms.

1. **Textiles are resold through retail stores** after collection and sorting by wholesale collectors and distribution by secondhand product wholesalers, as detailed in section 4.3.5.
   - They are sold through independent shops or department stores (7éme Ciel of Parisian Printemps).
   - With the development of the secondhand market, it is worth noting that some secondhand textile products are now also imported from China by wholesalers such as Inditex and sold in batches at very competitive prices.
   - If the brand and care labels are no longer attached to the product, there is no available information related to the origin or the composition of the product.
   - To create value, some retailers are now creating their own secondhand textile product brand and seasonal collection, like for new products (Cent Neuf).
2. **Textiles are resold by hypermarkets, mass-market retailers or even charity organizations in their own stores**.
   - Hypermarkets such as Carrefour have opened secondhand corners which compete with online C2C platforms. In the case of Carrefour, they take back products directly from customers in exchange for a voucher to be used in the store within a limited timeframe (2 weeks). Products are sent to their partners for inspection and, where relevant, refurbishment. They are then sold in their stores with other textile items coming from other sources (wholesalers). In these cases, information on the garments is only available when the brand and care labels are still attached to the product.
   - Mass-market retailers such as Decathlon or C&A also take back used products from their customers, in return for vouchers that remain valid for two years in its own stores, in the

case of Decathlon. A store dedicated to the sale of second-hand products has just opened in Spain as a pilot project. Used products come from two distinct sources:

- *Returned "new" products* (wrong size, not fit for purpose, "I've tested it, it doesn't suit me") of which the vast majority are in very good condition. After a thorough inspection, these returns are offered for sale as second-hand, with an average discount of 25% on the original price.
- *Used items from their take-back programs*. A buy-back estimate can be made online, before being confirmed when the product is returned to the store, as illustrated in Figure 28. The trade-in value is a maximum of 25% of the original price for an item less than one year old and in perfect condition.

- In this case, the objective of the brand is not necessarily to create value with secondhand product sales, but to increase customer loyalty and brand image.

Figure 28 – Decathlon take-back: example of buy-back estimate

•	**Type of product**	
	Veste	
•	**Brand**	
	ADIDAS	
•	**Original price**	
	100 €	
•	**Age**	
	2 - 5 years	
•	**Product condition**	
	Visual condition	In perfect condition
	Functional condition	In perfect condition

Buyback estimate	
Indicative estimate excluding repairs :	**up to €22**

Source: Decathlon website

3. **Textiles are resold by brands through their own e-commerce site or by specialized secondhand e-commerce platforms**

- With the development of the secondhand market in Europe and the success of the C2C platforms, many brands are now integrating a second-hand section into their business model. This started originally with brands like Patagonia but is now the case for European brands that sell secondhand products online, such as Aigle (which calls it Second Souffle), luxury brands like Isabel Marant (through the Onceagain platform), and mass retailers like Decathlon (on its own website).
- In the case of Aigle, consumers can sell Aigle used products on the Second Soufle platform (also in stores). For items in good condition, sellers can get up to 30%-50% of the item original value in vouchers to be spent on Aigle products. Before they are made available for resale, Aigle products are inspected, cleaned, and repaired if necessary. Consumers can buy secondhand Aigle products on the same Second Soufle platform, which then serves as an e-commerce platform. The data that are provided for the item are:
  - Product category
  - Size
  - Color
  - Condition
  - Main material
- In the case of Decathlon, inspected and cleaned second-hand textile products from brands other than Decathlon are sold on the Decathlon website, but only from selected vendors such as Meduzastore, an online platform for second-hand textiles. There are no Decathlon secondhand products sold on its website. The information that comes with the secondhand items are:

