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Final report on demonstrations of the circular economy business models and eco-services

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1. Executive Summary

This report describes the work performed to demonstrate C-SERVEES eco-innovative solutions and summarises the activities carried out to improve circularity throughout the whole life cycle of the four large demonstrators selected to represent different EEE categories: washing machine (large household appliances), printers and laser toner cartridges (IT equipment), ALM products (telecommunications equipment) and TV sets and displays (consumer electronics equipment).

The four large scale demonstrations were planned to comprise the whole life cycle of the target products, their associated value and supply chains and the following CE principles and eco-innovative services: (i) eco-design of EEE, (ii) EEE eco-leasing, (iii) WEEE re-use and remanufacturing, (iv) WEEE recycling and (v) ICT services.

The report summarises the activities and results from the demonstrations of the Circular Economy Business Models implemented and the evaluation of their sustainability by means of Life Cycle Assessment, Life Cycle Costing and Social Life Cycle Assessment. The report also includes an assessment of the main eco-innovative services and solutions used across the demonstrations cited above, and other technologies employed such as 3D printing.

The washing machine and TV set demonstrators, led by Arçelik, focused on developing eco-designed products and demonstrating the viability of eco-leasing, refurbishment and re-use through the development of new business lines that could be implemented in Europe for Arçelik brands in collaboration with other actors in the supply chain. It also explored improvements in the dismantling and disassembly operations to recover valuable materials and spare parts from end-of-life products. The potential to use 3D printing technology for the production of spare parts was explored for both washing machine and TV sets, highlighting several difficulties to obtain viable parts.

The printer and toner cartridges demonstrator, led by Lexmark, focused on the analysis of levers and enablers to expand the printers' refurbishment business within the MPS offered by the company. The two main issues identified in the demonstration as critical for the new CEBM (cost and customer acceptance) have been addressed in depth. Furthermore, research in collaboration with recyclers allowed to determine the viability of a new business line to recover spare parts and also to reuse secondary raw materials from EoL printers and toner cartridges. Needs and expectations from customers have been analysed through targeted surveys and live testing with refurbished printers.

The ALM demonstrator, led by ADVA, started with the development of eco-designed passive sensors for the ALM system for increased energy efficiency and longevity. The transition to a PSS for the ALM products was subsequently explored and tested with a selected customer. Most importantly, ADVA developed and validated an LCA-based lifetime optimisation model for ICT products, generalised it to other EEE and presented a useful tool for the determination of the most sustainable lifetime period depending on the use model of a given E&E product. This was complemented by a PSS assessment model, since different PSS may apply depending on the influence of the use phase. The outcome of this model provides useful guidelines for EEE manufacturers and to policy makers. In collaboration with recyclers, guidelines for disassembly and eco-design measures for ICT products have been developed.

The use of ICT tools as support to the CEBM activities and goals was demonstrated through the testing of the integrated C-SERVEES ICT platform, where the different functionalities have been tested across the four demonstrators: certification of recycled content by ICT, Smart Questioning, reverse logistic optimisation and secure information exchange among the various actors in the supply chain.

Content

Acronyms and abbreviations

ABS	Acrylonitrile Butadiene Styrene
ALM	Advanced Link Monitoring
B2B	Business to business
B2C	Business to customer
BAU	Business as usual
CE	Circular economy
CEBM	Circular Economy Business Model
CapEx	Capital expenses
Ctl	Close the loop
EEE	Electric and Electronic Equipment
E&E	Electric and Electronic
EF	Emission factor [kgCO_2e/kWh]
EoL	End of life
E2N	Equal to New
FMD	Full material declaration
GWP	Global warming potential [kgCO_2e]
ICT	Information and communication technology
IEP	Information Exchange Platform
LCA	Lifecycle assessment
LCCP	Lexmark Cartridges Collection Program
LDPE	Low Density Polyethylene
LECP	Lexmark Equipment Collection Program
MPS	Managed Print Services
NPV	Net Present Value
NWC	Net Working Capital
OEM	Original Equipment Manufacturer
OpEx	Operational expenses
PA	Polyamide
PC_ABS	Polycarbonate - Acrylonitrile Butadiene Styrene
PETG	Polyethylene Terephthalate Glycol
PLA	Polylactic Acid
PP	Polypropylene
PSS	Product-service system
RE	Renewable energy / electricity
rPETG	recycled Polyethylene Terephthalate Glycol
UPR_{10}	10-years use/production ratio (GWP)
WEEE	Waste Electrical and Electronic Equipment
WACC	Weighted Average Cost of Capital

2. Introduction

C-SERVEES aims to change the way electrical and electronic (E&E) products are developed and consumed and to make all stakeholders think about new approaches to improve circularity in the E&E sector by considering the whole life cycle of the products and introducing eco-innovative and sustainable solutions at any stage: design and production, distribution and use, and end-of-life (EoL).

The overall principles of circular economy (CE) are generally accepted but integrating them in business models remains challenging. Despite various types of drivers, the adoption of circular economic business models (CEBMs) in the sector of electrical and electronic equipment (EEE) is not widespread. The lack of a conceptual framework to classify or denominate CEBMs and the concomitant uncertainty around the benefits of CEBMs makes matters worse.

The C-SERVEES project addressed these challenges by developing a CEBM for the EEE sector, including guidance for its implementation by manufacturers developing product-specific business models. This generic CEBM was then adapted to the four demonstrators: washing machines, printers, telecom equipment and TVs. A 'CE Action Plan' was drafted for each demonstration, containing all short-term CE actions to be implemented in the demos, which were reviewed and prioritised by the manufacturer and the project partners involved in the activities.

Central to these demonstrations were the original equipment manufacturers involved in the project, ADVA, Arçelik and Lexmark. The demonstrations were aimed at testing and validating the new CEBMs by integrating four basic pillars: eco-design, eco-leasing, improved WEEE management and ICT services. In addition, the testing of end-users' acceptance was addressed via surveys and living labs.

The project has also developed three ICT tools to support the effective use of the CEBMs through value chain transparency, connect stakeholders with each other and enable optimised reverse logistics.

The evaluation of the proposed solutions was done by applying life cycle sustainability assessment (LCSA) in the demonstrations to measure their performance in relation to the three pillars of sustainability: environmental life cycle assessment (E-LCA), life cycle costing (LCC) and social life cycle assessment (S-LCA).

For detailed insight visit the publications section of the C-SERVEES project website, which provides links to the reports produced during the course of the research, including those submitted to the European Commission.

3. Washing machine demonstrator

The washing machine demonstration was led by Arçelik and this section provides an overview of the activities, results and findings during the demonstration period.

3.1. Company and product description

3.1.1. About Arçelik

Arçelik is a consumer durables and consumer electronics company founded in 1955 in Turkey. The company offers production, marketing and after sales support services in both sectors. Today, the company has a global network with 22 production facilities in 8 countries. The products and services are sold in 146 countries with 12 brands. There are 35 sales and marketing offices worldwide, and 17 R&D design centres. The company has its in house R&D capabilities. There are more than 30.000 employees working for the company globally.

Arçelik is Europe's fourth biggest white goods company in total sales. Arçelik is market leader with Arçelik brand in Turkey, Arctic brand in Romania, Defy in South Africa and Dawlance in Pakistan. Arçelik also operates with the global Beko and Grundig brands as well as the remaining 10 local brands that makes up its portfolio.

Arçelik's sustainability strategy is based on integrating sustainability as a business model in the core Business strategy and among each and every department in the company. Arçelik also aims to create an ecosystem to include its stakeholders, such as its suppliers and customers in acting responsibly towards to the world and its resources as a value chain.

With its in-house R&D capabilities, Arçelik invests in sustainable innovation to produce industry leading products. Increasing plastic recycled content in products to 40% by 2030 is one of the ambitious targets Arçelik has set for the near future. To achieve this goal, Arcelik R&D develops high-performance and eco-friendly recycled plastic formulations to replace their virgin counterparts without sacrificing the durability of the products.

Arçelik has two WEEE recycling plants in Turkey, one in Eskişehir and the other one in Bolu. At our Waste Electrical and Electronic Equipment (WEEE) plants in Bolu and Eskişehir, a total of 299 GWh of energy was saved since 2014 until the end of 2019, the equivalent amount of energy almost 36 million households would use in one day. Through recycling, Arçelik saved the same amount of energy as 46 wind turbines of 2.5 MW power would produce in one year. In addition, we prevented the release of approximately 143,000 tons of carbon dioxide through the recycling of waste products and saved 6.2 million tons of water by replacing old-tech products with new eco-friendly ones.

3.1.2. Product description

Arçelik selected a Grundig Washing Machine for the demonstration purposes.

Grundig is a subsidiary of Arçelik A.S. established in 1955, Arçelik is one of the largest household appliance producers in Europe. It is also the leading home appliances brand in Turkey, offering extensive and innovative ranges of consumer electronics, freestanding and built-in appliances. Today the company provides products to consumers in over 140 countries.

The C-SERVEES demo product (reference number 7150341600) is a washing machine with a load capacity of 9 kg, max spinning 1200 rpm, energy efficiency class A+++ (-30%) and with connectivity features. It is produced in Çayırova, Istanbul and planned to be sold in Turkey & in the EU market.

This connected washing machine is part of Arçelik HomeWhiz products, aimed to provide the customer with home appliances to turn their home into a smart home.

Demo Product Features
Number of programs: 16
Connectivity: Wifi +BLE
Homewhiz
Spin Speed: 1200 rpm
Capacity: 9 kg
Fascia: Grundig
Control system: Good++
Motor: Prosmart (Brushless motor, 10-years guarantee)
Energy Class: A+++ (-30%)
Loading Diameter: 340 mm
Noise Declaration: 55/72 dB (Washing/spinning cycle)
Panel Language: Spanish and Turkish
Water consumption per year: 11000 L
Energy consumption per year: 152 kWh
Guarantee period: 2 years

Raw Material Information
Tub: Leo-PET (include 10% recycled PET bottle in the formula)
Detergent box group (except drawer): Eco-PP (include 63,5% recycled PP in the formula) - detergent box group: detergent box, detergent box cover, detergent box cover body
Inner cover: Eco-PP (include 63,5% recycled PP in the formula)
Control panel, front door and top plate: ABS
Motor board: PC/ABS
Shock absorber and hose holder: PA6.6
Packaging: LDPE and Styrofoam
Pulley: Aluminium
Drum: Stainless Steel

3.2. Demonstration activities

Washing Machine demonstration

Demo leader: ARÇELIK

Baseline	Demonstration activities
• No recycled plastic content	Increase recycled plastic content in specific WM components
• Product manual in printed form • No QR codes	Certify the recycled content by ICT and make this information available through a QR code in the product
• OEM information accessible only on request	Use QR codes and blockchain to provide information about materials, components and relevant procedures to all the value chain
	Develop a renting/eco-leasing model for B2B market. Demo sites: nursing home in Spain, student dorms in Turkey, partner company in Italy
• Linear business model (B2C/B2B sales)	Obtain feedback from B2B and B2C customers via questionnaires
	Capture customer feedback on the use of circular economy business models: living lab experience
• No refurbished product sales (only for Arçelik employees)	Initiate new business line to recover, refurbish and give a second life to used WMs with Emaús in Spain
	Develop dismantling and repair training programmes
• No refurbishment centres outside Turkey	Improve communication across the value chain to facilitate repair, refurbishment and reuse
• No refurbished spare parts used	Explore 3D printing potential for washing machine parts
	Dismantling of products and analysis of business case for recovery and reuse of EoL products' parts
• Recycled plastic bought from external sources	Analysis of the potential to recycle and reuse plastics from EoL washing machines

3.3. Demonstration results

3.3.1. Increase recycled content

In order to demonstrate the feasibility of introducing increased amounts of recycled plastic content and using the novel formula for PET, Arçelik manufactured 100 units of eco-designed washing machines based on a Grundig model (demo product number 7150341600), a washing machine with a load capacity of 9 kg, max spinning 1200 rpm, energy efficiency class A+++ (-30%) and with connectivity features. This model is sold in Turkey & in the EU market. The demo product was also provided with a new control panel and QR codes with information about the product and the C-SERVEES project.

Table 1. % Recycled content for reference and C-SERVEES demo products

Recycled Material Type	reference product with plastic scrap	demo product with plastic scrap	reference product w/o scrap	demo product w/o scrap
Recycled content: metal	7,68	7,95	7,68	7,95
Recycled content: plastic	1,6	3,49	0	1,95
Recycled content: glass	0,33	0,33	0,33	0,33
TOTAL	9,61	11,77	8,01	10,23

- → Reference product total recycled content with scrap: 9,61%
- → Demo product total recycled content with scrap: 11,77%

The 2% increase in recycled content is calculated considering the total weight of the washing machine (~74kg), including the concrete material which is not subject to being substituted by a secondary raw material. Considering only the total plastic content of the washing machine, this calculation would yield an actual increase of 23,93% on the recycled plastic content considering plastic scrap, and an increase of 13,43% on recycled plastic content without considering plastic scrap.

The LeoPET plastic material used for the C-SERVEES washing machine tub was obtained from recycled PET bottles, developed by Arçelik's R&D Center and patented by Arçelik.

The ECO PP material was developed from recycled PP sources and used in a novel formulation for the C-SERVEES demo product's detergent box (except drawer) and front door inner cover. The C-SERVEES project has given Arçelik the opportunity to use both recycled materials in Grundig 1200 rpm products for the first time.

A blowing agent was also introduced for plastic parts: inner cover, detergent box, detergent box cover, detergent box cover body. Blowing agent is a substance that can be used in plastic parts production in order to form a cellular interior structure. The agent causes a chemical reaction and emits gas which leads to bubble formation. Thanks to this agent, it is possible to develop eco-friendly parts and products by reducing plastic raw materials and energy consumption.

Figure 1. Manufacture process of the C-SERVEES washing machines

New labels were introduced in the C-SERVEES demo product's panel:

- QR Code Label
- C-SERVEES Label

The recycled content of the washing machine was certified using the blockchain-based Circularise tool, to provide absolute proof of the circular economy solution using decentralised, encrypted data to track material and product characteristics. By scanning the QR-Code on the product, anyone can access the data of the digital twin and verify that it has been certified as recycled.

Circularise mobile App can be downloaded from the following links:

- For iOs: https://apps.apple.com/us/app/circularise/id1243006391
- For Android: https://play.google.com/store/apps/details?id=com.cirqr&hl=en

3.3.2. Obtain customer feedback about eco-leasing models for WMs

Arçelik had previously considered the pay per use models, which did not turn out to be feasible due to a variety of factors. Extensive persona studies were carried out to understand how consumers react to new business models such as pay per use or rent model. The personas subject to research included: 54% single people, 23% couples, 15% AirBnB & Dormitory professionals, 8% construction professionals. The persona included working singles, university students, young couples planning to get married, etc. These studies consider both washing machines and TV sets.

The below mentioned factors which have been outlined in Arçelik's previous studies also contributed to our mindset for coming to a conclusion on the feasibility of the model for C-SERVEES project and Arçelik's business strategy. The main insights were:

- Most important criteria for washing machines include short programs, spin speed, volume of the tank as well as less water and electricity consumption. The families with kids also attach greater importance to drying the garments.
- B2C consumers are generally ok with the idea of using a second-hand product if the hygienic conditions are strictly improved. A refurbished product is associated with eco-friendly and sustainable product claims. They are willing to use a refurbished product as long as the product is hygienic, clean, sterilized and smoothly working.
- For B2B customers such as dormitory or AirBnB owners, as long as the appearance of the appliance is good, it does not matter if the product is second hand.
- Both B2B-B2C consumers see an advantage in being able to afford to upgrade a new model within a few years with the rent model.
- Not owning a product provides consumers the ability to be free and decreases the hurdle with carrying the home appliances when moving to a new home but at the same time, some users express their dislike for paying money for a product they will not own at the end. This raises the probability that after a prolonged rent period, the customer can be offered the product with a discounted price.
- For B2B purposes, the rent model provides flexibility to the business owners such as dormitory or hotel owners in terms of the decreased investment cost.
- Dormitory owners express further interest for such systems if the same rent package offers several appliances and not just one appliance.
- In a B2B scenario, having connected appliances and a centralized ICT payment tool might not be as necessary as it is in the B2C scenario
- Arçelik's washing machines are not well suited for hotels or laundromats as these require an industrial type of washing machine. However, elderly care homes and dormitories do provide an opportunity for this business line.
- Students, singles and dormitory owners are much more interested in the product compared to married couples and couples with children.
- All time service guarantee is the most attractive point for single people, but it still does not justify the price as they do not expect a high quality machine to break down in 3-4 years.

3.3.3. Feasibility study of eco-leasing model for corporate customers

Arçelik studied the viability of introducing a renting/eco-leasing model for their corporate customers, offering the product as well as maintenance services and taking care of the products once the client decides to terminate the contract or requests a substitution or upgrade. The washing machines would then be examined to determine the need for repair or refurbishment and given a second life whenever possible, in accordance with circular economy principles.

To carry out the eco-leasing demonstration, washing machine demo products were sent to selected locations in Turkey, Spain and Italy. An agreement was reached between Arçelik and the demo sites both in Turkey and Spain. In Italy, C-SERVEES partner ERION agreed to place two washing machines at their company's facilities to test intensive use of the newly eco-designed products.

In Spain, 25 washing machines were installed across 7 centers of Fundacion Matia, an institution for elderly care. In Turkey, 35 washing machines were installed in dormitories at the Bolu Abant İzzet Baysal University and another 40 in Samsun University dormitories. In Italy, 2 washing machines were installed in Ecodom's facilities for worker's use.

Figure 2. Washing machines during the demos in Fundacion Matia kitchen facilities (left) and dorm facilities in Turkey (right)

A survey was created and shared via QR code to obtain customer feedback from the demo sites, related both to the product and the leasing model. The survey provided the opportunity to compare the results obtained with those of a previous survey made while preparing the CEBM mode, where Arçelik conducted extensive persona studies to understand how consumers react to new business models such as pay per use or renting models. The second benefit was the use of the outputs for the feasibility of the rental model. For example, learning that customers prefer the rental period to be no less than 3 years.

The feasibility studies for the WM rent model were simulated for the Spanish and the Turkish markets. The results show positive NPV for a 10 year period, especially for Turkey due to the fact that labour costs are cheaper than in Spain. Sensitivity analyses show that the most important factor in making this model economically viable is the increase in the number of customers.

The risks Arçelik might face if this business model is to be conducted is provided below. As we see in the market, competitors set up a different business structure and a different company and approach this business in the mindset of a start-up. After the feasibility study, despite the positive NPV, we are also of the opinion that since the circular economy business models are new models, their NPV results should not be compared directly that of a business-as-usual scenario and a start-up mindset is needed.

Table 2. Items factored into consideration for the feasibility study

<table>
<tr><th>Revenue Items</th><th>OPEX Items</th><th>FCF Items</th></tr>
<tr><td>• Current Sales price of the TV: EUR 500</td><td>• Installation costs</td><td rowspan="2">• 4,5% WACC for Spain and 8,3% WACC for Turkey (EUR based valuation)</td></tr>
<tr><td>• Current Sales prices of the WM: EUR 482</td><td>• Logistics costs</td></tr>
<tr><td>• Optimum monthly rent price: EUR 15</td><td>• Product service call rates, service and maintenance costs</td><td>• 10-year term</td></tr>
<tr><td>• The prices and COGS are moved forward by inflation rates annually</td><td>• Refurbishment costs</td><td>• Maintenance CAPEX</td></tr>
<tr><td>• Rent duration: 3 years</td><td rowspan="4">• ICT tools to allow for maximum interaction with the customer and allow collection of monthly rental fee (Customer application costs (hardware, software))</td><td rowspan="2">• NWC need</td></tr>
<tr><td>• EUR 35 rent deposit and EUR 70 cancellation fees</td></tr>
<tr><td>• Number of initial customers</td><td rowspan="5">• Taxes</td></tr>
<tr><td>• Customer churn rates within a specific period</td></tr>
<tr><td>• Continuity of demand from customers following the initial contract term</td><td>• Marketing and sales expenses</td></tr>
<tr><td>• Refurbished product revenue</td><td rowspan="2">• General and Administrative expenses - including call centre costs, credit card commission costs, etc.</td></tr>
<tr><td>• Scrap revenue</td></tr>
</table>

Risks for turning this into an applied business model by Arcelik:

- In Turkey, dealers provide very long instalments without any financial obligation to the consumers and therefore they may not be interested in rent.
- In Turkey, where Arçelik's dealer network is very strong, this creates a competitive business model for dealers. In Spain, we do not foresee this risk.
- The model is very sensitive to the number of customers to use the program as well as the service and installation costs. If the churn rate of customers cannot be properly factored, this might pose risks in terms of feasibility of the model.
- The variable costs such as marketing expenses or other administrative expenses might go higher than planned.
- The refurbished products might not meet as much demand as anticipated by the model and this might be a downside for the feasibility of the second-hand refurbished sales forecasts.

Feasibility Results:

Changes in the below mentioned parameters make the feasibility results sensitive:

+/- changes in price
+/- changes in number of first contract customers
+/- changes in installation, warranty, logistics costs and other administrative expenses
+/- change in WACC

Differences between the model in Turkey and Spain: Cost of labour is cheaper in Turkey and thus the installation, service, logistics and refurbishment costs are cheaper. The WACC is taken as 4,5% in Spain and 8,3% in Turkey (valuation in TR done based on EUR currency).

The table below shows the results from the sensitivity analyses considering Spain and Turkey as target market countries.

Table 3.Washing Machine Leasing Feasibility in Spain and Turkey

Price	Increase in customers	NPV - Spain	NPV - Turkey
-10%	-10%	-67%	-59%
-15%	-15%	-84%	-76%
-20%	-20%	-96%	-87%
-25%	-25%	Not feasible	-94%
no change	-10%	-50%	-46%
no change	-15%	-65%	-61%
no change	-20%	-77%	-72%
no change	-30%	-90%	-85%
no change	+10%	88%	80%

Customer numbers are the main factor impacting the feasibility analyses, both the increasing rate of new contracts and the recurring customers. Although the Net Present Value is positive, the actual number is not very high, which does not support the adoption of this business model as substitute for the current 'business as usual', but rather as an additional scenario.

3.3.4. Customer experience at living labs

To test the acceptance of final user towards the eco-designed and refurbished products, pedagogic/testing events were carried out with potential customers in Emaús' ecocenter in Arrasate (Basque Country, Spain). The objective was to obtain relevant feedback for the project regarding eco-design, eco-leasing and WEEE recovery and reuse, and this experience is known as a "living lab". This process has been designed and carried out by the strategic design company H-Enea.