    - Product category
    - Size
    - Color
    - Condition
- H&M sells its second-hand products on the specialized e-commerce platform Onceagain, which also sells many textile products from other brands. They use the same platform for their takeback program when customers want to receive cash (whereas when products are returned in stores, the takeback is against vouchers as described in section 2 above). Only textiles in good condition, free of stains, holes, alterations, deformations, discolorations, etc., are accepted. Products must be identifiable with the original brand label indicating the size.
- When buying a secondhand product on the platform, the following information is provided:
    - Product category
    - Brand
    - Size
    - Color
    - Dimensions
    - Main material
    - Condition
- Products intended for resale are inspected by experts, but there is no guarantee of the origin or quality of products supplied by the platform to the buyer.
- On the Onceagain platform, there is no difference in take back price based on product condition or age, just the brand as illustrated in Figure 29. In terms of value, a H&M vest bought by Onceagain at 1,70€ is sold for between 6 and 12€. For comparison an Adidas vest bought for 8,10€ is sold as secondhand for 27€.

Figure 29 – H&M garment take-back prices

BRANDS	CATEGORY	PRICE
H&M	Shirts and blouse	€0,78
H&M	Overalls	€0,98
H&M	Jeans	€0,63
H&M	Skirts	€2,08
H&M	Coats	€4,50
H&M	Pants	€0,62
H&M	Sweaters and cardigans	€0,98
H&M	Dresses	€1,20
H&M	Shorts	€0,48
H&M	Top and t-shirts	€0,48
H&M	Vests	€1,70
Adidas	Vests	€8,10

Source: Onceagain website.

4. Textiles are resold by consumers directly to other consumers

- In the past, consumers used to sell their used textile products in consignment stores, but today this occurs mainly on specialized C2C platforms such as Vinted (45 million users in 13 countries, 3 million items from 12,000+ brands), Vestiaire Collective (luxury brands) etc. or non-specialized such as Blocket in Sweden or Le Bon Coin in France.

- These online platforms enable consumers to buy, sell and trade fashion items. The consumer-seller takes a photo of his or her item for sale, describes it and sets his or her own price. The following information is typically provided on the site:
    - Product description
    - Date of online publication
    - Gender e.g. men or women
    - Category e.g. Clothing
    - Sub-category e.g. Sweaters, vests
    - Designer e.g. Chloé
    - Condition e.g. Very good condition, never worn
    - Material e.g. Wool
        - Colour e.g. Brown
        - Size e.g. M (International size guide)
        - Location e.g. Vestiaire Collective France, France at seller Laura
        - Reference number
- The item is then posted free of charge on the platform's application or website. The buyer can accept the proposed price or make an offer to propose an alternative price. In the event of a sale, however, the platform charges the buyer a sales commission on the final price (70 cents, plus 5% to ensure buyer protection for Vinted, 14% plus 3% payment processing fees for Vestiaire collective and no commission for Le Bon Coin). Buyer protection fees allow the buyer to be reimbursed if the item does not arrive at its destination, is damaged or does not conform to its description. It does not cover items that do not fit or do not please.
- A seller rating system allows a potential customer to read what other consumers have said about their buying experience with that seller. The platforms also offer an expert authentication service (either for buyers or for sellers) where experts carefully check the items and ensure that it is an original.
- The platforms offer a secure method of payment. After payment by the buyer, "pending" funds are temporarily held by their payment service providers until the transaction is completed. The buyer has only two days to make a claim if there is a problem with the item after the platform has been notified of delivery.
- The advantage of these platforms is that they make it easy to buy and sell second-hand items, but there is a risk of obtaining counterfeit, damaged or non-descript items. These platforms have developed partnerships with by tech-fashion agencies such as Arianee and Reflaunt, which provide support in product take back and evaluation. Agencies, such as EON are also currently developing Digital Product Passports based on what they believe it will contain. Chloe is for instance the first partner of EON to use Digital ID’s on the Vestiaire Collective, which includes a DPP that provides access to product and material information, repair assistance and resale options.

4.3.6.2 Potential improvements made possible by the use of a DPP

There are currently no obligations for proving either the origin of secondhand textile products, nor if they meet REACH requirements in terms of hazardous substances. One could think that if a product is on the European market, it is automatically compliant, but with imports described in point 1) of section 4.3.6.1, this is probably no longer the case.

However, the current situation described above demonstrates that the highest value for the resale of second-hand products is achieved when the origin of the product can be authenticated. This authentication currently takes the form of visual inspection by experts who certify the product's origin (brand) and condition. This has a cost for the consumers in the form of buyer protection or in the expert authentication service fees. Platforms are also integrating the risk of wrong authentication into their fee structures.

The platforms that do not offer such services provide information limited to the brand label attached to the product. One of the main difficulties encountered in authenticating used textiles is the absence of brand labels and even care instructions. Customers either cut them off or they disappear when the product is used or washed. As a result, all of the information initially available, even if limited, is lost. And when basic information is missing, products are usually not sold on online platforms, but in secondhand retail stores at lower value.

Implementing a DPP seems to be the simplest way to provide long-term access to this data and limit the risks and costs for all parties involved in the sale of second-hand products. It should minimize the expert authentication and risk cost, but also reassure the buyer of the quality of the items he buys and the potential value for a next sale after use. The higher the quality and durability, the higher the long-term value.

The minimum data requirements would be the brand, the item identification number (at model level), composition (main components) and REACH compliance. Other data that would support the increase of second-hand product value when sold are:

- First date of purchase i.e. summer or winter collection of a specific year
- Availability of spare parts for repair
- Care instructions to keep the product in good condition

Table 10 illustrates which data attributes are useful to buyers or sellers for increase the for-sale item value.

Table 10 - Value of DPP data attributes for product resale

Information categories	DPP data attributes	Useful to sellers	Useful to buyers
Product origin	Brand and date of first commercialization	x	x
Functional and technical specifications	Minimum durability of function (repellence to oil, water and stain, color fastness, dimensional changes)		x
Materials & composition	CE marking, fiber composition, other substances	x	x
Product design & service	Description, size, color	x	x
	Hazardous substances	x	x
	Maintenance and repair information incl. spare parts availability and disassembly map		x
Usage history			x
Repair and reuse history	Repairability	x	x

The partnership between Chloé, Eon and Vestiaire Collective on the spring/summer 2023 collection should enable evaluation of whether making this data available really creates value for the platform (lower cost, lower risk), for the brand (lower risk of counterfeiting, traceability of customer usage) and for the seller (higher price, lower cost).

4.3.6.3 Benefits and barriers

As described above, access to product data should create value for the various players involved in the value chain of second-hand textile product resale. It should increase the volume of products that can be sold online, either directly from consumer to consumer, or via e-commerce platforms, as they become easier to authenticate and trace.

Product authenticity appears to be the critical criteria for assessing the value of a textile product. Availability of relevant data in a DPP is expected to reduce inspection costs, both for the platform and the seller or buyer (depending on the platform business model), and reassure the buyer regarding the quality and value of the secondhand product he or she is buying.

One of the barriers for secondhand product resellers, whether they are professionals or consumers, is that the data they need come from product brand owners on whom they have no influence. As a result, it is critical that most data defined in the previous section are made available in the DPP.

The use of permanent data carriers on textile products is another barrier. As many consumers tend to remove the brand and care label from the item purchased, or because can be worn away with use or washing, new solutions need to be developed to enable permanent product identification.

In addition, it is critical to make it easy for consumers that sell and buy online to access the information from the data carrier, preferably with their phones.

Finally, there is no standardized method for assessing the condition of a used textile product, so if an item is assessed as being in perfect condition by an expert on one platform, it may be assessed differently by an expert on another platform.

Given all the barriers identified above, we believe that, as with use case 5, there will be a significant time lag in the availability of reliable data for the growing second-hand textiles market.