The process consisted of an analysis to understand the context of the products proposed as a purchase option. This analysis includes the perspective of manufacturers and reconditioners of C-SERVEES products, in this case televisions and washing machines. A demonstration space was designed in the Emaús sales area. User profiles that can match with the offered products were created and defined. Once defined, they were recruited. A total of 17 tests were carried out to measure the interest in the reconditioned washing machine product and another 17 to measure interest in the reconditioned television product. Subsequently, the data were collected and the test results were analysed.

Different infographic prototypes were designed for the living lab test. The main objective of the infographics is to describe the C-SERVEES pedagogically to explain the results of the project related with the business models for televisions and washing machines.

The infographic prototypes were contrasted by all project partners involved in the demonstrations. As a result, the demonstration was illustrated by a large general C-SERVEES description in 6 steps with examples of the results of each of the steps.

The usage profiles varied between young profiles and environmentally conscious profiles. The questionaries for Washing Machine and Televisions are similar, to see the predilections of the users. Below the main conclusions of the experience are summarised.

The **eco-design** of new household appliances and the **3-year renting** model looked attractive to participants. They approved of purchasing reconditioned appliances but expressed doubts about the durability of these products due to the higher frequency of use as compared to a standard household product.

The participants expect the washing machine to last longer than the television, so they may be more **reluctant to buy** if the product they purchase comes from a leasing where the frequency of use of the appliance is high, as in supervised flats with several people are living together.

Participants are **more willing to buy** a refurbished TV than a refurbished washing machine. It is likely to be related to the fact that washing machines are associated with cleanliness and at certain prices consumers prefer to buy something new because they do not know the cleaning habits of previous users.

As for the proposed **prices**, they are seen as competitive with respect to the initial prices, but there is a representative percentage of people in all the sessions who were unsure whether they would buy.

The participants are interested in the **materials** contained in household appliances and their impact. They are concerned about the **deterioration** of household appliances before being sold on the second-hand market. They believe there is a lack of data on whether appliances are designed to last longer or not. It is perceived that a lot of information is given on how eco-design has been improved, but less about **durability**.

Figure 3. Qualitative inputs based on the feedback received at the C-SERVEES living labs.

3.3.5. Use 3D printing for refurbishment operations

During the washing machine demonstration period, Particula worked in cooperation with Arçelik and Gaiker to develop a methodology to obtain and validate 3D printed washing machine spare plastic parts.

Arçelik prepared and sent several sets of three-dimensional objects (3D objects) in digital format (.stp CAD file) introducing several washing machines parts for testing and 3D scanning to determine the most suitable 3D printing technology for the washing machine parts.

Furthermore, different raw materials and formulations provided by Arçelik were evaluated for potential use and compounding processes with the goal of producing 3D filaments and 3D printed parts in a vertically integrated system which will be in accordance with CEBM developed model. Fused Deposition Modelling (FDM) technology was selected as the most suitable one for the selected pieces, considering the quality and cost required.

Printed models were created with PLA (polylactic acid), ABS (Acrylonitrile Butadiene Styrene), PETG (Polyethylene Terephthalate Glycol), rPETG (recycled Polyethylene Terephthalate Glycol), Facilan C8 and PLA Strongman (polylactic acid) and sent to Arçelik for testing. Results of the tests showed that rPET and PETG filament are the most suitable for washing machine spare plastic parts production.

Initially, detergent box group was selected for 3D printer trials. This is a visible part, and also a part that the customer values for hygiene, so they may wish to change it at some point. However, this part was still too large for the 3D printer. Since the demo product includes a liquid detergent container group, Arçelik & Particula decided to select this part due to the small dimension. Particula sent 3D printed parts for Arçelik validation tests.

Figure 4. 3D printed siphons, left to right: original liquid detergent siphon, 3D printed siphon, 3D printed siphon after the test, 3D printed and polished siphon, cracked siphon after testing.

The unpolished part' siphon surface clogged with detergent in early cycles and also deformation was observed during the tests. For the polished part, in early cycles swelling and cracking occurred. Therefore, these specimens did not pass approval tests.

From the results obtained, it was concluded that producing washing machine parts by 3D printing was quite challenging, due to the limited selection of 3D printable parts and the conditions under which they need to work (high temperature and chemicals).

3.3.6. Improve repair and refurbishment operations

As part of the demonstration, Beko Spain, Arçelik and Emaús worked together to implement standardised repair and refurbishment operations for the washing machines once the renting period is completed and/or the products need to be repaired/replaced.

The most relevant parts for refurbishment operations were identified: belt, detergent box group, door lock, drain pump, front door, gasket, heater, motor and shock absorber.

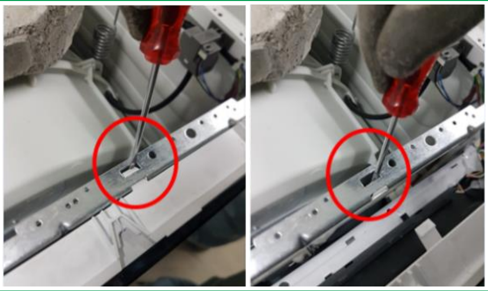
For these parts, replacement instructions and manuals were provided by Arçelik R&D and were translated into English and Spanish. These protocols will be used in the preparation for reuse operations to grant the used products a second life and sell them at Emaús facilities. Figure 5 shows an extract from one of the manuals created during this activity.

Deterjan kutusu - pano bağlantı vidası sökülür.

Detergent box - panel connection screw is removed (indicated with red circle).

Pano braket - pano bağlantısı sökülür.

Bracket - panel connection is removed (indicated with red circle).



Panodaki 3 adet soket sökülür.

Sockets are removed (indicated with red circle).

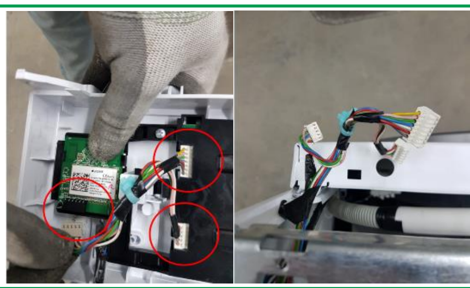
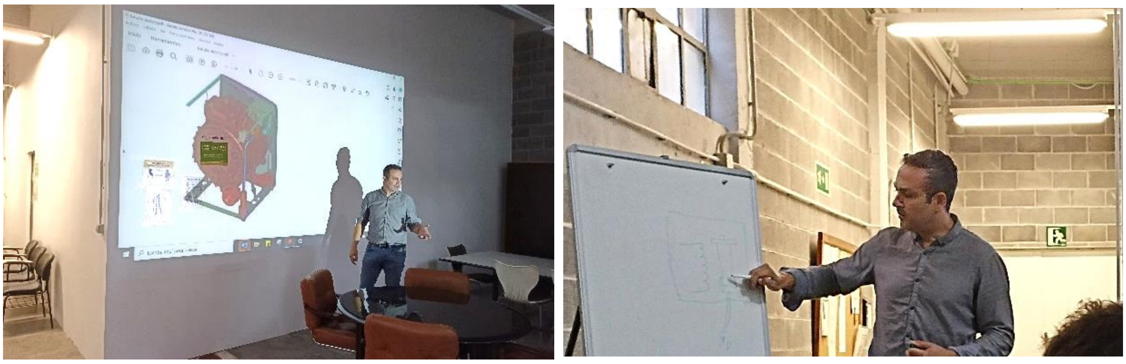


Figure 5. Steps from the detergent group box replacement manual prepared for C-SERVEES refurbishment operations with WMs.

There has been an improvement in the quality of the protocols, increasing the WEEE refurbishment or recovery rate from 3% to 3,5%, which is above average.

Beko Spain organized trainings for Emaús personnel to improve the skills of workers at risk of exclusion that are part of Emaús social programs, facilitating their integration into the labour market.

Training was imparted to Emaús workers to use the procedures in their WEEE reuse preparation center, organized by Sareteknika. The first training session was focused on generic refurbishment processes applicable to all types of washing machines of any brand or maker. The second training session was more focused on specific refurbishment processes based in Arçelik's eco-designed washing machines.



1st training session – generic refurbishment

2nd training session – refurbishment of washing machines

Figure 6. Training courses on WM refurbishment with Emaús workers

Among the refurbishment operations, the gasket replacement is one of the most labour intensive and difficult to perform as it requires considerable manual dexterity. The belt replacement, on the other hand, was the easiest operation.

In terms of profitability, the review and the comprehensive cleaning operations which verify the proper functioning of the machine as well as the belt replacement were the most cost-effective.

3.3.7. Analysis of business case for recovery and reuse of end-of-life product's parts and materials

Recovery of WM parts from dismantling operations

Three washing machines from the dorms in Turkey were sent to Greentronics in Romania for an in-depth analysis of the dismantling operations. 16 different parts/components of the WM were considered relevant for potential use as spare parts:

1	Cabinet & back wall	9	Valve & drain pump
2	Top plate	10	Belt
3	Detergent box group	11	Pulley
4	Panel (with electric card group)	12	Motor
5	Front door	13	Spring
6	Front wall	14	Welded tub group (tub & drum)
7	Gasket	15	Heater
8	Upper& lower counterweight	16	Cable group

Greentronics analysed the viability of recovering the list of spare parts and prepared a dismantling procedure for the demo product. The aim was to facilitate the extraction operations of non-damaged spare parts from EoL washing machines and to provide expert advice on design-for-recycling or design-for-dismantling measures to Arçelik.

Greentronics also recorded dismantling times for the whole washing machine and for all selected parts individually. A dismantling template was used to analyse the cost of recovering pre-selected WM parts/components based on time/human labour/shipment costs.

	Recycler
Time to dismantle/check parts (mins)*	22
Time to pack parts ready for shipment (mins)*	14
Cost to pack the parts (€)*	50
Cost to ship the parts (€)*	180/730
Hourly rate (€)	3,8

**Average time per WM part*

The template was completed with the following information:

- an average time of 22 minutes per WM part
- a packing time of 14 minutes for the components
- an average cost of the materials to protect the parts
- cost options to ship the parts, considering two destinations: Arctic Plant in Romania or Arçelik facilities in Istanbul

After this analysis, the following conclusions can be derived:

- Even though Arçelik has a WM factory in Romania (Arctic Plant) there is no Reassessment Center like in Turkey, so at the current time spare parts could not be used there.
- Finding a company in Romania to purchase these parts and use them for washing machine refurbishment processes would make this business case possible, but the current costs of the dismantling, packaging, labour and shipping provided by dismantlers is not competitive compared to the cost of obtaining new components. This makes it

unlikely for repair companies/manufacturers to opt to use these recovered components instead of new ones.

- Although these parts could be used in the Arçelik Reassessment Center in Turkey, transportation costs in this estimation render this solution too costly.
- As discussed in the first section of the report, the recovery of the components by a refurbishment company rather than a recycler can add more value considering the complexity of the recycling process and the low chances of recover at the site of the recyclers coupled with high costs. Additionally, due to the logistics costs, it makes more business sense for the sake of circularity overall to invest in infrastructure to increase number of sites that can recover components in close proximity to manufacturers/repairers.
- Arçelik has its own washing machine refurbishment centre in Turkey and the current dismantling costs and labour costs provided by the recyclers are not competitive with the current costs incurred by Arçelik in Turkey.

Recovery of WM secondary raw materials from dismantling and recycling operations

The main objective of the study was to analyse the technical feasibility of reusing polypropylene (PP) from end-of-life products belonging to Arçelik brands and incorporate the recycled plastic material into new WM parts.

At the beginning of the study, two plastic material streams from end-of-life washing machines were identified as potential candidates for recovery and reuse: ABS and PP. Although ABS is used in larger quantities in the WM, the requirements for this material included specific color and gloss which is difficult to obtain from secondary (recycled) materials. Due to this fact only PP was selected for this study.

Detergent drawers from end-of-life Beko and Grundig washing machines were collected by Emaús at their facilities. Both brands are sold by Arçelik in Spain, so in order to ensure that the composition of the WM parts was within Arçelik standards only those were selected for this study. The WM part recovered was the detergent drawer as this is entirely composed of PP.

Figure 7. Detergent drawers from EoL washing machines (Beko/Grundig) and PP flakes obtained

To ensure only PP was collected and processed, the pieces were analysed in Gaiker by NIR spectroscopy to detect the presence of non-PP plastic pieces or inserts. Once these non-desirable parts were removed (the front panel of the detergent drawer, for example, is made in ABS), the rest of the material was processed to obtain recycled PP flakes.

The material was then processed by Aimplas to obtain testing samples for characterisation. Received shredded sample from Gaiker was washed and dried to remove detergents, soaps, dust and humidity. Grinded material was then shaped into injected test specimens, used for characterization.

Table 4. Characterisation of recycled PP from EoL washing machine detergent drawers.

	STANDARD	ACCEPTANCE LIMITS PP %43 $CaCO_3$ filled	RESULTS OF RECYCLED PP
PHYSICAL PROPERTIES			
Density, g/cm^3	ISO 1183	1,3	1,268 ± 0,001
Melt Flow Rate, g/10 min	ISO 1133	10	16,2 ± 0,5
MECHANICAL PROPERTIES			
Flexural Modulus, MPa	ISO 178	2100	2370 ± 60
Flexural Strength, MPa	ISO 178	33	33,4 ± 0,4
Izod Impact Strength, kJ/m2 (notched)	ISO 180	3.1	3,04 ± 0,44
Tensile Strength at yield, MPa	ISO 527	22	17,8 ± 0,1
Elongation at yield, %	ISO 527	3,8	3,8 ± 0,1

The tests showed positive results and are compliant with Arçelik specs except for physical properties such as MFI and mechanical properties such as Izod and tensile strength. These properties can be improved to meet Arçelik standards by including virgin materials and reformulating. According to the usage area of this raw material, the expected material properties can be accepted or improved.

Arçelik WM plants are located in Turkey, Russia and Romania and Turkey restricts the import of recycled raw materials. Therefore, although using the recycled raw materials recovered by Emaús/Greentronic/Indumetal would prove to be a very viable option if Arçelik would be able to import recycled raw materials, in practice, this is not possible due to the regulation in Turkey. It would be good option for Romania factory. On the other hand, Arçelik has its own WEEE recycling plants in Turkey and the products collected from the market regardless of their brand are manually dismantled in these facilities. Arçelik can try to be collect these materials from own WEEE plants. Turkey can be recycled and recovered to be used in WM components like detergent drawer.

3.3.8. Initiate new business line to recover, refurbish and resell used WMs

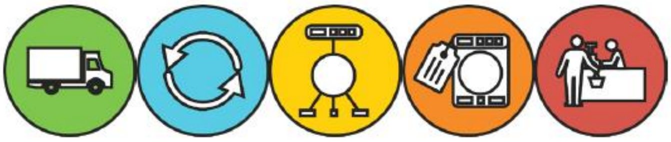
For the demonstration’s purposes, 18 ecodesigned washing machines and 44 ecodesigned televisions were installed in Matia Fundation’s sites for a year, with the aim of testing the devices in a real environment where a significant use was made in order to obtain feedback about their design and use conditions and, after that period, testing and optimising the refurbishment processes using the same devices.

Thanks to this three-way collaboration between Emaús, Matia Fundation and Arçelik, a new business opportunity has been created. That opportunity is related to a household appliances eco-leasing model, described below.

The collaboration proposal between the company Arçelik and Emaús Fundación Social aims at generating an alliance that contributes to developing the sustainability and circular economy strategy of both organizations.

The opportunity arises from the obligation contained in the Spanish Royal Decree (R.D)-Law 110/2015 on waste electrical and electronic equipment. In its article 43, it indicates that producers, through Extended producer responsibility (EPR) schemes, must finance the treatment of domestic WEEE deposited in the facilities of local entities and distributors; as well as the waste management organizations with whom they have reached agreements.

The following collaboration proposal specifies areas in which it is possible to work together and that can be applied to the development of all the PRCs that Arçelik wants to support internationally. In this way, the collaboration in Spain between Arçelik and Emaús Fundación Social can facilitate the replication of these experiences in other countries.



Contribution of Arçelik	Contribution of Emaús Social Foundation
Ongoing training process for employees	Waste recapture to comply with legislation
Eco-design for the circular economy and product repairability (modular design)	Recommendations for eco-design and repairability of products
Facilitate agreements with distributors	Preparation process for reuse and recycling
Facilitate agreements with logistics operators	Collaboration with logistics operators and platforms that are part of the Beko network and with its commercial network
Develop joint circular economy marketing campaigns (institutional and private clients)	Consumers’ education and awareness
Possibility of studying a new business model linked to WEEE	Collaboration in the creation of a community

3.4. Environmental, social and economic analyses

Life Cycle Assessment

The environmental impacts were determined using the LCA methodology according to ISO standards (14040/14044). The assessment comprised the whole life cycle of the products, including extraction and processing of raw materials, manufacturing, transport and distribution, use, maintenance (when required) and end of life. The method ReCiPe was used to assess 18 midpoint impact categories, in this summary only four representative ones are shown: global warming (climate change), human health, ecosystems and resource use.

Environmental benefits due to recycling were not added to the total life-cycle environmental impact of the EEE products but they are shown as recycling credits. Additionally, the Material Circularity Indicator (MCI) was determined to assess the circularity of the current products and business models.

Life Cycle Costing

The Life Cycle Costing (LCC) methodology was used to assess all economic costs associated with the complete life cycle of the target product, including internal cost (related to product manufacturing, use and end of life), as well as environmental externalities. The costs of environmental externalities were calculated by monetary valuation of the endpoint environmental impacts (obtained with the LCA).

Social Life Cycle Assessment

The social impacts for the target product were calculated using the S-LCA methodology. In particular, the method and the indicators of the Social Hotspot Database were used. A cradle-to-gate assessment was applied, with 26 social subcategories grouped into 5 categories. The SHDB offers a weighted model that converts the impact values of the social subcategories into aggregate impact values for each social category, which in turn can be aggregated into a single global social footprint for the products (the so-called Social Hotspot Index or SHI).

The results are shown for one washing cycle with an Arçelik 7150370100 washing machine as Reference product and Arçelik 7150341600 as C-SERVEES product, excluding the use of energy and consumables.

Circular economy actions considered in the analyses:

- Eco-PP inner cover and detergent box group.
    - Inner door: 64% recycled
    - Detergent box: 64% recycled
- Recycled PET TUB.
    - Tub: 10% recycled
- Mass reduction in tub, inner cover and detergent box group.
    - Reduction of 1,09 kg in tub
    - Reduction of 17 g in inner cover
    - Reduction of 21 g in Detergent box

Table 5. Main environmental, life cycle costs, and social life cycle indicators for one washing cycle of the washing machine.

Indicator	Unit	Reference	C-SERVEES	Relative improvement
LCA				
Global warming	kg CO_2 eq	0,141	0,139	1,3%
Human health	DALY	1,11E-06	1,11E-06	0,2%
Ecosystems	species.year	1,20E-09	1,20E-09	0,3%
Resources	USD2013	1,27E-02	1,27E-02	0,8%
Recycling credits	kg CO_2 eq	-1,17E-02	-1,17E-02	0,0%
Material Circularity Indicator	-	0,25	0,25	1,7%
LCC				Relative reduction
Internal	€	0,8126	0,8126	0,00%
External	€	2,0454	2,0451	0,02%
Total	€	2,8581	2,8577	0,01%
S-LCA				Relative reduction
Labour Rights & Decent Work	Pt	0,24	0,24	0,0%
Health & Safety	Pt	0,29	0,29	0,0%
Human Rights	Pt	0,17	0,17	0,0%
Governance	Pt	0,38	0,38	0,0%
Community	Pt	0,14	0,14	0,0%
Total – Social Hotspot Index	Pt	1,22	1,22	0,0%

All these changes in the materials used reduced the global warming impact category during component, manufacture and at the end of life. However, energy and detergent, the most impactful, remain unchanged, leaving a total reduction for the whole life cycle by 0,2%. No change is produced in the recycling benefits. These improvements increase the material circularity indicator 1,7%, from 0,249 to 0,253.

The reduction in the external costs is due to the reduction of the environmental impact.

3.5. Life-cycle validation summary

From the results of the environmental, social and economic analyses of the washing machine demonstration it can be concluded that for products with similar characteristics in terms of composition, use and end of life, it can be reasonable to scale up the demonstrator's results. In addition, the results are expressed on a functional unit basis so that they can be compared with other products using the same functional unit.

The results obtained are credible due to the data quality used. The data used to create the inventory model is as precise, complete, consistent and representative as possible with regard to the goal and scope of the study.

- Primary data were provided by Arçelik from the most recent BoM of the product. The data used for the study is considered to be of the highest precision. Ecoinvent database was the main secondary data source used to model the product system.
- Completeness was judged based on the completeness of both the inputs/outputs per unit process and the unit processes themselves.
- Consistency refers to modelling choices and data sources. The goal was to ensure that differences in results occur due to actual differences between product systems investigated and compared, and not due to inconsistences modelling choices, data sources, characterisation factors, etc.

Also, an LCA sensitivity analysis on lifetime and use intensity was performed to determine the conditions under which faster or slower changeover of the products may be beneficial under a circular scenario. Sensitivity dependence is the relative variation of the environmental impact with respect to the relative change in the number of units over the lifetime.

The results for the washing machine are shown in the figure below.

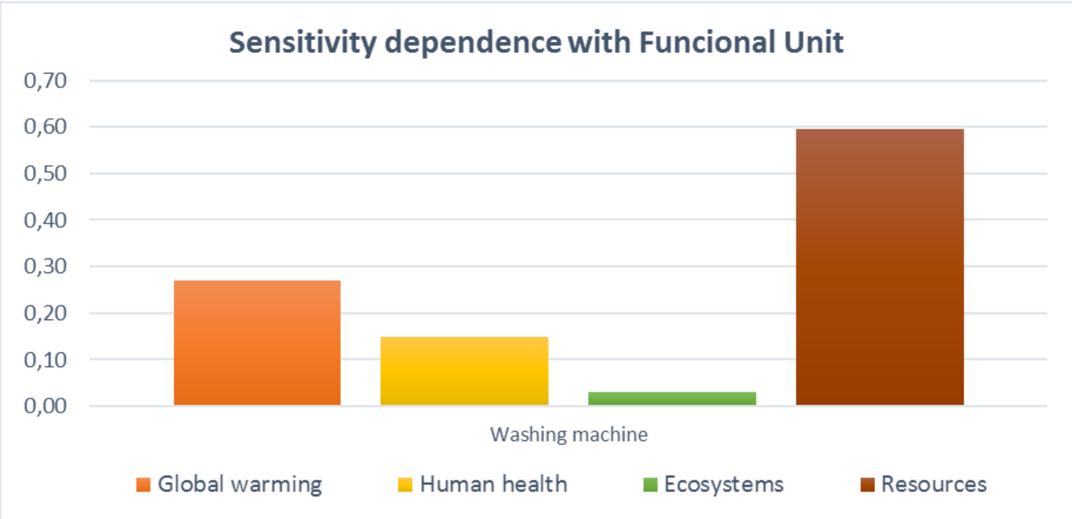


Figure 8. Sensitivity dependence with the change in the number of units during the lifetime of the washing machine

All values of the SD are less than one, meaning that the relative environmental impacts variation is less than the relative variation of the number of units. Values closer to 0 mean lowest dependence. According to these results, the washing machine could still further improve its environmental impacts by increasing their lifetime in the future.