4.3.7 Perspectives from fabrics and apparel producers

Implementing a DPP for all products should be easier for companies that already have a digital strategy in place. This is the case for Decathlon, who has developed a data collection system based on its own standardized data attributes, centralized in a database containing all product digital twins at item level. However, it is worth noting that the initial drivers for the implementation of such a digital strategy were:

- the transparency and the traceability up the supply chain;
- to facilitate repair, both for the customers and Decathlon repair department;
- to develop new circular business models such as rental, rather than to develop and increase the value of the secondhand market.

This is actually aligned with what frontrunner brands such as H&M are putting in place when working with fashion technology companies.

From the stakeholders we interviewed, we recognized that brands underestimate the importance of identifying products with unique identifiers and implementing a solid digital strategy to manage their supply chain. This gap is now being addressed by technology providers and many startups are developing solutions and IT support services to be offered to brands.

However, when brands acknowledge what is needed in terms of digital strategy, we understood that there is often financial and resource barriers (IT system, processes, people etc.). Technology providers have also told us that, due to the lack of regulation, most brands launching DPP activities only have a budget for a pilot project and not for scaling up.

More importantly, and as mentioned before, most companies in the textile industry are SMEs and it is clear from different interviews that they are not even aware of the forthcoming textile regulations and the associated DPP. Consequently, they have no data acquisition or management activities in place or planned. In addition, if issuing of DPPs became mandatory, they claim that they would provide data for minimal compliance such as REACH, but see no value in providing data for a secondhand market in which they won't participate.

This attitude is different to that of luxury brands or mass retailers, who see the development of the secondhand market as a threat to new product sales. They are, therefore, starting to participate in this small but growing market, either directly or through partners.

5 Identified benefits and barriers

This section summarizes the identified benefits and barriers in the creation, contribution to, or usage of DPPs, which are common to all three sectors (Battery, Electronics and Textile). These benefits and barriers are clustered in four stakeholder categories based on their role (cf. Table 11) and are listed in Table 12. The sections 5.1.1 and 5.1.2 provide a short description of these benefits and barriers with some illustrative examples from the battery, electronics and textile sectors.

Table 11 - Primary role related to DPP for each stakeholder category

	Primary role related to DPP		
	DPP creation	DPP contribution	DPP usage
1. DPP creator the economic operator placing the product on the market. It can be manufacturers, brands, importers or their authorized representatives or remanufacturing actors.	X		
2. Customers / users			X
3. Product Life extension actors involved in activities such as maintenance, repair, resell, sharing, refurbishment, remanufacturing		X	X
4. End-of-life managers involved in activities such as waste collection, sorting and treatment, recycling			X

Note that for the European Commission, the usage of DPPs should benefit public authorities and policy makers, enabling them to link incentives to sustainability performance. It should also benefit market surveillance and customs authorities by making required information more reliable and easily available. For example, customs authorities have a role in product compliance verification. They may release a product for free circulation only after having verified as a minimum that the unique registration identifier and the commodity code provided or made available to them correspond to the information stored in the DPP registry. This verification shall take place electronically and automatically via the interconnection of EU Customs Single Window Certificates Exchange System (EU CSW-CERTEX) and the EU DPP registry. A "positive" verification allows to release a product for free circulation but shall not be deemed to be proof of compliance with other European Union law. These two DPP use cases are not covered in this report.

Table 12 - Identified benefits and barriers in the creation, contribution or usage of DPPs

1) DPP creators	
BENEFITS	**BARRIERS**

Qualitative benefits:
• Compliance with legal requirements: Batteries as of 2027, Textiles, etc.
• Contractual requirements from customers. (e.g. request from customer to provide specific environmental data or product composition)
• Reputational benefits: enhanced reputation for sustainability and transparency, which could lead to increased sales and customer loyalty.
• If access to data during use phase is enabled, this could lead to improved product design and improved customer service.
Economic benefits:
• Manufacturers who can demonstrate the sustainability of their products, through DPPs, may be able to charge a premium price.
• Opportunity to create new business models (sharing, Product-as-a-Service, resell…).
• Reduced cost for delivering standard data to all supply chain customers rather than in individual customer specific data format.
	• **Costs:** developing and maintaining DPPs will have associated costs.
	• **Data availability:** lack of and/or difficulty in accessing all the data necessary to create DPPs.
	• **Data privacy:**
	  ○ Risk of intellectual property loss for manufacturers.
	  ○ Risk of limited feedback loop due to consumer/user data privacy.
	• **Additional workload**: legal obligations and administrative burden.

2) Customers / Users	
BENEFITS	**BARRIERS**

Qualitative benefits:
• Identification of hazardous substances.
• Reliability of use time. (e.g. increased trust in product performance thanks to access to product use history and maintenance)
• Identification of repaired parts.
Economic benefits:
• Lower operational costs and simplified process from standardized supplier data.
• Value retention.
• No disposal/waste cost.
	• **Costs:** premium price for products with DPPs.
	• **Knowledge and trust**:
	  ○ lack of awareness.
	  ○ trust in information quality (green washing).
	• **Geographical perimeter**: no legal requirements outside of Europe.

3) Product Life extension actors	
BENEFITS	**BARRIERS**
Qualitative benefits: • Access to all relevant information about the product, including its specifications, components, and warranty information. • Repair work is done in accordance with manufacturer guidelines. • Reduced risks of errors or misidentification. • Enhanced customer service, providing records of their product repair history. **Economic benefits:** • Time savings. • Higher margins (when reselling).	• **Costs**: maintaining DPPs will incur costs (manpower, training, technology investment and credentials authentication). • Capacity to handle variety of products with different data carriers. • Transparency about repairs (when reselling products secondhand), requiring inputs to the DPP by repair actors.

4) End-of-life managers	
BENEFITS	**BARRIERS**
Qualitative benefits: • Compliance with regulations **Economic benefits:** • Identification of end-of-life products. • Enhanced recycling and waste reduction (identification of contaminants). • Scarce metals recovery. • Lower operational costs and simplified process from standardized supplier data. • Value retention. • Lower disposal/waste cost (e.g. identification of products with no hazardous substance). **Environmental benefits**: • Identification of hazardous substances.	• **Costs**: perception that complementing and maintaining the necessary process and technology for using DPPs may outweigh the benefits, e.g., investment in readers, allocation of new space needed for increased and more granular sorting, etc. • **Trust**: perception that the evaluation of the physical product is more reliable than data accuracy in a DPP.

5.1.1 Benefits

The main drivers for the implementation of a DPP for **manufacturers** are either the legal or contractual obligations and the reputational benefits, rather than economic benefits, lower cost, or growth from new business models. This means it is perceived as a “must do” for keeping or growing their customer base, but not for the sustainable development of the company.

A good example of the benefits of a DPP for meeting legal obligations is the creation of the IMDS[82] data collection systems by the automotive industry itself (car manufacturers and suppliers). Once data collection has been put in place to facilitate compliance with national and international regulations, the system has been exploited for a number of efficiency and quality-related reasons (e.g. improving the flow of information within the organization and reducing the cost of collecting data from suppliers along the supply chain, etc.).

An example of reputational benefits comes from the textile industry, which has been much criticized over several years for the negative impact of fast fashion on the environment. Brands like Zalando or H&M (which, as specifiers, are considered garment manufacturers) use a DPP-like solution not only to meet legal obligations on child labor due diligence, but also to provide transparency on materials sourcing, bio-sourced or recycled materials composition and garment production location.

There are, however, a few examples of manufacturers that have gone beyond legal or reputational benefits. This is the case for Decathlon, a French sports goods and equipment company, that is now offering its products for rent based on a subscription business model. The economic benefits here are made possible by the identification and traceability of products at item level. In addition, this DPP-like system has drastically reduced the costs for logistic and stock management.

An economic benefit is currently demonstrated by battery manufacturers who, more and more, are interested in the traceability of their products for either reselling in less demanding applications (energy storage) or ensuring the recovery of critical raw materials (more than 95% of materials value comes from less than 5% of materials weight). This is the case for a major global battery manufacturer for electric vehicles, who produces in Europe and can identify the batteries at item level.