The limitation of the conducted analysis is that the improvements considered do not focus on the use phase. It can be found that electricity and detergent consumed by the washing machine have by far the highest environmental impacts for the use phase, while the contributions of the product distribution and water consumption are comparatively very limited. In addition, when comparing both scenarios for electricity consumption, it is clear the important role that the increase of renewable sources in the electricity mix can play in the coming years.

The use of a detergent with less environmental impact could affect the use phase positively and reduce the impact of the washing machine.

3.6. Manufacturer's review

In terms of trying new circular economy business models in washing machine production, the C-SERVEES projected acted as a catalyst to speed up Arçelik's interest in working on a new business opportunity focusing on selling second hand refurbished products in Europe. This can involve either Arçelik working with a professional repairer like EMAUS or setting up Arçelik's own centralized repairing facilities in Europe. As the first step towards this action, post C-SERVEES project, Arçelik has contacted its major retail customers to work on a mutual project to repair and refurbish products and sell them via the retailers' channels in the EU. EMAUS is also helping Arçelik on finding a manufacturer with enough capacity to repair washing machines in the EU. Arçelik's first focus will be on pilot countries such as Austria or the UK. One of Arcelik's retail customers also sees a huge potential (current market is around 12M USD and is forecasted to reach 32M USD in 2026). in this newly developing market in the EU, given the rising costs of living due to inflation which urges customers to look for more economic solutions. Combined with energy efficient offerings, the second hand product market will be one of the interesting areas of play for home appliance manufacturers going forward.

With the help of C-SERVEES project, we have seen that the repairers in the EU such as EMAUS are more equipped to repair washing machines and based on customer questionnaires carried out during C-SERVEES, we have seen there is also demand in the market from customers.

It was the first time we started working on using ICT technology to trace the recycled raw materials from suppliers. Post C-SERVEES project, we collaborated with Circularise to work on tracing of bio-composite materials with Circularise's ICT technology. Together with 10 other partners in different industries, under Circularise's leadership, we involved in a project in which public blockchain was tried for mass balance certification of biomaterials used in products.

With the upcoming regulations in the EU on Digital Product Product Passport, thanks to C-SERVEES project, we now have expertise on digital raw material tracking from suppliers and we will continue to work on expanding the use of ICT tools in our material tracking system. As the market gets further regulated on the use of recycled and biomaterials and more assurance certificates will be required, partnership with Circularise will help us on this journey.

In the C-SERVEES project, for the first time we tried using recycled plastics in visual parts in the washing machine. The trials were successful in terms of perceptional and mechanical quality and we will continue to integrate recycled plastics in the visual parts of the machine going forward. Additionally, it was the first time we used recycled plastics in the tub of 1200 rpm Grundig washing machines. We have expanded the use of recycled plastics in all washing machine groups after C-SERVEES project.

During the project we also had the chance to try 3D printing. It is in the early stages and not ready to be put in serial production at the moment. We will follow improvements related to 3D printing, especially to be able to use these parts as spare parts.

4. Printers and laser toner cartridges demonstrator

The printer and toner cartridges demonstration was led by Lexmark and this section provides an overview of the demonstration activities, results and findings during the demonstration period.

4.1. Company and product description

4.1.1. About Lexmark

Product sustainability has been a priority for Lexmark since its inception. Continual work on energy efficiency, circular design, durability and remanufacturing contribute to our mission of minimizing the impact on the environment. Lexmark performs life cycle assessments (LCAs) on all branded product families. These assessments enable us to understand each phase of the product's lifecycle and focus on areas where we can improve.

Durability is a key part of Lexmark product design. Products are intentionally designed to last over 7 years. Materials are selected to ensure products are robust, durable and meet strict ecolabel and regulatory compliance requirements. This longer life avoids additional manufacturing and the creation and use of virgin material.

Lexmark engineers select **post-consumer recycled (PCR)** plastics in hardware and supplies to lower the product environmental impact. With a goal of 50% PCR content in plastics in both devices and supplies by 2025, in 2021, we achieved an average of 39% in both products.

The metal content in Lexmark printers is dominated by steel products, primarily used for the sturdy steel frames, that provide extended product life. Published industry averages indicate that commercial grades of steel commonly contain between 30% and 80% recycled content

Over 90% of the materials used in hardware products by weight are **recyclable**. Our cartridges are primarily comprised of the same materials as the hardware and are designed for zero waste to landfill. We favour the use of post-consumer recycled (PCR) materials over the use of biobased materials for durability and recyclability.

Through our award-winning **Lexmark Cartridge Collection Program (LCCP)**, cartridges are collected and recycled in our R2 certified Recycling centre. The LCCP facility utilizes the materials from the returned cartridges back into our own products for a true closed-loop process. Our engineers innovated our own in-house extrusion and compounding process to produce high quality, 100% recycled resin that is reintegrated into new toner cartridges. We have qualified over 60 components with up to 100% closed-loop PCR plastic. Lexmark also offers a responsible choice for disposal of end-of-life printers. Through our **Lexmark Equipment Collection Program (LECP)**, Lexmark also provides additional options to give a second life to printers.

Lexmark extended its web platform "Collected by Lexmark" to printers to boost the 'Take back and Buy back' process via more performant digitalisation processes. Take back and Buy back are processes aiming at getting "end of life" printers back to the remanufacturing location in Poland for the aim of being dismantled for parts and remanufactured.

Lexmark prioritizes **reusing components over recycling** in alignment with the waste hierarchy. Lexmark is an industry leader in the use of reclaimed plastic with 39% of the plastic content, by weight, in Lexmark branded toner cartridges coming from post-consumer plastic. In fact, 65% of this reclaimed plastic is from remanufacturing reuse, with 10% coming from the LCCP PCR feed stream and the balance coming from purchased PCR resin. Our goal is to increase the use of reclaimed plastic through the PCR and product reuse processes to 50% by 2025.

Lexmark's goal is to achieve **carbon neutrality** across its global operations by 2035. The company is implementing a detailed plan of certifications and initiatives in its processes and manufacturing complexes, then offsetting remaining carbon emissions by funding certified projects through Climate Impact Partners.

- Single-use plastics in product packaging reduced by 19% since 2018
- Greenhouse gas emissions reduced by 62% since 2005
- Water consumption decreased by 72% since 2005
- Average recycled content plastic use is 39%, with a goal of 50% by 2025

4.1.2. Product description

Three Lexmark printer models were selected, from one of the simplest printers in the company’s product portfolio to one providing the highest level of functionalities. They have been chosen based both on their representativeness of the various market segments and on their functionality and engineering content.

Same as most of the industry players, Lexmark doesn’t develop all the printers of its product portfolio inhouse. Indeed, for some product ranges, manufacturers make the choice to acquire the printer from another OEM. While this strategy has benefits by avoiding significant investment, when it turns to refurbishing, the control on the spare parts supply chain is diluted and can be a challenge, therefore, investigating harvesting spare parts becomes of high interest. For this reason, one of the selected printers is an acquisition one (A3 model).

The models selected are shown in Figure 9:

- A low-end Multifunction, Color Lexmark OEM A4 printer CX510
- A high-end Multifunction, Monochrome Lexmark OEM A4 printer: MS812
- A high-end Multifunction, Color acquisition A3 printer: X950

OEM A4 printer CX510 OEM A4 printer MS812 A3 printer X950

Figure 9. Lexmark printers used during the demo

Supplies description

The demonstrator includes the printer supplies, which were also investigated in order to determine how to improve the recycling process and overall circularity of the LCCP. 3 different categories of supplies, representatives of the various product architecture and design/material found in a Lexmark cartridge, were selected.

MS/MX Toner Units C95x Bottle MS/MX Imaging Unit

Figure 10. Lexmark toner cartridges used during the demo

4.2. Activities

Printer and toner cartridges demonstration

Demo leader: LEXMARK

Baseline	Demonstration activities
• Managed Print Services, mostly new devices, with limited sales for refurbished printers	Obtain feedback from customers testing refurbished products
	Obtain feedback from competitors and other actors in the value chain
• LCCP successful for the recovery and refurbishment of toner cartridges	Expand LCCP and/merge with LECP program (collecting and refurbishing whole printers and key components)
	Use ICT to improve information sharing across the supply chain: Smart Questioning and information exchange tools
• High dismantling and refurbishing costs	Dismantling exercise with recyclers to analyse potential for eco-design with 3 different printer models
	Analysis of dismantling operations with recyclers' feedback, improvement of dismantling protocols with Lexmark's remanufacturer
	Validation of business case on recovered printer parts for refurbishment operations
	Explore competitiveness of 3D printing for spare plastic parts
• No recycled plastic coming from EoL printer/cartridges • No recycling facilities	Analysis of the potential to recycle and reuse plastics from EoL printers and cartridges
	Certification by ICT of the recycled content in new toner cartridge parts using recycled plastic from end-of-life cartridges and printers

4.3. Results

4.3.1. Collecting customer feedback

Targeted interviews

As a starting point, Lexmark conducted several interviews to engage with key customers (total of 8 customers located in Germany, France, and Italy). Those companies are either distributing printers and copiers or using their own printer fleet for sales or logistic purposes. The objective of the interviews was to better understand their needs, expectations, and outlook on how to boost refurbished printers and other ICT devices.

The main findings from the interviews were:

- In general, companies do not sell back their end-of-life printers to the respective OEMs. Only few buying back programs exist for end of-life printers. Reverse logistic cost seems to be a significant issue.
- Companies prefer to refurbish printer models that can be sold with an attractive margin. The main focus lies on high end A4 and A3 printers.
- Price and quality are the two most important criteria for refurbishing a product. The quality must be high and the price of refurbishment low. This is the challenging equation that each company needs to solve while keeping at the same time an attractive sales margin.
- In general customers can accept products that show cosmetic issues.
- The main important enablers to encourage the use of refurbished products are:
    - Environmental laws for manufacturers offering a bonus / malus system
    - Public Procurement targets for refurbished products
    - Eco-design laws forcing manufacturers to design their products to be repaired and put back into circulation
    - Legal obligation for manufacturers to produce spare parts necessary for the repair and functioning of the products
    - Security features to a same level as new products
    - New or prolonged warranty and associated services
- Customers would need to better understand the environmental advantages of acquiring and using refurbished products. The right environmental story telling will drive Circular Economy solutions.
- Refurbished products have the advantage when facing delivery problems for new products (e.g., container shortages, natural disasters, trade tax discussions, etc.).
- Refurbished products can satisfy specific customer needs when flexibility, quick solutions and aggressive price offers are needed. Not all customers need the latest product model on the market.
- Innovation is a key element to improve the cost equation of refurbishment. QR codes can help to accelerate the acceptance and improve the business case.
- Products need to be designed in such a way to increase their value after the end of life, a modular approach is an option.
- An end-of-life product needs to be easily updated with the latest software and firmware and integrate the latest security features.

Refurbished printers testing at customer locations

Following on the qualitative interviews with customers, this activity aimed to assess customer acceptance in terms of cosmetic defects on refurbished printers. Visible parts such as covers and housings are expensive, as they are ordered by large Minimum Order Quantity and come from far east Asia with a high freight cost. Lexmark was looking for acceptance related to small cosmetic defects like scratches, bumps, dents, or discoloration on the printer cover which currently would not be acceptable with Lexmark's standards.

Lexmark chose two product models representative of mid-range mono and colour: CX725de and MS823dn. Lexmark also provided customers with necessary cartridges to run the testing. The printers were refurbished according to Lexmark specifications using visible parts with cosmetic defects from as many categories as possible (dents, scratches, discoloration…) but also considering what customers could easily accept.

Figure 11. Cosmetic defect samples on housings used for the activity

The users received the printers with instructions on how to proceed. They testing period lasted 3 months. Lexmark created an online survey which was completed after 6 weeks of testing and again after the 3-month period. Finally, the users participated in a face-to-face interview with Lexmark to share their experience.

Figure 12. Printers installed at companies 1, 3 and 4 (left to right) during the testing period

Company 1, based in Italy, is a producer responsibility organization providing regulatory compliance services, management of all waste from electronic products. The printer was installed at the entrance of the office, next to the reception.

Company 2, based in Germany, manufactures equipment for landscape maintenance. They have installed the printer in a logistic area which has a rough, dirty environment and they used it 16 hours a day, 5-6 days per week.

Company 3, based in Spain, is devoted to research and offering innovative technological solutions for corporations. The printer was installed in their main office, and it was available for around 25 people who work in the technical department, mostly researchers.

Company 4: a CX725 printer model was shipped to Lexmark Budapest offices in Hungary and was installed in the Lexmark office at the reception area, which is easy to approach from any part of the office. There are 380 employees working on the site.

The main conclusions of the activity were:

- Performance and quality of the refurbished device is the most important parameter for the users: as far as the printer performed as expected and especially as a new one, users are satisfied
- Price still mentioned as a key element in decision making to use or not a refurbished unit, it therefore reinforces the need for OEMs such as Lexmark in identifying opportunities to make such devices more cost attractive
- Printer location is seen as being an important criterion to determine if refurbished device is an option or not. Indeed, when located in areas where potential visitors, customers may come, there is still reluctancy towards a refurbished device.
- Customer acceptance level of cosmetic defect has evolved, and customers are now willing to accept defects that do not pass Lexmark actual cosmetic specifications.

This last finding drove Lexmark to investigate the impact of revisiting the cosmetic specification. A study was conducted for a given printer model, as shown in Table 6. Grade A is the base line, i.e. today's specifications which are quite stringent and drive an equivalent to new printer looking. Grade B is including a revised cosmetic specification

For each grade, 3 yield points are used, 45, 60 and 80%. A yield point is representative of the ratio between received units and refurbished ones. The higher the ratio, the lower the opportunity to recover parts from received printers. For each yield, 3 refurbished techniques were identified, from the standalone one which consists of refurbishing a printer from a to z by the same operator to the progressive line which is the most optimized option.

The "Cosmetic" cost driven by the cost of changing covers of the printer is decreasing significantly, from 121.7€ to 79.1€ a unit, a 40+€ cost cut as an example for a yield of 80%, or from 49.5 to 28.8€, a 10+€ cost cut for a yield of 45.

Table 6. Analysis of cosmetic specifications impact on refurbishment costs

GRADE	YIELD	PRODUCTION	Labor	Cosmetic	BF	MK	Packging	TOTAL with MK	Cost gap	Volume initial	Volume final
		Standalone	€ 150.8	€ 121.7	€ 12.9	€ 60.5	€ 40.0	€ 386.0	100%	3500	2800
		DSM + Stand Alone	€ 117.0	€ 121.7	€ 12.9	€ 60.5	€ 40.0	€ 352.2	91%	3500	2800
	80%	Progressive line	€ 110.3	€ 121.7	€ 12.9	€ 60.5	€ 40.0	€ 345.5	90%	3500	2800
		Standalone	€ 150.8	€ 90.1	€ 12.9	€ 60.5	€ 40.0	€ 354.3	92%	3500	2100
		DSM + Stand Alone	€ 117.0	€ 90.1	€ 12.9	€ 60.5	€ 40.0	€ 320.6	83%	3500	2100
	60%	Progressive line	€ 110.3	€ 90.1	€ 12.9	€ 60.5	€ 40.0	€ 313.8	81%	3500	2100
		Standalone	€ 150.8	€ 49.5	€ 12.9	€ 60.5	€ 40.0	€ 313.8	81%	3500	1575
		DSM + Stand Alone	€ 117.0	€ 49.5	€ 12.9	€ 60.5	€ 40.0	€ 280.0	73%	3500	1575
A	45%	Progressive line	€ 110.3	€ 49.5	€ 12.9	€ 60.5	€ 40.0	€ 273.3	71%	3500	1575
		Standalone	€ 150.8	€ 79.1	€ 12.9	€ 60.5	€ 40.0	€ 343.3	89%	3500	2800
		DSM + Stand Alone	€ 117.0	€ 79.1	€ 12.9	€ 60.5	€ 40.0	€ 309.6	80%	3500	2800
	80%	Progressive line	€ 110.3	€ 79.1	€ 12.9	€ 60.5	€ 40.0	€ 302.8	78%	3500	2800
		Standalone	€ 150.8	€ 47.4	€ 12.9	€ 60.5	€ 40.0	€ 311.7	81%	3500	2100
		DSM + Stand Alone	€ 117.0	€ 47.4	€ 12.9	€ 60.5	€ 40.0	€ 277.9	72%	3500	2100
	60%	Progressive line	€ 110.3	€ 47.4	€ 12.9	€ 60.5	€ 40.0	€ 271.2	70%	3500	2100
		Standalone	€ 150.8	€ 28.8	€ 12.9	€ 60.5	€ 40.0	€ 293.0	76%	3500	1575
		DSM + Stand Alone	€ 117.0	€ 28.8	€ 12.9	€ 60.5	€ 40.0	€ 259.2	67%	3500	1575
B	45%	Progressive line	€ 110.3	€ 28.8	€ 12.9	€ 60.5	€ 40.0	€ 252.5	65%	3500	1575

Based on this study, we can conclude that cosmetic defect acceptance level is a significant driver to make printer refurbishment more cost attractive.

4.3.2. Eco-design for dismantling/recycling

The following quantities were processed during this activity in the demonstration:

- Cartridges: 1860 made of 1004, 750, 106 for each location, total of 3.720
- Printers: 5 of each model for each location, total of 30 units

The printers and toner cartridges were dismantled C-SERVEES recyclers partners Indumetal and Greentronics as well as Lexmark European manufacturer Syncreon.

The purpose of the dismantling activity was to collect feedback from the 3 parties on potential design improvements to ease the dismantling and recycling operation and to make it more cost efficient. The 3 parties were asked to proceed with the same activities based on Lexmark's instructions, so the results could be comparable. As appropriate, they were asked to provide details of energy and time consumption, required human resource, financial aspects, and information on difficulties they encountered. The 3 parties were asked to take one of each printer model and perform regular recycling of the product and the obtained data was used as a baseline. The second exercise consisted in performing disassembly of the printers without the use of any supporting documentation. The third exercise was to perform disassembly using a regular service manual (for the printers) issued by Lexmark for the purpose of servicing the printer during its average lifetime. The purpose of this last exercise was to drive the parties to access certain parts/subassembly which could be recovered with no damages and save it for further usage. For EH&S purpose, toner was removed from cartridges before shipping to the recyclers.

Exercise #1 (BAU recycling operation):

Table 7 shows the results from the first exercise, for each product: (i) the dismantling cost incurred by the recycler to dismantle the products, (ii) the benefit the recycler can get out of the various fractions resulting from the exercise and (iii) the net between the two.

Table 7. Results from the cost-benefit analysis of dismantling printers (w.o. support)

PRINTER	Dismantling cost	Estimated market price	Difference
CX510	9.5 €/device	6.16 €/device	-3.84 €/device
MS812	14.26 €/device	5 €/device	-9.26 €/device
X950	41.5 €/device	30.3 €/device	-11.2 €/device

Exercise #2 (dismantling without support)

Table 8 shows the results from the second exercise, for each product: (i) the dismantling cost incurred by the recycler to dismantle the products, (ii) the price Lexmark pays today for the various recoverable spare parts and (iii) the net between the two.

Table 8. Results from the cost-benefit analysis of dismantling printers (with support)

PRINTER	Dismantling cost	Estimated market price	Difference
CX510	10.33 €/device	10.16 €/device (1 part)	-0.17 €/device
MS812	16.65 €/device	101.55 €/device 14 parts)	84.9 €/device
X950	46 €/device	39.7 €/device (3 parts)	-6.3 €/device

Exercise #3 (dismantling with service manual)

A final exercise was carried out by Syncreon to determine standard in-factory costs of dismantling for each of the printers:

- CX510: 20 €/device
- MS812: 23 €/device
- X950: 66 €/device

A similar exercise was carried out with toner cartridges, to analyse cost-benefit of dismantling at recyclers' facilities vs. in-factory dismantling.

Exercise #1 (BAU recycling operation)

Table 9. Results from the cost-benefit analysis of dismantling cartridges (w.o. support)

Cartridge model	Dismantling cost	Estimated market price	Difference
95X Tube	0.0284 €/unit	0.0025 €	-0.026 €/unit
Pirate Imaging Unit	0.237 €/unit	0.091 €	-0.14 €/unit
MS/MX Toner	0.283 €/unit	0.18 €	-0.1 €/unit

Exercise #2 (Dismantling)

- 95X Tube: 0.0449 €/unit (no purchase nor market price)
- Pirate Imaging Unit: 0.2 €/unit (no purchase nor market price)
- MS/MX Toner: 0.37 €/unit (no purchase nor market price)

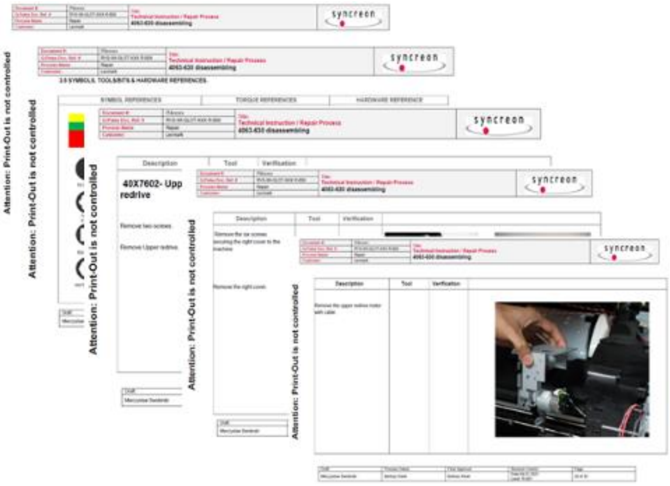
The main conclusions and findings were:

- For an easy dismantling of the printers, a modular construction of subassemblies was recommended by the recycler. Also, the use of colour code to easily identify parts/sub-assemblies would be of great help.
- Disassembling printers to sort parts by material without any prior knowledge is often less time consuming than using the provided service manuals: printer design already supports the easy disassembling. This led the team to consider putting together a specific document aiming at easing the dismantling operation: a dismantling manual. Using such manual revealed to be time and cost efficient compared to using the service manual or work without any support. Such document can also be used to identify specific parts which can be valuable.
- The highest cost of the dismantling operation is generated when cleaning the dismantled parts, therefore, specific cleaning technics should be developed.
- A path forward could be to dismantle printers at recyclers premises and harvest valuable spare parts which can be of interest for the OEM (Original Equipment Manufacturer) such as Lexmark, using a dismantling manual associated with ICT technology to bring process efficiency. For cartridges, Lexmark already reuses the entire product and therefore very few specific parts are qualified by Lexmark to be reused in the manufacturing of cartridges.
- Identifying companies able to provide grinding services reveals to be a challenge. It seems companies grinding plastic are vertically integrated and do not offer grinding services. This situation is even worse for compounding.

4.3.3. Business case on recovering spare parts from EoL printers

Based on above findings a dismantling activity was set up aiming at determining if getting a recycler to dismantle a printer to harvest spare parts can bring monetary value versus regular recycling. Printer model MS 812 was selected (representative of high runner printer, mid-range mono product), and a total of 85 units were shipped by Lexmark to the two recyclers' facilities. Lexmark selected a short list of 20 spare parts to be harvested by the recyclers and based on the list a dismantling manual was developed by Lexmark's remanufacturer and engineering team at Syncreon.

MS 812 printer



Extracts from dismantling manual.

Dismantling of fuser

Dismantling of left cover

Dismantling of mother board

Dismantling of duplex motor with cable

Figure 13. Examples from the dismantling operations on Lexmark printer MS 812.

Based on the results from this exercise an improved version of the dismantling manual was produced with better formatting, added pictures to easily locate the parts and changing the order to access the parts to minimize the number of times the operator must rotate the printer.

Economic assessment of the business case

The other (main) outcome is related to the business case for the recovery of printer parts from end-of-life printers.

The net cost reported by the recyclers to dismantle 10 printers is between 104€ and 142€, including revenue generated by the non-recoverable part. Adding to this cost the necessary packaging to protect and ship the parts to the printer refurbishing site as well as the freight cost, we end up with a cost per printer of 41€ for Greentronics and 55€ for Indumetal. This cost gap is explained mainly by freight cost difference. A conservative assumption is made of 70% of parts passing the specific quality requirements, upon arrival to Syncreon. This drives the per unit cost respectively to 58€ and 79€.

	Greentronics	Indumetal
Cost to dismantle 10 printers	€ 181	€ 140
Revenu ot of the non recoverable parts	€ 39	€ 36.5
Net cost to harvest parts on 10 printers	**€ 142**	**€ 104**
Packaging cost for parts coming from 10 printers	€ 72	€ 70
Associated labor	€ 130	€ 120
Freight cost to syncreon	€ 62	€ 260
Total	**€ 406**	**€ 554**
Per printer	**€ 41**	**€ 55**
per printer cost	**€ 41**	**€ 55**
Assumed yield	**70%**	**70%**
Average per printer cost	**€ 58**	**€ 79**
Handling/sorting cost @syncreon	€ 10	€ 10
Repair cost @ syncreon	€ 51	€ 51
Total	**€ 119**	**€ 140**
Cost to buy new parts	**€ 172**	**€ 172**
Potential benefit	**€ 52**	**€ 31**

Adding the necessary repair cost (actual cost incurred today when recovering parts at Syncreon), as well as some cost to account for additional sorting that Syncreon would need to perform, the total cost is respectively 119€ and 140€ per unit.

To be compared with the cost of procuring new parts: 172€ (doesn't include other logistic, inventory and other OH which would apply also to the recovered parts at recyclers). All in all, an average of 40€ potential benefit per printer assuming all parts from the short list are re-used when refurbishing a printer, which is not the case as mentioned in the introduction.

These results supported the conclusion that recovering parts at a recycler location can be cost efficient.

During this demo activity other interesting feedbacks from Greentronics and Indumetal were collected as well:

- The major challenge faced by recyclers is that dismantling activities are out of the recycler business as usual scope, meaning that they had to organize accordingly for such activity. For such an activity to become profitable, the need to change recyclers' business scope must be considered.

- Another major issue for recyclers remains the existence of hazardous material, therefore they recommend having these, if present, highlighted in the dismantling manual.

Combined with the ICT tool, recovering parts at a recycler could be a powerful approach: there is potential to have dismantling manuals embedded into a QR codes for various EEE products and links to drive recyclers to liaise with the OEM and quickly determine what parts can be worth recovering.

As a next step, it was identified the need to confirm the above findings by getting recyclers to process a larger batch of units and get data related to sorting and cleaning at Syncreon. The challenge was to have recyclers receiving enough printers of the same type during the timeframe of the demonstration period to run the activity. Lexmark therefore collected and put aside printers from the same model at Syncreon (Lexmark collection center) and when enough were collected, put aside 60 of them with a plan to process 20 units at each location (Indumetal in Spain, Greentronics in Romania and Syncreon in Poland).

Another major challenge at this stage was to determine which parts would be worth dismantling at the recyclers' location. Lexmark engineers ended up with a short list of 20 parts, including parts which would ideally require pretesting (these being the most expensive parts), despite the recyclers not being requested to perform this "pre-tests".

Quality specifications were provided to the recyclers and included in the dismantling manual. Recyclers were trained by video conference on cosmetic defect acceptance criteria. The objective was to avoid as much as possible extra costs driven by packing and shipping parts which would not pass quality criteria at the refurbishing stage.

A template was then developed to provide the same instructions to the 3 companies: Indumetal, Greentronics and Syncreon. For each printer it was requested to note if the part passed the quality inspection with criteria set by Lexmark and also to collect time spent per part and cumulative time, in case only some parts would show specific interest.

	1	2	3
	40X7678	40X8017	40X7673
	Rear door	Fuser - MS81x Fuser Type 06, 220-240V A4	Top cover
Printer 1			
Printer 2			
Printer 3			
Printer 4			
Printer 5			
Printer 6			
Printer 7			
Printer 8			
Printer 9			

			Time (sec)	Cumulative time (sec)
1	40X7678	Rear door		
2	40X8017	Fuser - MS81x Fuser Type 06, 220-240V A4		
3	40X7673	Top cover		
4	41X0976	550-sheet tray insert		
5	40X7680	Right Cover		
6	40X7679	Left Cover		
7	40X7578	HVPS		

The current process for printers dismantling at Syncreon is as follows:

1. Pretesting: to gather page count and test motors, fan, fuser units and mother board
2. Dismantling
3. Storing dismantled parts to stock location
4. When any part is requested, it is pulled out of stock and repaired if required or cleaned and packed

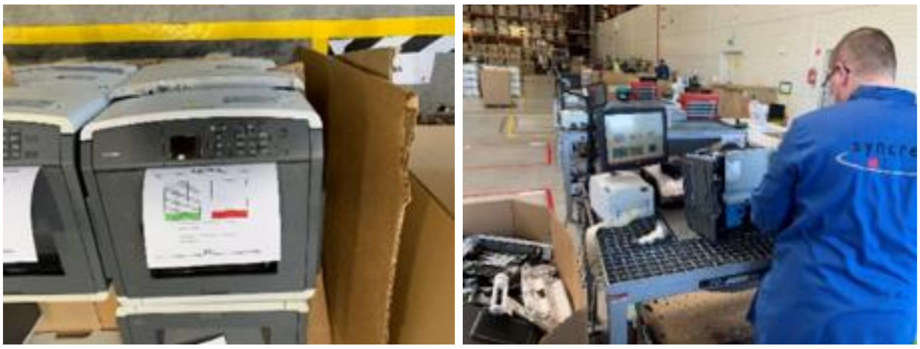


Figure 14. Pretesting of end-of-life printers at Syncreon

As explained above, for the purpose of this activity parts were dismantled at recyclers' locations without pretesting, same for Syncreon.

In a second step, Syncreon was requested to receive, sort and as appropriate test the parts received from recyclers as well as the ones they dismantled themselves.

The objective was in a first step to compute the following cost:

Cost to dismantle the parts at recycler's location
\+ *Cost to ship the parts to Syncreon*
\+ *Cost of sorting, testing, and refurbishing at Syncreon*

Cost of getting parts from recyclers

Figure 15. Recovered parts at the recycler's location, checking and packing process

An interesting finding is that, despite differences in hourly rates, in the end the per unit cost of recovering parts (while not fully representative) is fairly closed around 3€. Below are the details of the cost analysis to get parts from recyclers.

The two main cost parameters are for both recyclers' labour as well as shipping.

Indumetal

19 printers processed		
Total recovered parts		**298**
Total theoritical number		380
Total time to dismantle (mins)		549.1
Total time to pack the part (mins)		515.6
Cost per hour	€	30
Labor + dismantling + packing	**€**	**532**
Material cost (packaging)	€	77
Shipping	€	200	w/o VAT
Total cost	**€**	**809**
Number of recovered parts		**298.0**
Avg per unit cost	**€**	**2.7**

Greentronics

19 printers processed		
Total recovered parts		**221**
Total theoritical number		380
Total time to dismantle (mins)		399
Total time to pack the part (mins)		285
Cost per hour	€	19.8
Labor + dismantling + packing	**€**	**225.2**
Material cost (packaging)	€	120.0
Shipping cost	€	355.0	w/o VAT
Total cost	**€**	**700**
Number of recovered parts		**221**
Avg per unit cc	**€**	**3.2**

In parallel Syncreon ran the dismantling on 20 printers from same model. No packaging, pre-sorting or freight cost at Syncreon, only dismantling cost was incurred.

Syncreon

20 printers processed			
Total recovered parts		**420**	
Total theoritical number		420	
Total time to dismantle (mins)		306.7	
Total time to pack the part (mins)		NA	
Cost per hour	€	39	
Labor + dismantling + packing	**€**	**199**	
Material cost (packaging)		NA	
Shipping cost		NA	w/o VAT
Benefit from recycling remainings of the printers		NA	included in the hourly rate
Total cost	**€**	**199**	
Number of recovered parts		**420.0**	
Avg per unit cost	**€**	**0.5**	

In the last phase Syncreon was instructed to proceed with sorting, cleaning, and testing (as appropriate) all the dismantled parts, from both recyclers as well as Syncreon.

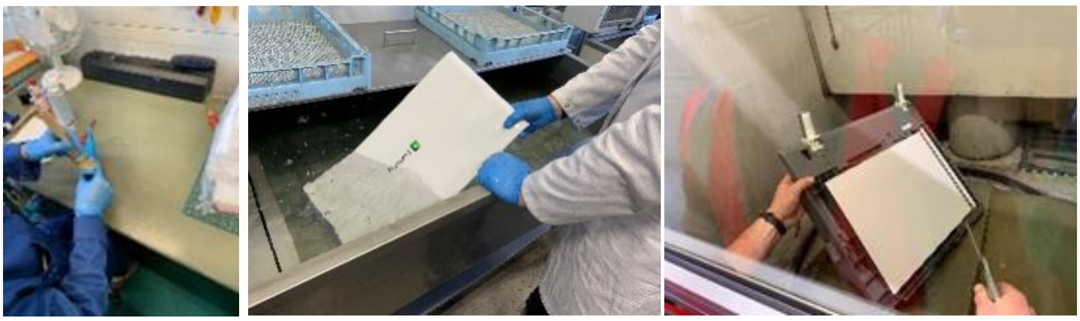


Figure 16. Printer parts cleaning at Syncreon

Data summary associated with above mentioned operations is shown in the table below.

- Higher sorting time and related cost at Syncreon due to no pre-sorting
- Despite the dismantling manual, 40% less good parts were recovered at recyclers than at Syncreon: many parts rejected for cosmetic issues, broken or damaged
- 30% of the parts shipped from recyclers considered as good parts after sorting (we were anticipating 70% from the previous activity)

	Total parts sorted	Parts for Repair	OK parts	Parts for scrap	TTL Time (minutes)	TTL recovered parts	Sorting and cleaning cost	Per unit
indumetal	295	38	40	217	716.8	78	€ 466.0	€ 6.0
greentronics	218	19	61	138	1121.17	80	€ 729.0	€ 9.1
syncreon	420	40	91	289	1367.37	131	€ 889.0	€ 6.8

We can observe that on a per unit basis, the most economical option is to get Syncreon (a specialized sorting center) to proceed and harvest parts, which is not surprising. As mentioned before, business as usual, Syncreon would perform pre-testing of the printer prior dismantling (which is not an option for recyclers), this pretesting would avoid unnecessary tasks, driving an even lower cost.

Total per unit cost summary

	Delivered to syncreon	Sorting & cleaning	**Total**		
indumetal	€ 2.5	€ 6.0	**€ 8.48**		
greentronics	€ 2.8	€ 9.1	**€ 11.94**		
syncreon	€ 0.5	€ 6.8	**€ 7.26**	**€ 5.97**	*with pretesting

This confirms the cost computed and reported previously, which was 119€ and 140€ per printer to recover 12 parts, meaning 9.91€ and 11.67€ per part respectively for Greentronics and Indumetal, not far from to the 11.94€ and 8.48€ in the table above.

Removing all parts which cost less or very close to 10.21€ (average dismantling cost per part) and considering that some of the remaining ones would need to go to repair (and therefore incur in cost) in case they are coming from dismantling, we end up with a short list of 4 parts for a total of 112€. In other words, getting those 4 specific parts from recyclers could be beneficial.

Basic computation would drive: 112€ – (10.21€ x 4) = 71€, although there is a bias here as recovering only specific parts would be more costly for the recyclers, due to longer time to access those parts and some fix cost absorption. Working on estimates, we can assume no more than 50% higher cost, therefore in this scenario, the case would still be favourable.

This activity confirmed that getting specific parts recovered at recycler's locations can drive positive financial outcome, assuming recyclers get such products in their WEEE stream, which may be a major challenge.

4.3.4. Explore 3D printing of spare parts for refurbishment operations

The purpose of this activity was to investigate potential benefits of using 3D printing technology to produce spare parts needed when refurbishing printers and changing damaged components, instead of using new parts or refurbished parts. Printers were chosen over cartridges since mechanical spare parts cost is not an issue when remanufacturing a cartridge: those parts are small and at a lower cost and on top of that, they are available locally as Lexmark cartridges are produced at Syncreon in Poland. Therefore, no anticipated benefits were identified for cartridges.

It is to be noted that spare parts are the first cost contributor to the total cost of refurbishing a printer. Current practice and options for replacing mechanical parts in a printer are as follow:

- **New parts:** these are costly as they mostly come from overseas suppliers which require a certain Minimum Order Quantity (driven by the molding process), increasing the financial cost of carrying inventory as well as warehousing cost with a high risk of obsolescence as all the ordered part are not always used. New parts require excellent forecasting skills. New unused parts can have a negative environmental impact if they go to scrap at the end of life of a product model.
- **Refurbished parts:** these have a cost advantage versus new parts as they are recovered from used printers but present the disadvantage of reducing the number of available printers for refurbishing. Another disadvantage is the reverse logistic cost as well as the carbon footprint, indeed, depending in which part of Europe they get recovered the cost and carbon footprint could negate the benefit.

For this activity the selected model was MS 812, a high-range mono printer, recent model, representative of Lexmark core market. The first step was to identify candidates (parts) to be 3D printed. This step proved to be a significant challenge for several reasons.

Lexmark asked Syncreon to proceed with printer dismantling and propose a short list of representative parts which could be good candidates for 3D printing based on their experience of changing parts when refurbishing printers. Prioritizing parts based on their cost, Syncreon proposed 6 parts from various printer models as shown below.

Figure 17. Printer parts selected by Syncreon for 3D printing

After reviewing with Particula these were declared as being not eligible to 3D printing for the following reasons: 5 of them show a textured surface and are visible parts, it appears that those highest cost plastic parts which are replaced during the refurbishment of a printer and are visible ones, called the covers, are by nature visible and therefore subjected to cosmetic criteria. The last one was quite complex and therefore was not selected either.

After a second selection round, Syncreon came back with 3 new candidates.

Figure 18. Final printer part candidates selected by Syncreon for 3D printing

This selection was then submitted to Particula which narrowed down the selection to one part, the one shown above on the right, named “deflector”, others were being not appropriate for 3D printing, one based on its geometrical complexity, the second one for its mechanical characteristics. Lexmark’s engineering & design experts raised some concerns on the deflector due to its function, which requires smoothness and flat surfaces. Despite this, the appropriate STL files were provided to Particula to proceed.

Particula printed 4 samples with different materials which were sent to Syncreon for analysis. Figure 19 shows pictures of the 3D printed parts and a comparison with the original molded part. Material references used: PETG, Facilan C8, rPETG and PLA.

Figure 19. 3D printed samples from Particula (left: original vs. 3D printed)

Despite the roughness that can be seen on the 3D printed part, a functional test was performed (assembling the part in a printer and printing 1000 pages), which revealed to be positive. However, based on the experience with this part and considering its sensitivity to various types of paper, the decision was taken by Lexmark engineers to not pursue the testing. This printer is designed to print more than a million of pages of various media with appropriate maintenance and request high quality and durable parts.

Particula proposed to polish the parts to avoid the surface issue and, while this could work, it would add significant cost. Considering only a few parts per year, 3D printing might be practical but with a requirement of several parts a month it does not seem a workable option.

While the conclusion was to not pursue 3D printing testing for printer refurbishing, in the meantime, Syncreon identified a potential candidate: a “packaging” part. This part is placed to lock some piece of the printer together to avoid damages during transportation and is removed by the customer before using the printer. Technical requirements for these parts are much lower than for a functional printer part and aesthetical requirements (one of the major bottlenecks of the previous finding) is not an issue.

Figure 20. In red, the parts used to lock the cartridges (left) and the drawer (right) during transportation

Three different parts were printed with ABS filament and tested successfully. 3D printer was procured accordingly and located withing the refurbishing area to allow to use it in "hidden time", meaning that the labour time involved is low (about a minute to launch a new part or new series of part (several parts of the same design), driving parts cost between 1 and 1.5 € per unit based on material content. This cost will go down with volume going up.

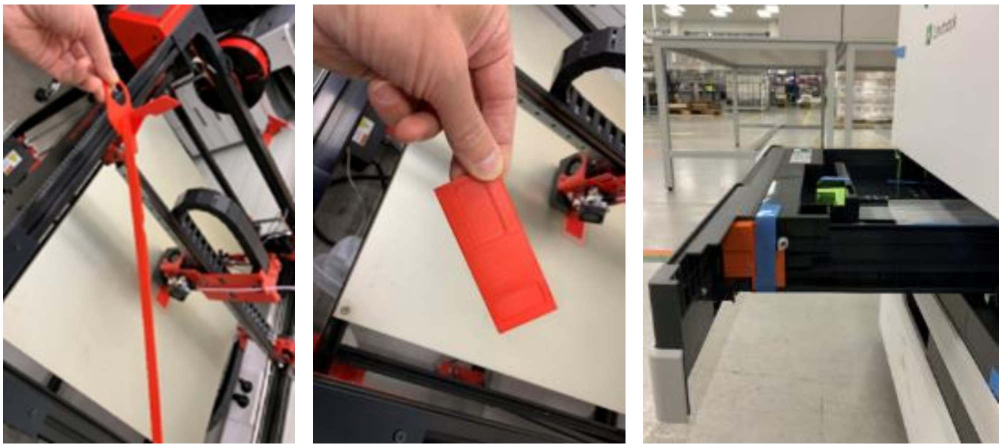


Figure 21. 3D printing of the cartridge locker (left) and the drawer locker (centre, right)

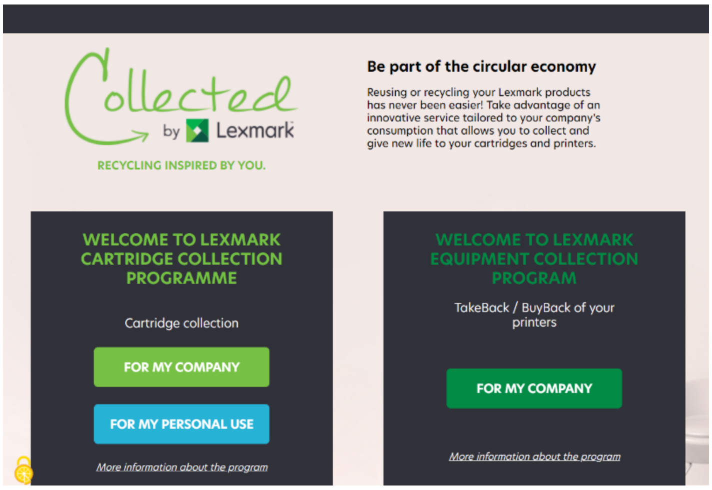
4.3.5. Expand LCCP and/or merge with LECP program

To address one of the end-of-life issues related to the cost challenge of making printer refurbishment a cost-effective activity and therefore boost the Circular Economy, Lexmark initiated a project activity related to the reverse logistic cost element.

The aim of this activity is to increase the EMEA refurbish volume by leveraging, enhancing and automating all internal related processes, and optimize costs as much as possible, mainly labour related cost as the various processes as we'll see below are much labour related. Another objective is to make it easier for customers and partners to get their used units returned, so they don't end to WEEE stream and get damaged.

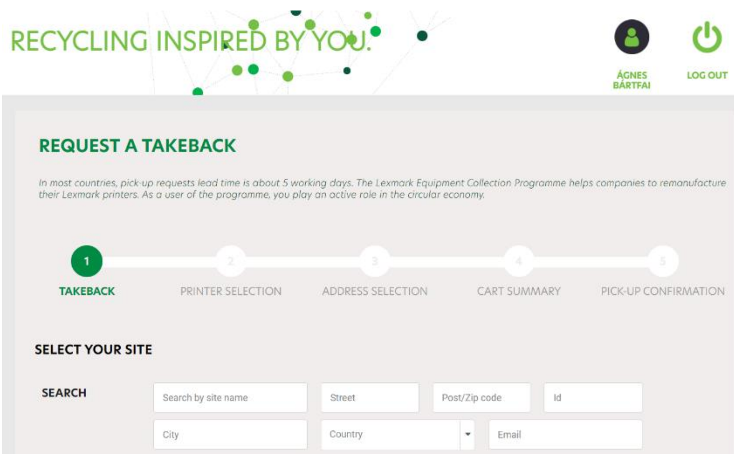
The activity scope includes developing the return flows for printers and enlarging the already existing LCCP (Lexmark Cartridge Collection Program) web platform to printer LECP (Lexmark Equipment Collection Program) - as this will accelerate our circular economy projects in Europe.