[82] International Material Data System https://public.mdsystem.com/en/web/imds-public-pages

The benefits for **customers or users** relate mainly to their ability to make more informed choices, especially relating to hazardous material content, and with respect to higher quality. Since data on product durability, upgradability, reuse etc. are still not commonly available, customers do not see yet the potential cost saving or economic benefits.

This is changing, however, thanks for example to the French law, loi AGEC[83], that imposes the requirement for customers to be provided with information on repairability (and durability) as of 2024, for home appliances and consumer electronics at model level. At the EU level, for smartphones and tablets, additional ecodesign requirements and information related to the repairability (to be displayed on the Energy Labelling) will become mandatory by June 2025[84]. As a result, the French retail company, Darty, that promotes repair already, favours selling products with high repairability scores that are traceable at item level. The company has created a new subscription business model for product repair that benefits their customers financially (all repairs are free for a monthly fee).

In the fashion market, consumers initially bought garments on the second-hand market for their lower cost. Some consumers are now changing their purchasing behaviour, favouring higher quality fashion garments with product data available at item level, like product authenticity, that they can resell on the second-hand market at the highest value.

For example, Chloé, the French luxury brand equips its garments (currently for one product range, but to be extended to all products in 2025) with a QR Code, also known as a "Digital ID" by the brand, which gives access to the provenance of the materials of the product purchased, advice on its care and repair possibilities, but also acts as a certificate of ownership enabling the buyer to resell the item on the luxury second-hand website Vestiaire Collective in just a few clicks. The owner of the Chloé item can collect the resale price, even before finding a potential buyer.

For **product life extension actors**, information provided by the DPP mainly reduces the risks of errors and supports higher quality of repaired products.

This is, for instance, the case in the Darty example, where each repair information is recorded at item level and is easily accessible in case of a new repair.

Economic benefits are the main drivers for **end-of-life managers,** resulting from either the better identification of end-of-life products, and hence enhanced recycling rate, or from the identification of hazardous materials (avoiding recycling contamination) and from scarce material recovery.

The more a product contains high value materials, the more this is true. This is the case for consumer electronics and battery dismantling/recycling companies.

5.1.2 Barriers

The main barrier for the **manufacturers** (DPP creators) is the costs for DPP data collection, issuing and maintenance and fears about data privacy.

Obtaining supply chain information for manufacturers to create DPPs is difficult and resource intensive. In addition, implementing downstream product traceability and data collection (after the issuing of a DPP) requires not only an investment in additional technologies e.g., RFID at product level,

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[83] Loi n° 2020-105 du 10 février 2020 relative à la lutte contre le gaspillage et à l'économie circulaire https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000041553759.

[84] For more details, see https://energy-efficient-products.ec.europa.eu/ecodesign-and-energy-label/product-list/smartphones-and-tablets_en.

but also in a digital strategy at the company level (IT infrastructure, data management etc.). This represents a significant upfront investment which is prohibitive for SMEs and explains why it is mainly the large companies that are currently involved in DPP related initiatives.

Data privacy (e.g. risk of intellectual property loss such as sharing product composition of cathodes and anodes) is also a barrier faced by a large Chinese company manufacturing batteries in Europe.

For **customers and users of products,** the limitations come more from trust in the information that is provided, rather than cost.

The current experience of data users of the automotive industry IMDS, shows that data reliability is key for ensuring the added value of the system. As it is currently based on self-reported, unaudited data, and provided when products are first sold (with limited updates in the event of product modifications), OEMs see some limitations due to the lack of data quality.

From these initial results, one could deduce that the value of data must be balanced with a potentially higher selling price (compensating DPP development cost), when the data provided have been audited or certified.