The new webtool, also called platform, is made by a third-party service provider who played a key role in the development of the new digital platform for LCCP. They created a new identity with « Collected by Lexmark » and a customer-friendly website, set up new efficient functionalities, and rolled out the program in 32 countries.

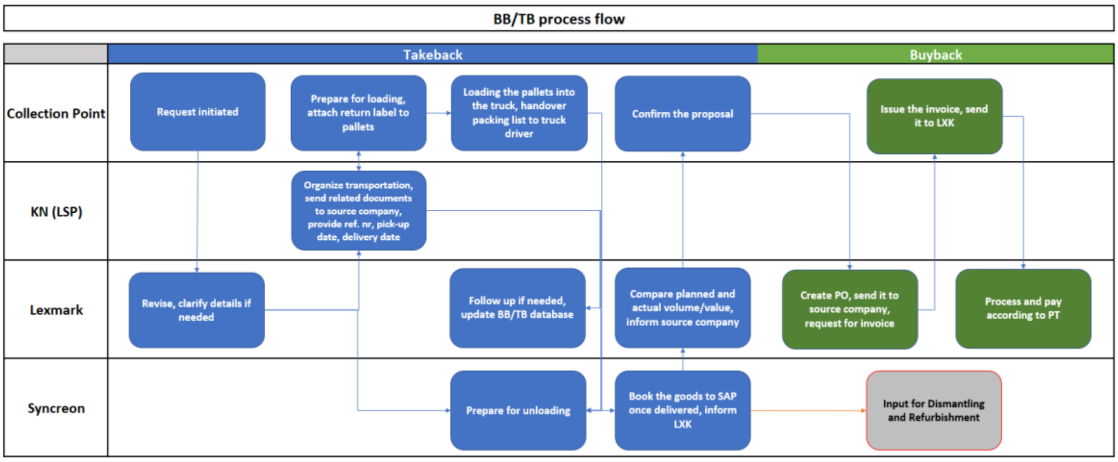


According to the EU electronic waste legislation, Lexmark as a manufacturer has to organise and finance the collection, treatment, recycling and recovery of the products.

Lexmark has to provide a Take Back (TB) service where the customers can return electric and electronic waste, free of charge. In case Take Back is not an option, Lexmark set a Buy Back (BB) process.



How the BB/TB (Buyback/Takeback) process (B2B) (Business to Business) looked like



Major differences between the manual and automated systems

	Original TB/BB process	TB/BB Webtool
Communication regarding a transaction during the process, like status update	via email only	automated email via the tool
Communication on other related topics like price change, eligibility list change	via email only	via email, but always available via the tool
Reporting for KPI	manually built excel database	database generated automatically
Printer volume	16.3k/year 2021	might be increased due to the ease of use
Transaction volume	251 / year 2021	minimal additional work for LXK in case the number of transactions increase

Comparing processing time

	Old Model		Estimations with the Webtool	
Description	Time (minutes)	Number of emails	Time (minutes)	Number of emails
Initial communication, alignment	10	2	5	0
Check if all details provided by the requestor, ask back if something is missing	10	2	5	0
Send the completed form to KN	2	1	1	0
Send pre-notification to Syncreon	2	1	0	0
Align with KN if needed	20	2	20	2
Align w/ Syncreon if needed	10	2	10	2

Add the transaction to the excel database and update it with the available data	20	0	15	0
Monthly KPI update	10	0	8	0
Final confirmation with the initiator	15	2	2	0
Sum:	75	12	42	4
Total hours / transaction	1.3		0.70	
number of emails / transactions		12		4

With the manual system it took ~1,3 hours to complete a transaction end to end and it needed about 12 emails. With the webtool it is expected to reduce the time by half (50%), less than an hour and to require only 4 emails. Significant productivity gains. End to end Lead Time (LT) from an average of ~25 days can be decreased to ~15-20 days with the automation. Another substantial productivity gain, which will help to get the printer available for refurbishment faster and therefore to customers.

One of the limitations of the manual system as mentioned above is resource related and one person couldn't handle much more than 60 requestors locations (mainly sales partners), the automated system should now allow for at least two times this number, which will drive higher volumes.

The numbers since the platform went live show that the total working time decreased by 26% in the first month with the new tool. Sending pre-notification to the refurbishing centre is every time done by our contracted freight forwarder company. And the communication needs also less time from Lexmark side, as the process is more automatic. Some issues have been identified during these first production weeks and they are being fixed. The team is confident that the original target of 50% processing time reduction can be reached.

We can conclude that investment in IT systems will be almost essential in the development of TB BB processes in the future, for printing industry but not only and it will likely benefit most of the EEE industry.

The new LECP platform can be reached at https://www.collectedbylexmark.com/

4.3.6. Business case on recycling plastic materials from EoL printers and toner cartridges

The main objective of this activity was to analyze the technical feasibility of reusing ABS plastic from end-of-life printers and toner cartridges and incorporate the recycled plastic material into new cartridges, using the Circularise ICT tool to track and certify the recycled content at each stage of the supply chain. Lexmark already uses 37% of recycled resin in its cartridge products and is looking at even using more (50% by 2025 is the latest target), however the market offer of recycled materials is very limited.

ABS plastic materials were collected from 3 different flows, in order to examine whether the origin of the ABS plastic is relevant for the outcome:

1. Lexmark printers
2. Lexmark cartridges
3. Other OEM Printer brands

<u>1) ABS material from end-of-life Lexmark printers</u>

Plastic parts from previously dismantled Lexmark printers at Indumetal were used for this activity. ABS plastic parts were manually separated without considering the printer model (CX510, MS812, X950) and a total of 30 kgs ABS was collected.

<u>2) ABS material from end-of-life Lexmark toner cartridges</u>

Another batch of material came from cartridges provided by Syncreon. Syncreon receives cartridges from different locations through LCCP (Lexmark Cartridge Collection Program) and they were able to collect 20 kgs of ABS parts.

<u>3) ABS material from non-Lexmark printers</u>

The third batch of ABS material from other brand's printers was collected by Greentronics in Romania. This required a very thorough examination of the dismantled printer parts by the operator at the recycling facility, to make sure only ABS pieces were collected. Around 25 kg of shredded plastic material were shipped to Gaiker for grinding and chemical testing.

The three batches were processed at Gaiker. First, they were grinded to 8 mm. Afterwards the flakes were washed and dried to remove dust and dirt. Other visible contaminants like metal inserts, stickers and non-ABS particles were manually removed and the remaining metallic contaminants were eliminated by eddy current separator.

Figure 22. ABS plastic parts from Lexmark printers (left), non-Lexmark printers (center) and ABS flakes obtained after processing (right)

Based on Lexmark instructions, Gaiker characterised the samples and completed the following analysis/tests:

- DSC (Differential Scanning Calorimeter)
- FTIR (Fourier Transform Infrared Spectroscopy)
- TGA (Thermogravimetric analysis)
- MFI (Melt Flow Index)

The results and the samples were then sent to Lexmark engineers for further examination. ABS from Lexmark cartridges was found satisfactory. In the flakes from printer parts, they observed small metals particles such as Aluminium and brass and several clear particles turned out to be small glass pieces (Figure 23). One black particle observed in this sample was Polypropylene with 30% mineral filler.

Additional tests were performed, molding ASTM standard Flex Bars to perform Izod impact and Flexural Strength testing. The bars had obvious and consistent swirl patterns in the molded parts, driven by rubber particles which is an issue as it would significantly alter the property of a molded part.

Molded flex bars were also used to complete Pendulum Notched Izod impact testing. The result of property testing showed promise in the quality of the recycled material.

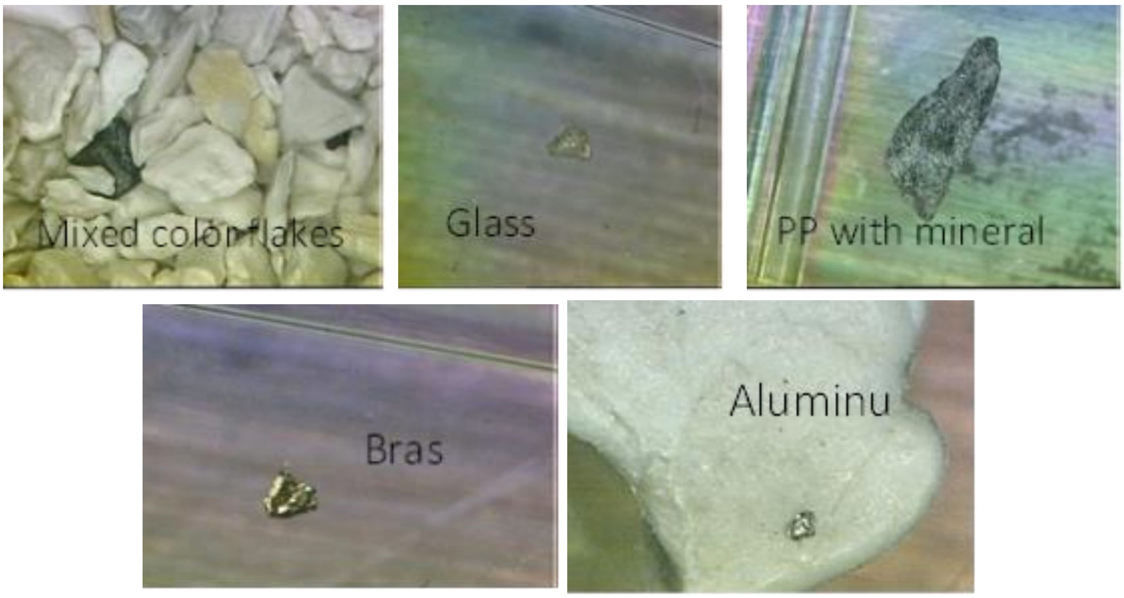


Figure 23. Images of particles found in the ABS samples analysed at Lexmark

Finally, analytical testing was performed, IR, DSC and TGA which did not show any significant contamination. However the XRF analysis indicated that the level of bromine in the sample from non-Lexmark printers was higher than Lexmark and electronic industry standards. This result reinforces the importance of getting material properly sorted and processed, which require the rights means and may need to be processed by a company specialized in resin processing to ensure proper purity.

The grinded ABS resin from Lexmark printers (25kg) and cartridges (15kg) were then shipped to the molding company Jabil/Plasticast to Hungary.

Jabil produced about 200 cartridges housings, mixing 20% of grinded material received from Gaiker with virgin material. A total of 20 welded subassemblies were sent to the Lexmark engineers and 70 units were sent to Syncreon for final assembly and testing. The results from the Functional Test, Drop Test, PPVT Print Test were positive.

Figure 24.Samples of cartridges produced from recycled ABS material

The activities showed that recovered plastic from cartridge parts could be successfully incorporated into new cartridge housings and passed all quality criterion and the recycled material content has been tracked by the ICT tool. One of the reasons of the success is that there is good control over Lexmark feed stream, limiting the risk of pollution with other kind of material. In case of Lexmark printer parts which has been dismantled and sorted by a recycler partner the test showed different contaminants (like Polycarbonate) as well as metal particles in the grinded material and therefore could not be used for further processes.

Resin recycling economic analysis

Considering the challenge to identify grinding and compounding capacity/suppliers in the market, Lexmark analysed the opportunity of setting up sorting/dismantling and grinding at its sorting centre location. It was decided in a first stage to not include compounding in the analysis.

The first step was to determine the volume at stake, looking at all products collected and sorted and selecting the ones made of ABS which ended up in scrap. Looking at the BOM to estimate the weight of these parts, we ended up with 14 000kg of ABS which could have been recovered.

The associated savings were determined as follows:

- Resin: at the time this business case was put together, virgin ABS was valued at 1.6€/kg. Tus total of 22k€
- Recycling cost incurred by the recycler: not considered as the recycler is also getting benefit out of those parts
- Freight cost to ship empty units to recycler: considered as not significant
- Toner: residual toner can be recovered from dismantled units. 9700kg of residual toner valued at 10€ per kg, a total of 97k€.

Total of about **120k€** savings, interestingly mainly driven by residual toner recovery and not much by resin. Which toner recovery may vary significantly depending on product mix.

The second step has been to estimate the cost associated with such sorting/dismantling activity. Lexmark worked with Syncreon to get this estimation.

- Vacuuming, installation: 60k€
- Specific equipment, such as grinder, conveyor with metal detection, second metal detection station…: 148k€
- Labour: at minimum, 2 headcounts: 40k€
- Total of about 240k€ associated cost, mainly driven by fix cost to procure equipment and get them installed

With the above working assumptions, there is a payback of 2 years (internal requirement is a year or less for such project). Various parameters influence such pay back, a significant one being the volume at stake, only 14000kg. An extended analysis considering volumes from previous years confirms that directionally with today's returns units, setting up grinding operations at the sorting centre is not an option from an economical viewpoint and therefore, the best option is to remanufacture those laser cartridges and maintain their value as long as possible in the economy. For most of its qualified products, Lexmark consider that its laser cartridges can be remanufactured up to 10 times, assuming proper process and materials are used.

4.4. Environmental, social and economic analyses

Life Cycle Assessment

The environmental impacts were determined using the LCA methodology according to ISO standards (14040/14044). The assessment comprised the whole life cycle of the products, including extraction and processing of raw materials, manufacturing, transport and distribution, use, maintenance (when required) and end of life. The method ReCiPe was used to assess 18 midpoint impact categories, in this summary only four representative ones are shown: global warming (climate change), human health, ecosystems and resource use.

Environmental benefits due to recycling were not added to the total life-cycle environmental impact of the EEE products but they are shown as recycling credits. Additionally, the Material Circularity Indicator (MCI) was determined to assess the circularity of the current products and business models.

Life Cycle Costing

The Life Cycle Costing (LCC) methodology was used to assess all economic costs associated with the complete life cycle of the target product, including internal cost (related to product manufacturing, use and end of life), as well as environmental externalities. The costs of environmental externalities were calculated by monetary valuation of the endpoint environmental impacts (obtained with the LCA).

Social Life Cycle Assessment

The social impacts for the target product were calculated using the S-LCA methodology. In particular, the method and the indicators of the Social Hotspot Database were used. A cradle-to-gate assessment was applied, with 26 social subcategories grouped into 5 categories. The SHDB offers a weighted model that converts the impact values of the social subcategories into aggregate impact values for each social category, which in turn can be aggregated into a single global social footprint for the products (the so-called Social Hotspot Index or SHI).

The results are shown for 1.000 printed pages with a Lexmark CX860dte professional multifunctional laser printer, excluding the use of energy and consumables.

Circular economy actions analysed:

- Remanufacturing
  - Refurbished parts reduce the mass of primary materials/components in the laser printer by 10.3% (from 129.75 kg to 116.36 kg).

Table 10. Main environmental, life cycle costs, and social life cycle indicators for 1.000 printed pages of the multifunctional laser printer.

Indicator	Unit	Reference	C-SERVEES	Relative improvement
LCA				
Global warming	kg CO_2 eq	2,779	2,558	8,0%
Human health	DALY	1,08E-05	1,00E-05	7,1%
Ecosystems	species.year	1,64E-08	1,51E-08	7,7%
Resources	USD2013	0,256	0,236	8,0%
Recycling credits	kg CO_2 eq	-0,387	-0,331	-14,4%
Material Circularity Indicator	-	0,484	0,543	12,3%
LCC				Relative reduction
Internal	€	65,48	65,48	0,0%
External	€	4,57	4,46	2,4%
Total	€	70,05	69,94	0,2%
S-LCA				Relative reduction
Labour Rights & Decent Work	Pt	35,12	34,56	1,6%
Health & Safety	Pt	49,54	49,10	0,9%
Human Rights	Pt	25,43	24,89	2,1%
Governance	Pt	61,48	61,86	-0,6%
Community	Pt	20,65	20,24	2,0%
Total – Social Hotspot Index	Pt	192,21	190,65	0,8%

Reusing part of the product modules for remanufacturing reduces the external cost of the production process by 8.4%, although this requires increasing the cost of the end-of-life phase by 16.9%, leaving the total reduction at 0.2%. Also, the environmental impact is reduced.

Reducing production costs in China by 5% shifted to remanufacturing in Mexico resulted in a decrease in social impacts by 0.8% on average, although with differences between -0.6% and 2% between different impact categories.

4.5. Life-cycle validation summary

From the results of the environmental, social and economic analyses of the printer and toner cartridges demonstration it can be concluded that for products with similar characteristics in terms of composition, use and end of life, it can be reasonable to scale up the demonstrator's results. In addition, the results are expressed on a functional unit basis so that they can be compared with other products using the same functional unit.

The results obtained are credible due to the data quality used. The data used to create the inventory model is as precise, complete, consistent and representative as possible with regard to the goal and scope of the study.

- Primary data were provided by Lexmark from the most recent BoM of the product. The data used for the study is considered to be of the highest precision. Ecoinvent database was the main secondary data source used to model the product system.
- Completeness was judged based on the completeness of both the inputs/outputs per unit process and the unit processes themselves.
- Consistency refers to modelling choices and data sources. The goal was to ensure that differences in results occur due to actual differences between product systems investigated and compared, and not due to inconsistences modelling choices, data sources, characterisation factors, etc.

As it is explained in the washing machine life-cycle validation summary, an LCA sensitivity analysis on lifetime and use intensity was performed to determine the conditions under which faster or slower changeover of the products may be beneficial under a circular scenario. Sensitivity dependence is the relative variation of the environmental impact with respect to the relative change in the number of units over the lifetime.

The results for the laser printer are shown in the figure below.

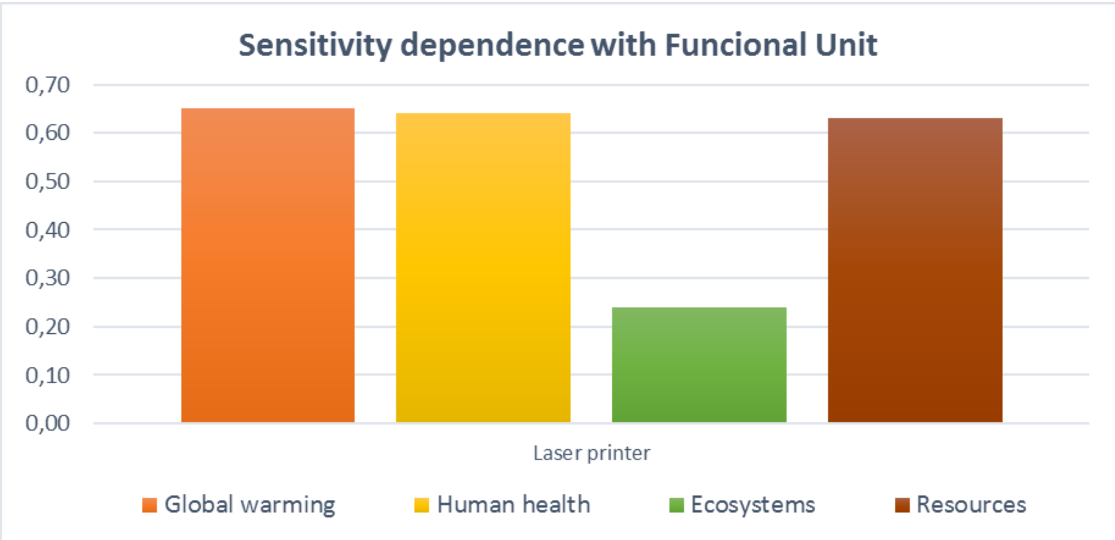


Figure 25. Sensitivity dependence with the change in the number of units during the lifetime of the laser printer

A value of 1 in this figure means that the value of the environmental impact with the modified number of units is the same as the impact with the standard number. Values closer to 0 mean lowest dependence. According to these results, the laser printer is the product with the highest sensitivity. The environmental impacts of consumables and maintenance of the laser printer are less significant than the impacts of the manufacturing, mainly due to electronics. This product could still further improve its environmental impacts by increasing their lifetime in the future.

The limitation of the conducted analysis is that the improvements considered do not focus on the use phase. It can be found that the paper consumed for printing has by far the highest global warming impact for the use phase. As the paper used for printing has the highest global warming impact of the use phase, using paper with less environmental impact could reduce the CO_2 emissions of this phase.

Electricity consumption also has relevant environmental impacts. In addition, when comparing both scenarios for electricity consumption, it can be found that the increase of renewable sources in the electricity mix contributes to reduce the impacts from the laser printers over lifetime.

4.6. Manufacturer's review

As per the project findings and outcomes, Lexmark has already implemented several circular economy actions explored during the project and will keep focusing on the most important ones to accelerate the Circular Economy concepts of its industry.

Based on the highlighted importance to retain ownership of the printers to ensure best in class Circular Economy practices, Lexmark will not only keep developing its existing Managed Print Services program, but it will also implement Print Shared Services model through a subscription program which has been recently launched. This will definitively help to determine the best options to extend the life of used products (extend warranty, upgrade, refurbish, remanufacture, recover parts, or ultimately recycle).

Lexmark is now better aware of customer acceptance changes and decided to make refurbished product offers more cost attractive. Lexmark will adjust its cosmetic criteria and launching grade A/B type refurbished product lines. This is a radical mind shift that accelerated internal processes towards more ambitious circular economy solutions. The newly developed subscription program should help to boost the refurbished products market and increase sales volumes.

A major focus needs to be on internal training and incentivizing sales of refurbished products. Lexmark started to promote take back/buyback programs supported by the recently launched web platform to automatize the reverse logistic process and make it easy for customers to give back their used products for free. This will be done through communication, social media campaigns as well as customer incentives. Several actions are already planned to develop appropriate marketing communication as well as internal communication for 2023.

Highlighted in the demo as well as during interviews with competitors and resource recovery actor, reverse logistics is a significant cost of product refurbishing. Lexmark is now participating in a pilot involving various competitors to join efforts and share fixed costs related to printing consumables (laser cartridges, ink jet …) collection and remanufacture.

A major request from customers was to better understand the environmental savings of a refurbished printer versus a new one. Lexmark intends to communicate the C-SERVEES printer LCA findings to improve customer's perception. Lexmark's refurbished printers reduce the carbon footprint of the manufacturing phase by up to 50% (compared to new products).

Lexmark is preparing a third-party certified Life Cycle Assessment for remanufactured cartridges to better measure the environmental savings of reused products (especially the reduced carbon footprint). The main goals are:

1. Develop a holistic understanding of the potential climate change impacts of a printer cartridge by means of a product carbon footprint (CFP) based on ISO 14067.
2. Understand the burdens and benefits of Lexmark's refurbishment program on the CFP of cartridges when compared to conventional, single-use ones.
3. Identify hot spots within and across all life cycle stages.
4. Derive potential improvements for design, manufacturing, refurbishment, distribution, and treatment at End of Life.
5. Understand regional impacts through comparison of manufacturing, distribution and EoL treatment in US vs. EU.

5. ALM products demonstrator

The ALM demonstration was led by ADVA and this section provides an overview of the demonstration activities, results and findings during the demonstration period.

5.1. Company and product description

5.1.1. About ADVA

ADVA was founded in 1994 and is headquartered in Munich, Germany. It has 38 locations globally and has significant operations in Germany, Poland, England, Israel, China and the USA. Between 2017 and 2022, the headcount was 1,900-2,000 employees, and total revenue was in the range of EUR 500-700 million.

ADVA is a global provider of open networking solutions. This comprises wavelength-division multiplexing (WDM) fibre-optic transport technology, Carrier Ethernet access, aggregation and network functions virtualization (NFV) technology and solutions for network synchronisation and fibre monitoring, respectively. Fibre monitoring is offered through the ALM, Advanced Link Monitoring, product line. These hardware products are complemented by the related software for equipment and network configuration management and monitoring.

The majority of ADVA's customers buy products together with maintenance and repair services, which can be regarded an entry-level PSS (product-service system). Revenue with these services is >15% of total revenue. The maintenance, in turn, is supported by monitoring functions in the products and their software, which includes failure analysis and even failure prediction and preventive maintenance. A certain number of take-back services at product end of life is also already in place. This includes the analysis of any equipment that is taken back regarding its potential for further reuse. This includes components reuse, where components extracted from equipment that has been taken back can, e.g., go into stocks for spare parts, thus prolongating the lifetime of certain products that require the respective components.

ADVA's business is purely B2B, and there are no plans to extend this to private end customers. Customers are private enterprises (in particular banks, insurance companies and other large companies, with a total revenue share of 25%), internet content provider (10%) and communication service providers (network operators, 65%). In addition, ADVA is the only vendor that is certified by the BSI, the German federal office for security in information technology. Therefore, also governmental networks are served.

The majority of the business is done via (value-added) resellers or OEM (original equipment manufacturers) partners. Examples of OEM partners include ICT manufacturers like Nokia or IBM. The difference as compared to other resellers is that OEM partners typically re-brand the products so that they no longer look like ADVA products. Take-back and recycling obligations in most cases are followed by the resellers or OEM partners.

5.1.2. Product description

The ALM (advanced link monitoring) system was originally developed for cost-efficient monitoring of access fibre plant. The ALM system is essentially an OTDR, an optical time-domain reflectometer. It sends light into the respective fibres, and by analysing the reflected light, it can monitor the fibre and its integrity. The complete ALM system splits into an active ALM unit (which contain the opto-electronics for the OTDR, the signal analysis and the management access) and passive fibre-optic sensors that act as partial reflectors at the end of the fibre that is to be monitored.

A typical application for monitoring radio-access-network fibres is shown in Figure 26. The active ALM unit is accommodated, together with the associated passive fibre couplers, in a central office of the network/service provider.

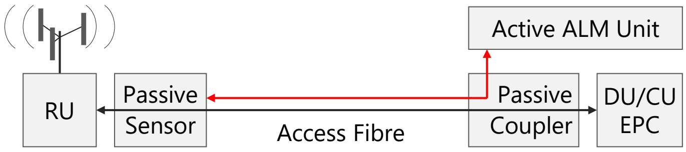


Figure 26. Application of an ALM in radio-access-network monitoring. RU: radio unit. DU: data unit. CU: control unit. EPC: evolved packet core (RU, DU, CU and EPC are part of the Internet).

The active ALM units is available in two different versions, with 16 fibre ports and with 64 fibre ports, respectively. These have half ETSI width (~27.5 cm) and full ETSI width (~55 cm), respectively. They are shown in Figure 27.

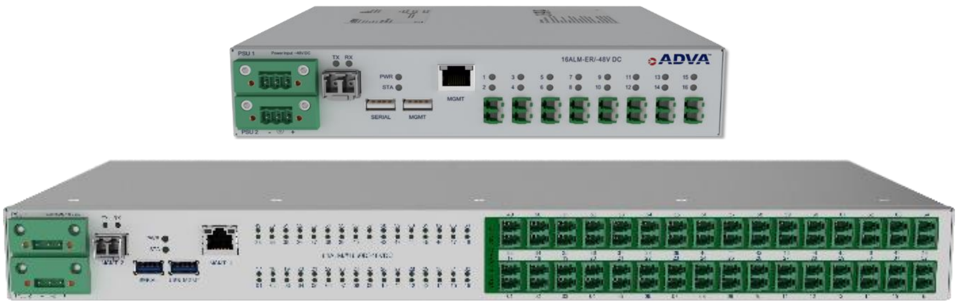
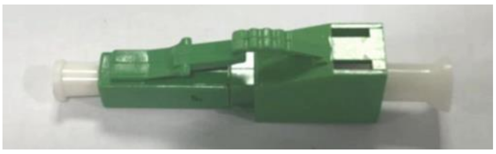


Figure 27. Active 16ALM unit (above) and active 64ALM unit (below) for -48 VDC powering

The ALM sensors are small, passive components that connect to the respective fibres. An example of a reflector that is integrated into a standard fibre-optic connector is shown. The device is mainly made of plastic and has a total length of ~25 mm. The reflector does not have any mechanically moving parts.



According to Figure 26, a complete ALM system can consist of an active unit, a certain number of passive sensors, and the same number of passive couplers that couple the monitoring signal into and out of the fibre. In the C-SERVEES ALM demonstrator, a slightly different configuration is used where fibres inside buildings are used for monitoring the buildings, but not for additional telecommunications services. Therefore, the passive couplers are *not required* in the ALM demonstrator since the monitoring fibres can be connected to the active ALM units directly.

5.2. Demonstration activities

ALM products demonstration

Demo leader: ADVA

Baseline	Demonstration activities
• ALM passive units for monitoring of optical fibre network stability	Development of new ALM passive units (sensors) with fire and water alarm detection to substitute current electric sensors
• Products eco-designed for energy efficiency and long lifetime	Analysis of ALM active units from the recycling perspective and proposal of eco-design measures
• Business model consisting of sales with maintenance services	Assessment of different PSS models for the ALM products, with extension to other ICT products
	Simplified LCA-based optimum EEE lifetime analysis
	Integration of PSS assessment with life cycle optimisation assessment
• Limited component reuse	Assessment of component reuse, LCA based

5.3. Demonstration results

5.3.1. Development of new ALM passive units

The active ALM units can monitor 16 or 64 fibres by switching the OTDR transceiver periodically to each fibre. This reduces the cost of the active opto-electronics per fibre. It also reduces the electrical per-fibre power consumption since one active unit serves several fibres. In addition, each fibre can contain several sensors, which further reduces cost and power consumption. Compared to electrical alternatives, this makes the ALM system advantageous in terms of cost and environmental footprint.

This activity focused on developing newly designed, LCA-optimized ALM sensors with intended lifetime of several decades (30 years). These ALM sensors (for whatever task like fire monitoring or access control) are small, passive devices. Apart from a small fraction of optical material (silica glass, dielectric thin films), they consist of plastic. They do not consume any energy. If installed as part of an infrastructure (e.g., for monitoring buildings or fibre plant), they can remain in their location for decades. Their integrity is periodically checked by the active ALM units anyway, so that any failures, no matter how unlikely they are, can be detected.

Sprinkler sensor

Early detection of fire can save lives and limit fire damage. One way to do this, especially in commercial and industrial buildings, is to monitor the status of the fire sprinkler system. Whereas common fire location systems are based on electronic systems, in our concept we developed a fully passive optical sensor that can directly be placed on the sprinkler heads of the fire prevention system. In case the sprinkler head is activated, the optical sensor changes its reflection characteristics and thereby the activation of the sensor can effectively be detected. Figure 28 shows a simple illustration of the configuration.

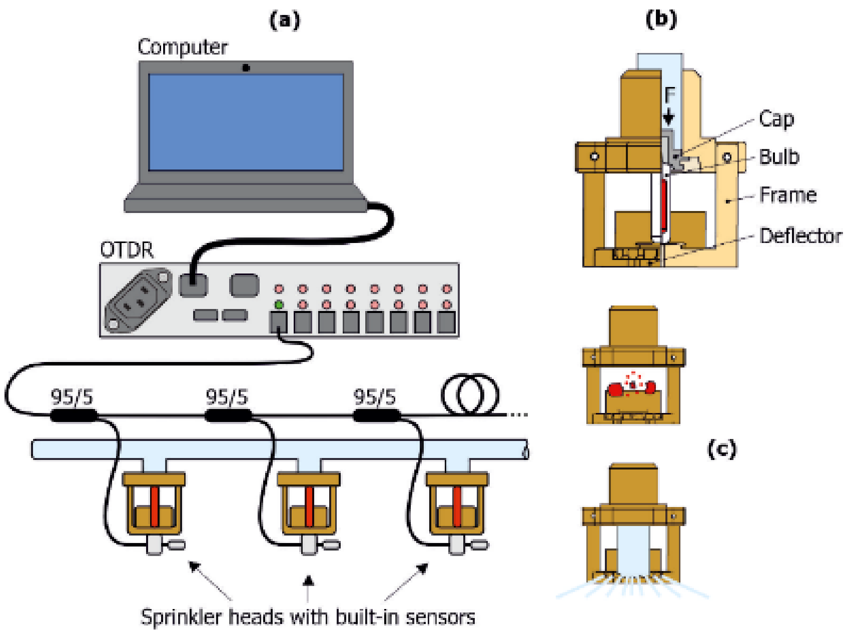


Figure 28. Sprinkler sensor architecture

In (a) the system architecture is shown. The ALM is used as OTDR in this configuration, and it periodically scans the status of all sensors. Per connection to the ALM up to 50 sensors can be connected in series.

Figure 29 shows various pictures with the different parts of the sensor and how it is attached to the sprinklerhead.

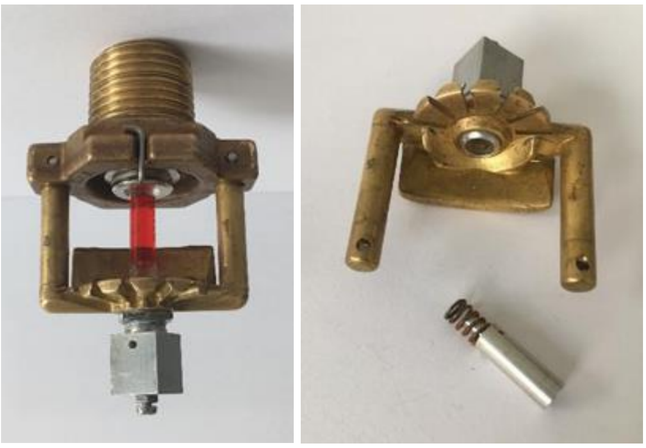


Figure 29. Sprinkler sensor and sprinkler head.

Electrical fire sensor

Fire doors are an effective mechanism to slow down the spread of fire. However, especially in offices oftentimes fire doors are not properly shut. Therefore, it is important to be able to detect whether a fire door is opened or not. Most important for the detection of fire doors is that even when the door is just slightly ajar, this is detected as well. The reason for this is that only properly shut fire doors provide the protection against fire that they are designed for. Initially, we investigated door sensors to be mounted at the hinge of the fire door. However, it turned out to be very difficult to detect doors that are ajar. Therefore, we chose a sensor design that is mounted on the other side as illustrated below.

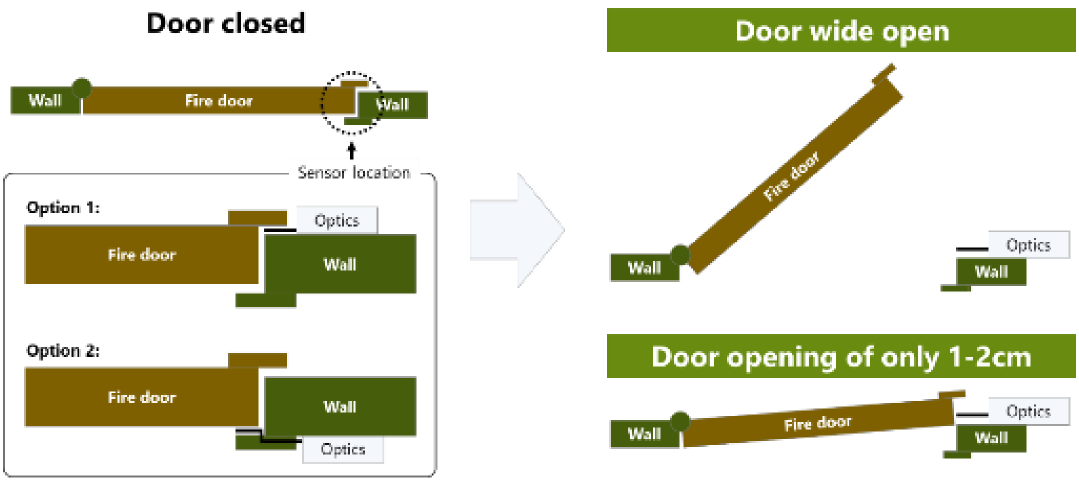


Figure 30. Fire door sensor operation principle

The operational concept of the door is identical to the sprinkler sensors described above. A range of designs has been made and evaluated. Please refer to the two illustrations below for a 3D model and the dimensions of the latest design.

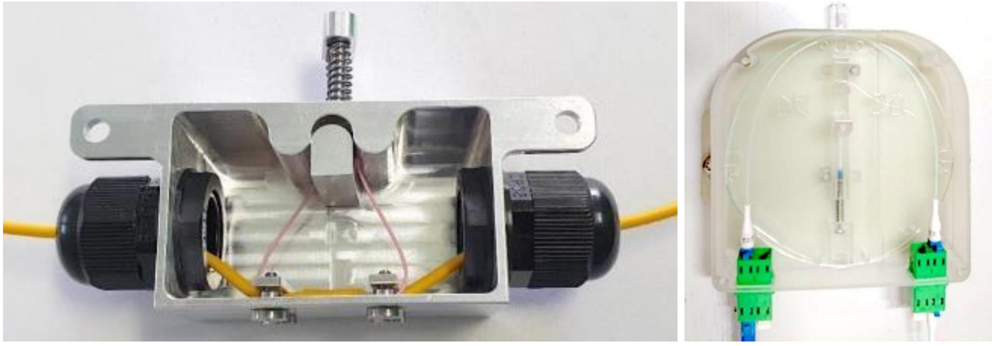


Figure 31. Original fire-door sensor design and final version design.

Sensor analysis

As previously explained, the ALM system with its passive sensors has clear environmental advantages over electrical monitoring. For a comparison between complete systems (active plus passive vs. fully electrical, including analysis units and displays and interfaces), a factor of six has been derived between similar monitoring systems in the context of second-life battery monitoring. This advantage for the ALM system is primarily driven by lower energy consumption *per sensor*, with a secondary smaller contribution from lower material consumption.

A secondary aspect is that the sensors have to be connected with fibre-optic cables. Electrical sensors, on the other hand, must be connected with copper cables, or they need suitable batteries and wireless access. That is, not only the passive ALM sensors themselves seem to have clear LCA advantages over electrical sensors. Their infrastructure (the cables), presumably, also could have certain advantages over the infrastructure required for electrical sensors.

Extensive tests of production samples of the sensors developed during the C-SERVEES project have been performed on the cabinet (door) and fire sensors in commercial test beds. In these measurements, parameters like the fibre-optic insertion loss depending on humidity and temperature were measured in order to capture the attenuation profile of the sensor. They revealed that the sensor is sufficiently insensitive against temperature and humidity, which allows its commercial application, e.g., to control door openings and similar in-door events. It needs to be noted that these sensors, together with the active ALM units, have very long lifetime (for the sensors: decades, for the active ALM units: at least 10-15 years), and that total environmental impact according to LCA is far better than the respective number of electrical sensors, as stated earlier already.

As next step, a commercial contract was closed for a first installation of the new sensors for door-opening and fire detection, together with active ALM units. The contract covers a PSS1 according to our analysis, that is, selling the products plus maintenance services. Further future deployments, in particular of the ALM system, shall be done with PSS3. (as per 5.3.3)

5.3.2. Analysis of ALM active units from the recycling perspective

Two actions were carried out on the active ALM units during the project:

- Manual disassembly of several 16ALM units (the 16-port active devices)
- XRF (X-ray fluorescence) analyses of plastic parts derived from disassembly

These actions aimed at gaining insight into (and confirming, if applicable) compliance of the active units with relevant regulations and suitability for easy disassembly and recycling. They were carried out by the project partners Gaiker and Indumetal. A total of 4 active units were disassembled and analysed.

The disassembly of the ALM units revealed quite a number of different small plastic parts that consisted of different material and had different colours. This contradicts recommendations that are already included in the DfE Guide. This will lead to a stronger focus on following the respective guidelines. The disassembly also revealed small rubber and metal parts, as shown in Figure 32.

Figure 32. 16ALM plastic parts (left), rubber (centre) and metal (right) after disassembly.

The remaining components fractions after manual disassembly were fibre-optic and copper cables, and large metal parts (chassis, heat sink), respectively, as shown in Figure 33.

Figure 33. 16ALM cables, Al heat sink and chassis after disassembly.

The disassembly further revealed the relative portions of each material fraction of the active ALM units. Results for the 16ALM are summarised in Table 11.

Table 11. 16ALM disassembly analysis.

Component	Material	Weight [g]	Weight %
Housing	Iron	909.3	54.8%
Screws	Magnetic SS	54.4	3.3%
Connectors	Non-magnetic SS	100.7	6.1%
Heat dissipation	Aluminium	190.2	11.5%
PCBs	-	304.9	18.4%
Wiring	-	33.4	2.0%
Optic fibre wire	Nylon	37.0	2.2%
Small plastic parts	Plastic	25.6	1.5%
Small rubber parts	Rubber	0.9	0.05%
Battery	Lithium	2.7	0.2%
Total		**1659.1**	**100%**

The analysis of the disassembled ALM units concentrated on potentially critical materials. A short summary of this analysis is shown in Table 12.

Table 12. ALM analysis of critical materials.

Component	Priority in disassembly	Comments
Lithium battery	High priority. It must be removed compulsory according to the WEEE Directive.	Is the battery needed? Can it be placed in a position where it is easier to remove it?
PCBs	Medium priority. PCBs >10 cm^2 must be recovered according to the Directive. However, it can be extracted during manual disassembly.	-
Plastic parts	Not critical	Bromine additive content has been checked twice

Regarding the Lithium battery, the comment regarding its necessity must be answered with "yes". Similar to each PC or laptop, the active units require a battery in order not to lose data immediately in cases of power-supply failures. The position of the battery with regard to easier disassembly will have to be considered in future releases of the active units.

The plastic parts were also analysed for any content of restricted substances with X-ray fluorescence (XRF) analysis. This analysis showed that the plastic parts that were investigated did comply with the relevant applicable regulations.

5.3.3. PSS analysis for ICT systems and beyond

Introduction

Circular economy (CE) depends on supportive business models. It is commonly agreed that product-service systems (PSS) best support CE. Different PSS are possible, ranging from selling products together with maintenance services to retaining product ownership and selling fully-managed services [1], [2].

In particular, PSS where product ownership is retained are considered very efficient in supporting CE. The main reason is that due to the retained ownership, the manufacturer has highest interest in getting the highest value out of the hardware part of the PSS, once the hardware cannot be kept alive as is anymore. That is, maintainability, upgradeability, repair, disassembly, components reuse and recycling yield must be considered from the beginning, before production. In return, these CE aspects can be supported more efficiently, thus potentially decreasing total lifetime cost or even increasing revenue.

However, as can be derived from Figure 34 by red highlighting, several PSS paths regarded very efficient do not work for infrastructure ICT (information and compute technology) equipment. By infrastructure ICT equipment, we refer to equipment that is used by ICT network operators or service providers, not by private end-user equipment.

Equipment sharing between lots of customers is done in ICT core networks by default. Concepts like virtualization, Infrastructure as a Service, etc. are used to maximize utilization. However, these concepts must be managed by the network operator, not the equipment vendor, since no example of a combined successful vendor-operators exists. In addition, utilization in core networks is upper-bound by queueing (communications) theory.

Product system substitution, the PSS regarded most efficient, is no general option. The (core) ICT infrastructure cannot be substituted. In turn, ICT is replacing physical meetings, travel and other resource-intensive systems. This narrows PSS paths for the equipment vendor.

Hereinafter, we analyze several PSS for ICT infrastructure equipment regarding commercial and environmental performance. This analysis is then extrapolated to certain other equipment as well.

PSS analysis for ICT equipment and beyond

Our analysis of PSS is based on a modified version of the PSS overview given in [1]. We complemented and corrected this overview with regard to infrastructure ICT equipment, the new version is shown in Figure 34.

Three aspects of potential PSS paths in the diagram are market red since they cannot be applied to ICT infrastructure equipment as already discussed – sharing is already optimized, and ICT substitution is not possible since no other, more efficient substitution for ICT exists. The opposite is true – ICT is the main enabler for virtualization or dematerialization and therefore, decarbonization, in other sectors.

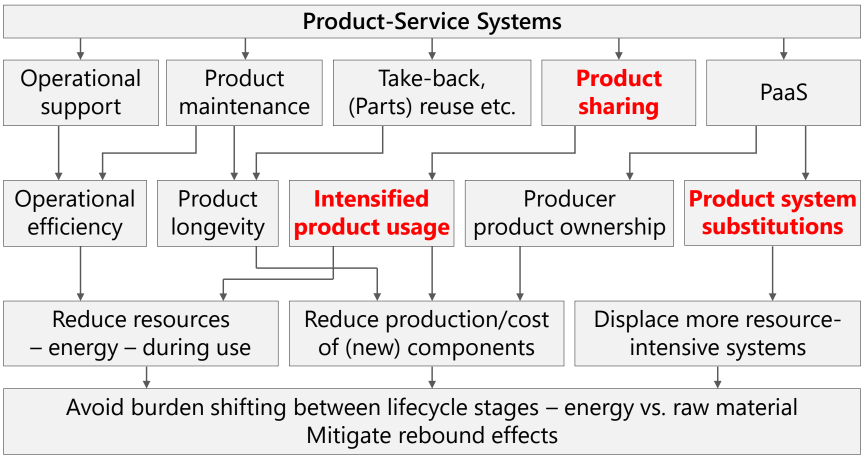


Figure 34. Modified overview on PSS, based on [1]. PaaS: Product (functionality) as a Service.