The cost of requesting access credentials and maintaining the DPP (i.e. writing new data or updating data in the DPP) is a major limitation for DPP implementation by **product life extension actors** (who are mostly SMEs) and could cause some disruption in data availability for users and end-of-life managers. This highlights the need to provide incentives for these actors to use and contribute to the DPP.

For garment repair shops, one of the barriers identified is the access to data through the data carrier which is often removed (cut) from the garment.

For **end-of-life managers**, data at the item level may not be used by sorting companies, which have to handle a very large volume of products to stay cost competitive.

In the electronics sector, a site visit at a major WEEE dismantling and recycling site in Italy (Treee) showed that the speed of product dismantling is critical to ensure financial viability. The current process, which does not include sorting of products (e.g., screens, laptops, etc.), would not benefit from availability of product information as it would decrease dismantling efficiency.

In contrast, the main business model of textile sorters is the resell of used garments. Thus, the identification of garments with high value on the second-hand market is critical and the DPP could drastically increase the efficiency of the sorting process, which is currently reliant on hand sorting and manual operations.

6 Conclusions and recommendations

The exploration of the Digital Product Passport (DPP) use cases in the circular economy activities of the battery, electronics, and textile sectors has revealed a compelling potential to address persistent data challenges. Engaging over 40 stakeholders, we analyzed six DPP use cases. Our main findings highlight the ability of the DPP to reduce information asymmetry and foster trust in second-hand markets and life-extension applications, as well as to increase the recovery rate of valuable materials and products at end of their life (or use). These findings advocate for large-scale piloting of DPP use cases to further quantify the benefits and enrich the repository of use cases. The mandatory implementation of ESPR requirements, including the DPP, should encourage frontrunners to allocate the necessary budget for faster scale up. Product-specific Delegated Acts should be able to evolve as scientific evidence of the economic and sustainability benefits of these use cases is gathered.

Throughout the stakeholder consultations, we also identified barriers to the deployment of the DPP, which are summarized below in the form of actionable recommendations. We believe that addressing these areas will enable advancements towards a more sustainable circular economy, leveraging the DPP as a pivotal tool in this transformative journey.

- **R1:** *Enable the possibility to add non-mandatory data in the DPP*
  The inclusion of non-mandatory data (in a standardized format) within DPPs, fostering a comprehensive data repository, serves a dual purpose: streamlining access to product-related information and establishing a singular, reliable data source.
- **R2:** *Ensure harmonized assessment methods across product categories to facilitate data collection from the value chain*
  Develop and implement uniform assessment methodologies across product categories. This harmonization will simplify data collection from the value chain (e.g. Product Carbon Footprint, recycled content, etc.).
- **R3**: Ensure that product-specific delegated acts require that the DPP be issued with an item-level granularity when item-specific circular activities are expected (e.g., maintenance, repair, refurbish)
  Facilitate stakeholder contributions to the DPP at item granularity level, catering to the needs of repairers, refurbishers, sorters and end-of-life treatment operators. This approach enables the inclusion of product-use-related data within a model or batch level DPP created by the original manufacturer.
- **R4**: *Prioritize remote-readable data carriers*
  Prioritize the adoption of persistent data carriers that are capable of being scanned from a distance, to support process automation in downstream applications, enhancing efficiency and accuracy in data utilization.
- **R5:** *Develop beyond-DPP digitalization support tools to accompany DPP implementation*
  Invest in the development of digital tools and resources to support stakeholders, especially SMEs, throughout the DPP implementation process. Exploiting the potential benefits of the DPP beyond compliance requires a corporate digitalization strategy and cross-functional collaboration (including data acquisition from supply chains, circular business models, etc.).
- **R6:** *Develop incentive mechanisms to ensure quality data sharing*
  Implement incentive mechanisms that reward the sharing of high-quality DPP data. Given the added costs for data holders to develop the infrastructure to enable and manage data access permissions, as well as enablement of data access by third parties, this approach should align with the EU Data Act, proposing an incentive model to foster industry participation and innovation in data-sharing practices.