All PSS shall be complemented by additional measures that aim at avoiding burden shifting and rebound effects. In certain cases, this can be quite tricky since often, more efficient products lead to higher production, thus in total increasing material intake. Note that meanwhile, the avoidance of rebound effects is one of the requirements of the EU Taxonomy [4], where it is referred to as the do-no-significant-harm principle.

Related to the trade-off between material efficiency and total-lifetime emissions, optimum-lifetime analysis can be used in order to avoid such adverse effects, see section 7.7 and reference [6].

With the PSS restrictions indicated in Figure 34, the following PSS were analysed for ICT equipment:

- PSS1. Product sold, together with maintenance, without take-back at EoL
- PSS2. Product sold, together with maintenance, with take-back at EoL
- PSS3. Leasing, including maintenance and take-back at EoL
  - PSS3a. **Only the product is leased**: "TeraFlex" fiber-optic, core-network transport system (used to connect data centers and large sites of network operators)
  - PSS3b. **Service offered by the product leased**: "ALM" infrastructure monitoring system (used to monitor fiber assets, buildings, etc.).

All PSS are combinations already since for all PSS, operational efficiency in the form of highest possible energy efficiency, is supported as well. PSS1 is mainly used to show end-of-life (EoL) effects. Therefore, the main comparison is between two PSS that both offer a certain functionality and include maintenance and EoL services.

The analyses were conducted for two ICT systems, called ALM and TeraFlex. They were then generalized to certain extent to non-ICT-products. To certain extent, this includes the three aspects marked red in Figure 34.

The duration of the analysed periods, 30 years for the ALM and 16 for TeraFlex (including replacement) was taken from the lifetime analysis in [6]. Estimates for the EoL yield (both, in terms of cost and resource-related emissions savings) were taken from older, published analyses on our ICT equipment efficiency in recycling and reuse [7], [8]. The respective values are small, which is primarily due to fast functional obsolescence of all involved sub-systems and components. We used the yield numbers summarized in Table 13. The difference stated in Table 13 proved insignificant as seen later.

Table 13. EoL / take-back yield parameters

EoL / take-back yield for PSS2	6%
EoL / leasing yield for PSS3	10%

These numbers may look small, but from all previous analyses, we do not have any indication that these numbers can massively be improved for equipment from a fast-paced market with functional obsolescence like the ICT market. Also, these numbers are above what is achieved today on smaller scale. For sensitivity analyses, we increased these numbers to up to 40% (which is regarded completely unrealistically for ICT).

When transferring our analysis to other equipment, however, these numbers must be re-considered and adopted.

The PSS analyses considered all relevant financial aspects over the considered periods, i.e., sales, marketing and administrative overheads, vendor and customer weighted average cost of capital (WACC, i.e., interest rate), hardware, installation and maintenance cost and revenues, which in total led to vendor net present value (NPV) or customer cost cumulating over time. In addition, we considered energy cost as well as the increase of energy and service cost over time. Parameters are summarized in Table 14.

Table 14. Commercial parameters

Vendor WACC	8.8%
Customer WACC	6.0%
CAGR of maintenance cost	1.0%
CAGR of hardware cost	0.0%

The vendor WACC value is the one for ADVA. It represents the profitability expectations on ADVA given its risk profile. The customer WACC is lower (better). This is driven by large customers that have lower WACC. Note that the higher vendor WACC is *not* in favor of the vendor (here: ADVA) in our assessment.

Commercial PSS comparison

The commercial comparison between the different PSS for the cumulative NPV is shown in Figure 35 for the two products under consideration. Note that only PSS1 *or* PSS2 are shown since both perform almost identical, with differences not visible in the diagrams.

Similar cumulative NPV at the end of the considered periods result since service charges have been adapted accordingly. This may be subject to negotiation in reality.

For TeraFlex, a fiber-optic WDM (wavelength-domain multiplex) transport system [5], one replacement was considered in the middle of the considered period. This follows from lifetime consideration [6]. Here, improvements in energy efficiency over time are so high that replacement makes sense if total-lifetime global warming potential (GWP) is considered.

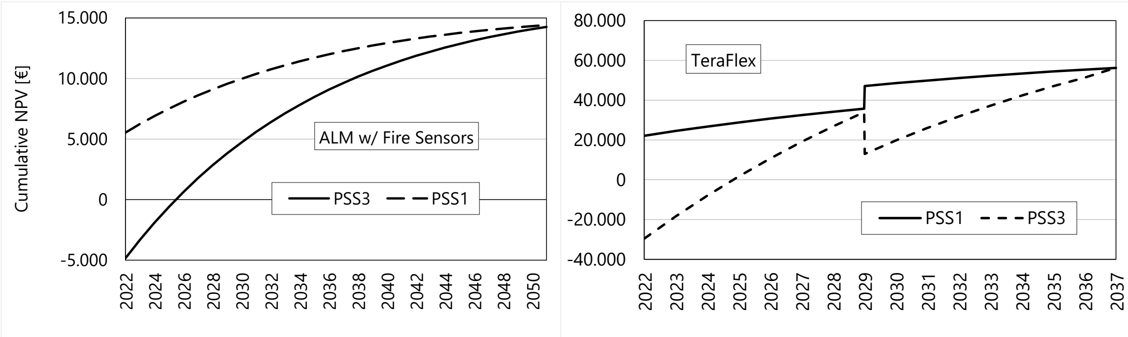


Figure 35. Comparison between PSS1 and PSS3 for the cumulative ALM NPV (left) and between PSS1 and PSS3 for the cumulative TeraFlex NPV (right).

The ALM, a fiber-optic monitoring system, was equipped with fire sensors. Compared to other sensors of that system, fire sensors require somewhat higher service and maintenance effort and cost due to legal requirements. In the assessment, this has a certain limited impact on the PSS3 cost.

In both cases (TeraFlex, ALM), the cumulative NPV was set such that both PSS achieve the same NPV at the end of the assessment period. This is likely unacceptable in many cases since return on invest (RoI) for the vendor is heavily delayed for PSS2/PSS3. If price (not cost) is increased to compensate for the delayed RoI, customer cost increases accordingly.

The comparison of the corresponding cumulative customer cost is shown in Figure 36.

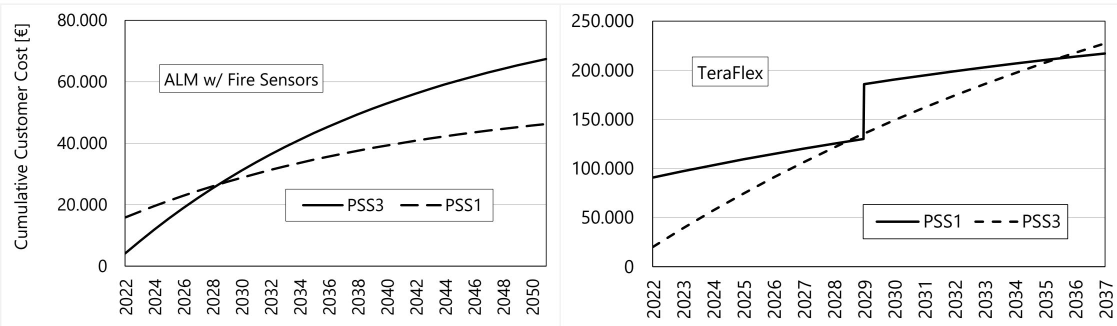


Figure 36. Comparison between PSS1 and PSS3 for the cumulative ALM customer cost (left) and between PSS1 and PSS3 for the cumulative TeraFlex customer cost (right)

For the ALM, higher customer cost of +45% result for PSS3. This covers the managed ALM fire monitoring service, which requires running an NOC by the vendor. For such a service, +45% is regarded a small mark-up. In real commercial offerings, the price mark-up for the managed service will likely be significantly higher.

PSS3 for managed services is regarded commercially viable subject to two aspects. First, the service leasing PSS is most suitable for customers who *do not own a NOC*. This can hold for small network operators and for operators of smart buildings and utilities. For such operators, the higher price can be attractive when they do not have the means and knowledge for operating an own NOC. In return, large network operators, who have their own NOC, may be less willing to pay the price premium of PSS3. Second, the *vendor must serve several customers*. Then, the vendor can share the cost of the NOC amongst the respective customers, thus lowering the service cost.

Further parameters and results of the three PSS for the ALM are summarized in Table 15.

Table 15. PSS comparison for the ALM

ALM	PSS1	PSS2	PSS3
Runtime [Years]	30		
Use mode	24/7 always-on		
Initial HW sales	Yes		No
Take-back	No	Yes	
Power consumption [W]	10		
Cumulative GWP [kgCO2e]	620	610	604

For TeraFlex, customer cost higher by ~5% result for PSS3. This covers the fact that the vendor now has the day-1 invest, which may lead to the necessity of cooperating with banks for financing. The customer cost mark-up is regarded viable given that the customer does not have the day-1 invest.

Table 16 summarizes the PSS parameters and results for TeraFlex.

Table 16. PSS comparison for TeraFlex

TeraFlex	PSS1	PSS2	PSS3
Runtime [Years]	16		
Use mode	24/7 always-on		
Initial HW sales	Yes		No
Take-back	No	Yes	
Power consumption [W]	1000		
Cumulative GWP [tCO2e]	30.1	30.0	29.9

End-of-life impact

In this chapter, the PSS are analyzed in more detail with special consideration of the EoL. The relevant parameter considered here is the EoL recycling or reuse yield. Based on analyses of the ADVA reverse-logistics process, a percentage range of 8…12% of the initial product cost has been considered for the analysis, refer to Table 13. This range is regarded optimistic and so far has not been matched in reality. Our reality, despite all necessary processes being available, approximately was half of that range so far. Even the optimistic range of up to 12% did not lead to substantive differences between the PSS, in particular between selling a product together with maintenance and EoL take-back (PSS2) and product or service leasing (PSS3), see Figure 37, top.

Next, the analysis is repeated with EoL yield for PSS 3 (40%) which is higher by a factor of 2 compared to PSS2 (20%). At least for infrastructure ICT equipment, both values are considered much too high. Results are shown in the bottom of Figure 37. This figure is a zoom into the final part of the diagram, for better visibility of effects. Despite the greatly increased EoL yield, no substantive differences between the PSS can be identified.

The zoom into the last year of the considered period in the bottom part of Figure 37 shows that there is almost no difference in NPV for the manufacturer between PSS2 (selling the product with maintenance and EoL take-back) and leasing the product's main function as a service.

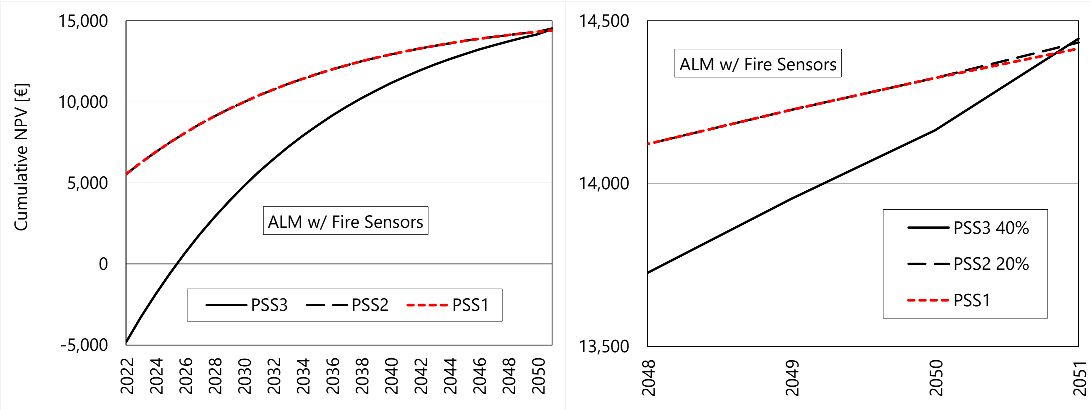


Figure 37. Cumulative NPV (left). Zoom into cumulative NPV (right) for 20% and 40% EoL cost yield, respectively.

However, given there is the obligation for take-back in both cases, and other relevant parameters like cost, considered period, provided product functionality (be it sold or leased) etc. remain the same as well, then there is no fundamental mechanism why the EoL yield should differ between selling and leasing a product.

In other words, *it is the EoL take-back mechanism that is relevant, not the leasing*. Therefore, leasing can be regarded a purely financial mechanism that is vastly independent of any circularity or EoL gains. It can and should be applied if financially viable, but the circularity gains are driven by take-back and successive recycling or reuse. In turn this means that for PSS like our PSS2, there must be the EoL obligation of take-back for the manufacturer.

Independent of this, leasing can and shall be implemented if it has financial advantages.

Environmental analysis

Next, the PSS impact on the most relevant environmental parameter, carbon emissions (GWP, global warming potential) is assessed. The result for PSS2 and PSS3 for the ALM is shown in

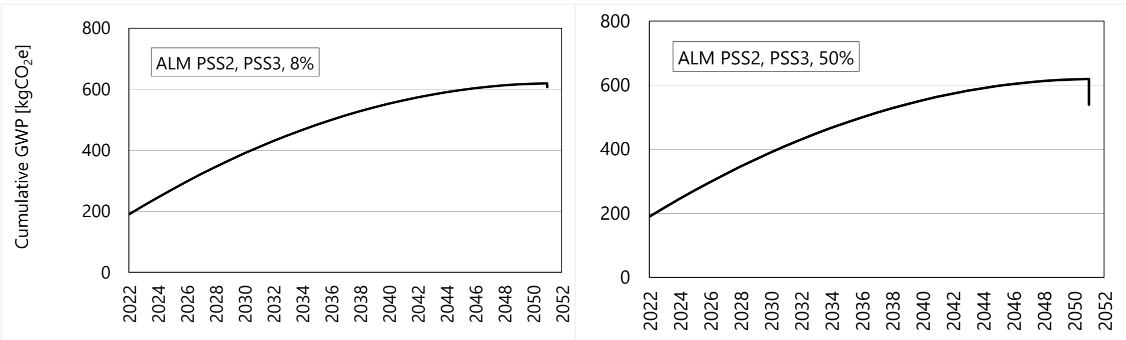


Figure 38.

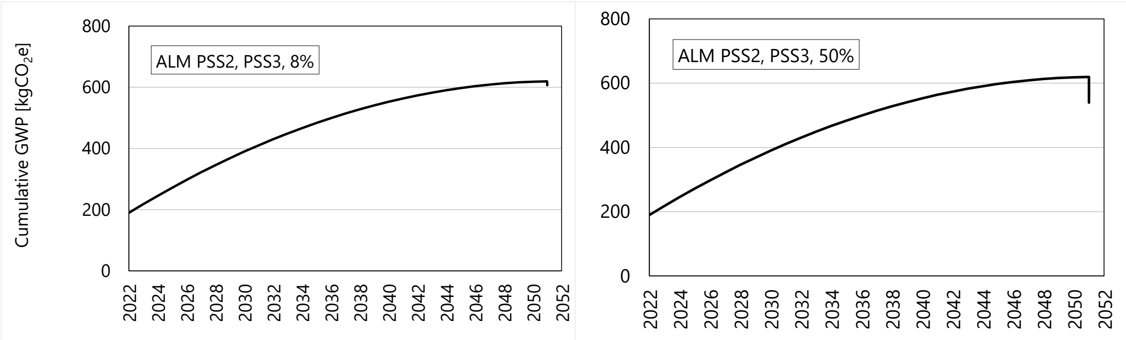


Figure 38. Cumulative GWP for different ALM PSS at 8% (left) and 50% (right) EoL yield, respectively.

The GWP curves show identical values for PSS2 and PSS3, respectively. The steep decline at EoL (year 2051 in the diagrams) marks the EoL GWP "gain" (avoided emissions) due to recycling/reuse at EoL enabled by take-back. Again note that we regard 8% EoL gain more likely to be achieved than 50%. With the exception of the EoL GWP gain, PSS1 shows an identical result.

The diagrams show that practically (for realistic EoL yield, as discussed earlier), the environmental impact is dominated by the use phase and production.

For TeraFlex, similar findings result with the difference that TeraFlex is even more dominated by its use phase (i.e., even smaller EoL impact).

Influence of energy cost

It is sometimes stated that energy cost can be as much as 20% of total OpEx for network operators. For an overview on network-operator OpEx, see [9]. Here we show that energy consumption, though significant in the TeraFlex case, is not a relevant cost driver for the respective PSS, even if electricity cost and related carbon-emission cost are considered. This is shown in Figure 39 for both systems, ALM and TeraFlex.

The left diagram shows the customer-cost comparison with and without energy cost for the ALM over 30 years. This was calculated for PSS3. For the other PSS, the difference is negligible as well. The hardly visible difference is due to the fact that the ALM energy consumption is comparatively low.

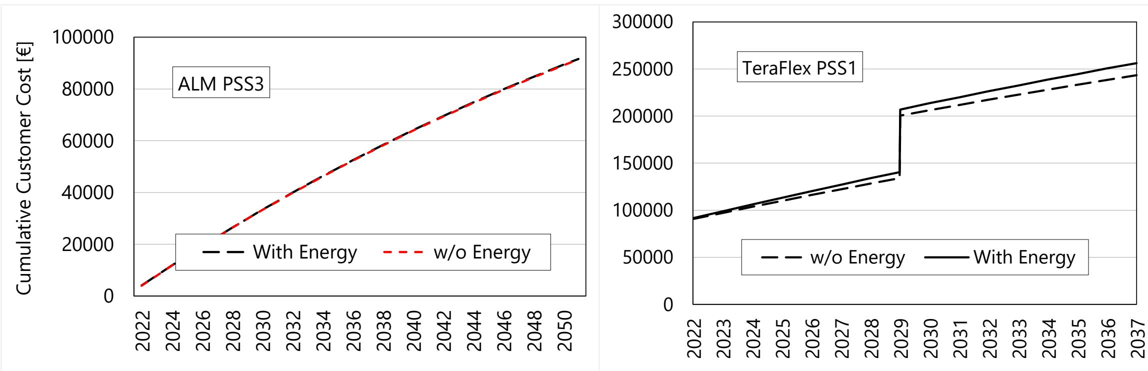


Figure 39. Cumulative customer cost with and without energy cost for the ALM in PSS3 (left) and for TeraFlex in PSS1 (right).

The right diagram shows the cost comparison for TeraFlex and PSS1. Again, PSS2 would show identical results, and the cost difference for PSS3 is also in the very same range. Now, the difference between the cases with and without energy cost is visible. This is because the

TeraFlex system has relatively high energy consumption, despite being very energy-efficient. However, no impact on the PSS choice results. As a result, energy cost does not have an influence on PSS choice, although energy consumption may have an influence via the optimum-lifetime consideration.

Table 17 lists the relevant parameters that were used for the energy-cost assessment.

Table 17. Parameters used for energy-cost calculations.

Electricity cost large industry customer (2021)	80 EUR/MWh
CAGR electricity cost	2%
Emission factors	As per [6]
Energy efficiency	As per [6]
Carbon tax [EUR/tCO_2e]	25 EUR/tCO_2e in 2021, linearly increasing by 8 EUR per tCO_2e per year. This leads e.g. to 65 EUR/tCO_2e in 2026, where this number and the start value have been taken from German carbon tax.

PSS selection generalization

Certain PSS become more attractive if for example, maintenance or operations cost are relatively high compared to system CapEx. Therefore, it is useful to define a ratio that relates CapEx to maintenance cost:

$$CMR_{10} \coloneqq \frac{\text{CapEx of the product}}{\text{Maintenance OpEx over 10 years}} \qquad \text{(Eqn. 1)}$$

CMR_{10} is the ratio of the product CapEx to the OpEx generated by 10 years of maintenance. We consider 10 years for the OpEx parameter. This duration results from our experience regarding infrastructure ICT lifetime. For massively deviating lifetime, the *CMR_{10}* ratio should be adapted.

Note that we do not consider other OpEx like energy cost here.

Two ranges with **CMR_{10} </> 1** can be discriminated.

$CMR_{10} < 1$ reduces the influence of the necessary day-1 invest (either for the customer in cases of PSS1 and PSS2 or for the vendor in case of PSS3). Therefore, small *CMR_{10}* points more toward PSS3 from the vendor viewpoint and PSS2 from the customer viewpoint since the respective day-1 invest loses its relevance.

In turn, **$CMR_{10} > 1$** points more toward PSS2 from the vendor viewpoint.

For the ALM with fire sensors, $CMR_{10} \approx 0.8$ results, for TeraFlex, $CMR_{10} \approx 1.8$ results. Note that this *CMR_{10}* range may be exceeded by other EEE. In such cases, the indication toward either PSS1/PSS2 or PSS3 becomes even clearer.

Products without ICT challenges and ICT features

Generic EEE products may neither show all the ICT-products challenges, nor their beneficial features. In the context of circular economy and PSS, the main challenges of infrastructure ICT products can be summarized as follows:

- Very fast development cycles, therefore massive functional obsolescence. This holds for both, complete products and their components. It strictly limits reuse.
- Environmental impact dominated by use phase. Therefore, energy efficiency is most relevant during the next years to come (until emission factors get better), and again, lifetime may be strictly limited.
- In many cases, further improvements in utilization are not possible
- The ICT infrastructure cannot be virtualized.
- In turn, infrastructure ICT products in most cases have these beneficial features
- Remote monitoring and supervision via the DCN (data communications network, which is a logical part of the ICT infrastructure), including failure prediction and the possibility to arrange *scheduled* maintenance.
- Modularity, including resilience of critical modules and high mean time to repair.

If the ICT-products challenges do not apply for generic EEE products, this can have influence on the most beneficial PSS. First, if functional obsolescence or energy efficiency are less critical, positive effects of reuse and parts reuse can become more apparent. In turn, this may make PSS2 and PSS3 of our assessment more attractive because EoL treatment may provide higher positive credits. This must be confirmed with LCA.

If the EEE products under consideration still have significant potential for higher utilization (e.g., by better sharing), then the PSS that focuses on sharing and product utilization should be investigated (see Figure 34). It can potentially lead to high yield since it can be combined with measures for either the reduction of resources during use or during production. Potentially, it may be limited by customer acceptance (e.g., acceptance of sharing a product with others).

Moreover, there is a chance that certain EEE products can be substituted by less resource-intense systems. Examples may include the integration of further functions into smart phones that than replace dedicated electronics hardware that supported these functions earlier. In that case, the PSS at the right edge of the PSS diagrams in Figure 34 (product system substitution) shall be assessed. Effects of such substitutions must again be calculated and confirmed by LCA in order to avoid adverse effects.

Finally, other EEE products may show stronger impact – yield – of EoL treatment. This can be enabled, e.g., by less or slower obsolescence. In these cases, PSS2 and PSS3 will get more attractive since they generate some revenue or cost and material savings at EoL.

Combination of PSS paths

In the PSS diagram in Figure 34, the impression may be generated that either operational efficiency or longevity or producer product ownership are supported by a particular PSS. This is not fully true. All PSS focus on specific benefits. However, other aspects rather than those of primary concern may be considered to certain extent in addition. For example, energy efficiency (an operational-efficiency aspect) can also be considered in leasing PSS. We did this by replacing TeraFlex units in our analyses. This may further complicate the PSS assessment, but it allows to find PSS that come without massive burden shifting.

Major commercial findings

For commercial results, we used PSS1 (selling product plus maintenance) as reference since this was a major and successful business model already.

The main finding is that all PSS analysed are financially viable to good extent. This contradicts older experience with leasing PSS in the infrastructure ICT market. For leasing PSS, this depends on the difference between leasing products or leasing products as a service.

For leasing products (including the respective maintenance and take-back at EoL, but not leasing the product as a service), customer cost cumulated over the considered period (16-30 years) is approximately 5% higher than in the case of selling the product including maintenance. This is considered a very small mark-up since the customer does not have the day-1 invest of buying the product. This obviously leaves space to slightly increasing the manufacturer revenue (the PSS have been normalized to identical manufacturer cumulated NPV in our analyses).

In the case of leasing ALM monitoring as a service, the cumulated customer cost is ~45% higher, compared to the case of buying the product (including) maintenance) and operating it oneself. The difference in cost results from the fact that now, a managed service is provided, i.e., the manufacturer must charge for the related operations it performs. In the ICT case, this necessitates a so-called Network Operations Center (NOC). Since this is not typical for manufacturers today, it adds cost. On the other hand, it releases the customer from the necessity to operate the product. Instead, the customer gets the results of the managed service. This can massively lower operational cost on the customer side. Therefore, the mark-up is regarded feasible in particular for customers without own operating facilities. This has the following impact:

- For ICT network operators as customers, it is not clear if they accept a managed service, instead of managing it themselves. They do have all means for managing their networks, network management is part of their core business. If they accept a managed service, the added cost (45% here) must be lower than the respective internal cost.
- For other customers – facilities operators in case of the ALM fire and door sensors – it should be very interesting to offer the managed service. Again, the cost mark-up compared to PSS1 should be very interesting, e.g., to facilities operators since it is likely clearly below their own cost of managing the respective service.

In summary, managed services should be particularly interesting for customers that do not have the respective operating facilities. If the customer does have such facilities, leasing the product (not the managed service) or selling it together with maintenance and EoL take-back seems more viable.

Moreover, monetary EoL difference between leasing and selling the product including take-back is negligible. The EoL yield to good approximation is independent of the PSS as long as take-back at EoL is mandatory. Therefore, PSS that consist of selling products with maintenance and EoL take-back do not have disadvantages here.

Major environmental findings

From environmental viewpoint, there are no significant differences between the PSS.

Given that take-back is mandatory at EoL, the PSS do not differ since the reduction of environmental impact depends on take-back and successive reuse or recycling. Since the latter do not depend on the PSS type, PSS with take-back perform equally good.

This also means that leasing should primarily be considered for financial reasons (e.g., avoidance of day-1 invest for the customer). In terms of environmental performance, other PSS with EoL take-back are equally good.

5.3.4. Assessment of component reuse for ICT products

In this activity, reuse guidelines for ICT B2B products were compiled. These guidelines are not restricted to the ALM. However, certain aspects may be explained with the ALM as an example.

The guidelines follow the findings according to an optimum-lifetime analysis based on UPR10, **see section 7.7** EEE lifetime analysis**.** That is, for UPR10 clearly above or below the crossover thresholds for replacement scenarios that minimize total-lifetime emissions, different guidelines and focus for reuse result. For products where optimum lifetime is less clear, generic guidelines are difficult to state. In such cases, product-specific considerations may have to be followed. However, certain generic guidelines like design for disassembly and design for recycling should be followed in any case. To certain extent, these support reuse, e.g., of components.

Products with UPR_{10} < 2.5 or UPR_{10EE} < 1.5 (grid mix)

For this product class, the ALM is a good example. Its UPR_{10} is 1.69, and its UPR_{10EE} is 0.93, respectively. These products do not need to be replaced for reasons of energy efficiency and reduced lifetime use-phase emissions. They should be given a maximum lifetime, which has to be supported by respective ecodesign, that is, design for longevity. This ecodesign comprises at least the following aspects:

1. Performance monitoring, failure diagnostics, failure prediction (ICT, B2B only)
2. Modularity, all modules are hot pluggable during operations (ICT, B2B)
3. Resilience of critical modules, e.g., PSUs, fans (ICT, B2B only)
4. ICT network elements stay functional in case of shelf-controller failure
5. Design for disassembly
6. Design for partial reuse
7. Design for recycling.

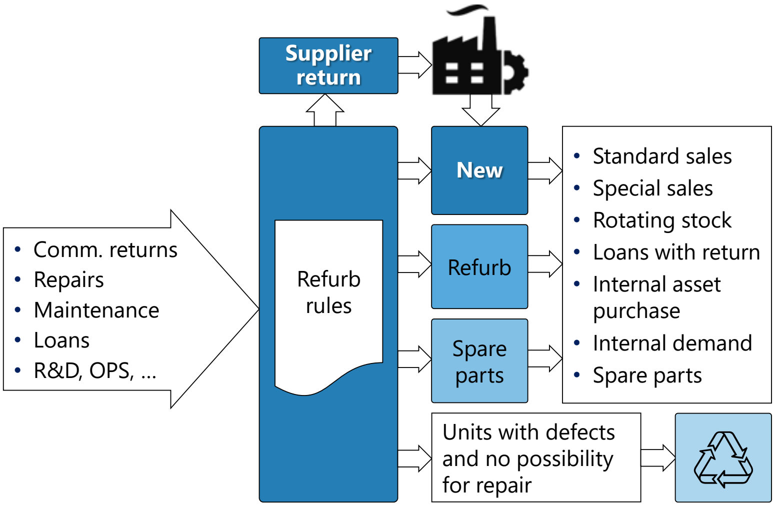
The first four aspects support long, uninterrupted usage and certain maintenance / repair without deactivating the product. They allow certain repair actions during use, e.g., replacement of a PSU or the shelf controller. Key is the modularity and the capability to plug / unplug hot, powered modules. Replaced modules, e.g., a failed PSU are sent back and repaired. They only go into recycling if there are no repair options.

The other aspects support partial reuse or recycling. Disassembly is described in more detail in the next chapter. Its aim is to recover parts or to separate the respective device into material fractions that are compatible in recycling (so that no or only small recycling losses occur). Design for recycling supports this by avoiding material compounds or clustering that cannot be separated prior to recycling. It also avoids certain materials completely, for example, hazardous substances where possible.

Partial or parts reuse may be limited, in particular after long lifetime. One reason are physical degradation effects like electromigration that cannot be avoided in semiconductor materials and that limit components lifetime. Ultimately, the respective components must be recycled.

Despite the challenges with components reuse, there are certain cases where this reuse is very beneficial. This is the case when certain components will not be produced anymore which are relevant to products that are not produced in large quantities and where redesign for a replacement component would be costly. In these cases, and given the respective components are physically still fully functional, the components can be extracted from EEE taken back and reused in new products. This can help extending the lifetime of certain products.

In general, all EEE taken or sent back shall be analysed for any components that can be reused. For the reasons listed above, this is limited so that finally, recycling and design for recycling must be considered as well. The respective process is depicted the figure.



Products with UPR10 > 5 or UPR10EE > 1.5 (grid mix)

These products really should be replaced for reasons of energy efficiency and reduced total-lifecycle emissions. They should not be given an arbitrary life extension or maximum lifetime. Ecodesign should primarily focus on highest energy efficiency.

For the same reason, parts reuse is even further limited as before. Many more-valuable electronic components like ASICs, FPGAs etc. have energy efficiency that is quickly getting obsolete so that reuse is not advisable. Therefore, design for recycling is relevant as well.

5.3.5. Disassembly guidelines for ICT products

In this chapter, a generic disassembly guide for ICT and electronics equipment is provided. This disassembly is intended to support most efficient WEEE recycling. The objective of this activity was to collect generic rules or guidelines that hold for a broad range of electronic equipment. Certain electrical equipment like household appliances are out of scope of these guidelines. The guidelines have been compiled from literature and from discussions with WEEE recyclers. The pictures provided were mainly taken from the ALM product, however, they are meant as illustrative examples only and are not restricted to the ALM or ADVA-specific ICT products.

Disassembly into minimum set of material fractions

So far, and with only a few exceptions like smart phones, efficient WEEE recycling requires manual disassembly or dismantling for best efficiency. The reason is that materials that are incompatible in recycling must be separated before recycling to avoid losses of recycled material. The second reason is that only products sold in large quantities (like smart phones) can feasibly and economically be disassembled by robots.

Incompatibility means that certain material is lost in recycling and cannot be recovered. A relevant example is iron, which in general needs to be separated from components that contain precious metals since the latter would be lost in recycling pathways that aim to recover precious metals if iron is present and no further care is taken.

From discussions with a WEEE recycler, the following **material fractions** that should be separated in manual dismantling can be derived:

1. PCBAs
2. Batteries, large (Tantalum) capacitors
3. Plastic parts (one or two fractions, see compatibility matrix hereinafter)
4. Cables (copper)
5. Metal parts (chassis, screws, heat sinks, EMC shields)
6. Power-supply units.

In addition, for fibre-optic equipment, fibre-optic (patch) cables may be separated. Likewise, other parts like rubber parts or thermal pads may be separated as well.

In general, manual disassembly or dismantling shall require as few tools as possible, and it shall not require any specialty tools. In product ecodesign, this must be supported by the avoidance of any fixed connections, i.e., rivets, welds and adhesives, and minimization of screws. A standard tool set may then be comprised of:

1. Screw drivers
2. Pliers, tweezers
3. Side cutter
4. Magnet.

When dismantling products, warnings for sharp edges etc. must be considered.

Generic disassembly steps

Following, generic disassembly steps are listed that can lead to the separation of the material fractions stated above. The respective pictures are meant as illustrative examples only, the steps are not restricted to the ALM product.

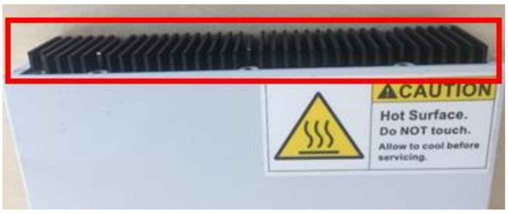
1. Remove all screws

This is necessary to get access to the (sub-) modules and to remove screws as metal parts. The effort related to this first step is also the reason why in ecodesign, the number of screws shall be limited.
Fixed-connection alternatives to screws like rivets, welds and adhesives shall be avoided because they make dismantling more complicated and may require specialty tools.

2. Remove all mechanical parts. Segregation of aluminium and steel

The second step consists of removal of mechanical metal parts. In general, these may consist of both, aluminium and steel, which can be segregated with the help of a magnet. These parts can comprise of chassis / covers, heat sinks, EMC shields and other mechanical parts

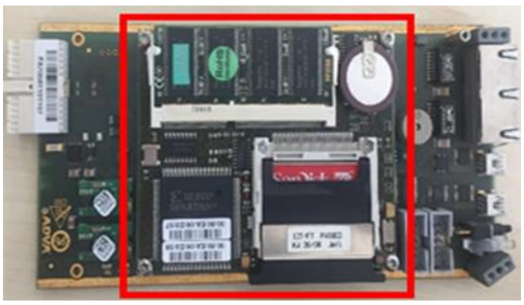
Heat sinks often consist of aluminium. Therefore, they should be separated, e.g., from steel parts



EMC shields protect sensitive components like certain ICs from electro-magnetic interferences. EMC shields are made of metal, but sometimes also contain red phosphorus. The latter may have to be considered in disassembly and recycling under the viewpoint of substances of very high concern

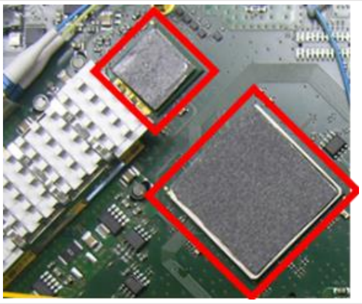
3. Remove submodules from the main PCB

This may not be necessary in all cases, e.g., when main PCB and daughter boards contain similar components and could go into the same recycling pathway. However, examples exist where separation should take place, e.g., the removal of PSU boards from the main PCB. PSUs should be separated because they often have a certain steel content and may contain large (Tantalum) capacitors



4. Remove thermal pads

Thermal pads are sometimes used to improve the heat dissipation of ICs.
Thermal pads consist of silicon or polymers.

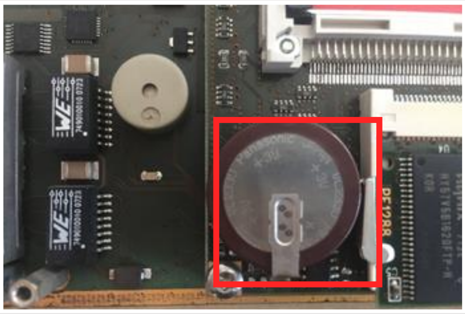


5. Remove all optical and electrical cables

Obviously, optical (patch) cables may only be found in opto-electronic equipment like certain classes of ICT equipment. Optical cables in most cases are metal-free. They contain the glass fibre, plastic primary buffer and sheath, and may also contain Kevlar strength members. Electrical cables contain copper and plastic. Often, relatively thick cables can be found connecting the PSU to the main PCB.
Connectors of cables that connect PSUs to other parts of equipment may contain red phosphorus. Similar to EMC shields, this may have to be considered in disassembly and recycling

6. Remove batteries

Batteries have to go into dedicated recycling pathways for optimum material recovery.
Often, micro cell batteries are used which may not be visible immediately.
Most mother boards or main PCBs contain a battery.



7. Remove plastic parts

The final step in disassembly is the removal of plastic parts. Ideally, no different plastic materials are used according to related ecodesign rules. If different plastic materials are used, preferably they are separated according to the plastic compatibility matrix. Obviously, PE and PP are mostly incompatible with other plastic materials and ideally should be separated as a material fraction on their own.

5.4. Environmental, social and economic analyses

Life Cycle Assessment

The environmental impacts were determined using the LCA methodology according to ISO standards (14040/14044). The assessment comprised the whole life cycle of the products, including extraction and processing of raw materials, manufacturing, transport and distribution, use, maintenance (when required) and end of life. The method ReCiPe was used to assess 18 midpoint impact categories, in this summary only four representative ones are shown: global warming (climate change), human health, ecosystems and resource use.

Environmental benefits due to recycling were not added to the total life-cycle environmental impact of the EEE products but they are shown as recycling credits. Additionally, the Material Circularity Indicator (MCI) was determined to assess the circularity of the current products and business models.

Life Cycle Costing

The Life Cycle Costing (LCC) methodology was used to assess all economic costs associated with the complete life cycle of the target product, including internal cost (related to product manufacturing, use and end of life), as well as environmental externalities. The costs of environmental externalities were calculated by monetary valuation of the endpoint environmental impacts (obtained with the LCA).

Social Life Cycle Assessment

The social impacts for the target product were calculated using the S-LCA methodology. In particular, the method and the indicators of the Social Hotspot Database were used. A cradle-to-gate assessment was applied, with 26 social subcategories grouped into 5 categories. The SHDB offers a weighted model that converts the impact values of the social subcategories into aggregate impact values for each social category, which in turn can be aggregated into a single global social footprint for the products (the so-called Social Hotspot Index or SHI).

The results are shown for one hour of the telecommunications equipment monitoring composed by an active ALM unit (ADVA 16ALM/#1650D/AC) and 50 passive sensors, excluding the use of energy and consumables.

Circular economy actions considered:

- Lifetime extended from 8 to 15 years.
- Recycled passive sensors
- 10% reuse in central unit

Table 18. Main environmental, life cycle costs, and social life cycle indicators for one hour of the ALM product monitoring.

Indicator	Unit	Reference	C-SERVEES	Relative improvement
LCA				
Global warming	kg CO_2 eq	1,37E-03	9,27E-04	32,6%
Human health	DALY	8,42E-09	4,70E-09	44,1%
Ecosystems	species.year	1,30E-11	7,57E-12	42,0%
Resources	USD2013	7,38E-05	6,23E-05	15,5%
Recycling credits	kg CO_2 eq	-1,14E-04	-6,62E-05	-42,2%
Material Circularity Indicator	-	0,41	0,71	73,1%
LCC				Relative reduction
Internal	€	0,3596	0,2001	44,34%
External	€	0,0221	0,0212	4,07%
Total	€	0,3816	0,2213	42,01%
S-LCA				Relative reduction
Labour Rights & Decent Work	Pt	0,14	0,07	46,9%
Health & Safety	Pt	0,23	0,12	46,9%
Human Rights	Pt	0,11	0,06	46,9%
Governance	Pt	0,19	0,10	46,9%
Community	Pt	0,07	0,04	46,9%
Total – Social Hotspot Index	Pt	0,74	0,40	46,9%

Using recycled passive sensors reduces the CO_2 emissions of passive units' manufacturing by 77%. On the other hand, the reuse of the central unit reduces de ALM unit's manufacturing by 42%.

It can be clearly seen how increasing the lifetime and reusing parts of product modules for manufacturing reduces al life cycle cost categories and on average by 42%. Also, these changes reduce 47% the social impact of the production process.

5.5. Life-cycle validation summary

From the results of the environmental, social and economic analyses of the ALM demonstration it can be concluded that products with similar characteristics in terms of composition, use and end of life, it can be reasonable to scale up the demonstrator's results. In addition, the results are expressed on a functional unit basis so that they can be compared with other products using the same functional unit.

The results obtained are credible due to the data quality used. The data used to create the inventory model is as precise, complete, consistent and representative as possible with regard to the goal and scope of the study.

- Primary data were provided by ADVA from the most recent BoM of the product. The data used for the study is considered to be of the highest precision. Ecoinvent database was the main secondary data source used to model the product system.
- Completeness was judged based on the completeness of both the inputs/outputs per unit process and the unit processes themselves.
- Consistency refers to modelling choices and data sources. The goal was to ensure that differences in results occur due to actual differences between product systems investigated and compared, and not due to inconsistences modelling choices, data sources, characterisation factors, etc.

As it is explained in the washing machine and MLP life-cycle validation summaries, an LCA sensitivity analysis on lifetime and use intensity was performed to determine the conditions under which faster or slower changeover of the products may be beneficial under a circular scenario. Sensitivity dependence is the relative variation of the environmental impact with respect to the relative change in the number of units over the lifetime.

The results for the ALM are shown in the figure below.

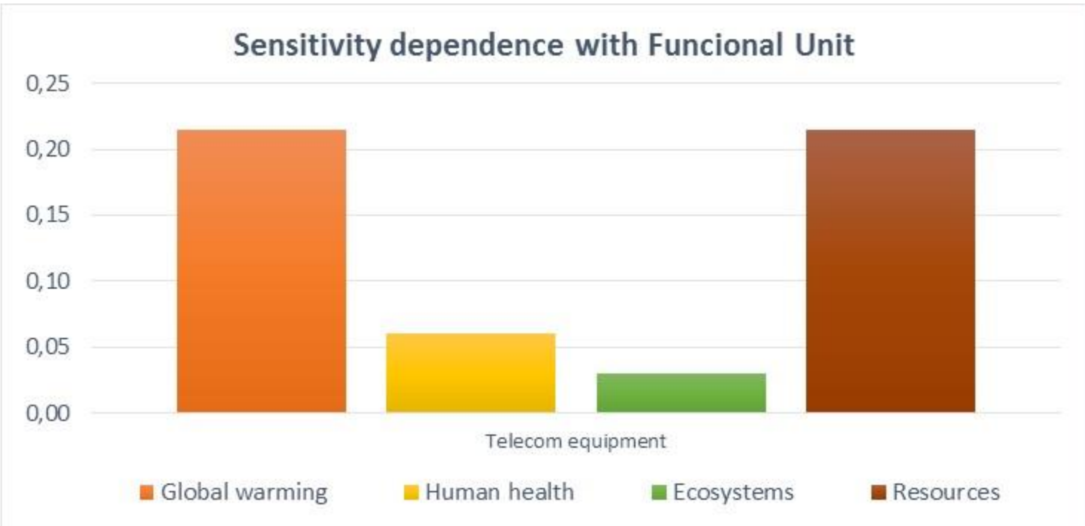


Figure 40. Sensitivity dependence with the change in the number of units during the lifetime of the telecom equipment

Telecom equipment is clearly the product with the lowest sensitivity dependence. This product is the only one that applies a strategy of increasing the lifetime to enhance circularity in the C-SERVEES project. The lowest sensitivity with lifetime increase is precisely the telecom equipment.

It can be found that electricity consumed by the ALM product have by far the highest environmental impacts for the use phase, while the contributions of product distribution are comparatively very limited. In addition, when comparing both scenarios for electricity consumption, it is clear the important role that the increase of renewable sources in the electricity mix can play in the coming years.

5.6. Manufacturer's review

Looking back, ADVA regards the C-SERVEES project highly successful and will adopt many of the project's findings for its future business. This holds for the newly merged company (in early 2023, ADVA merged with the equally sized company Adtran to constitute one of the few remaining big ICT vendors). It also holds for substantive parts of our value chain. This includes customers as well as manufacturing partners. ADVA also strived to extend at least parts of its project findings to beyond the ALM product line and even to other companies.

There are five particular areas where C-SERVEES results will influence our future business and product lines beyond just the ALM products.

Perhaps the most relevant of these areas relates to the PSS analysis that has been conducted in the course of the project. Prior to the project, we had quite an inconsistent view on PSS and also some disappointments related to early leasing attempts. After the project, PSS are an area that we will scale-up in the future. This refers to all major aspects that are feasible for ICT products – increasing maintenance services and take-back and providing leased products or even leased functionalities. The latter is new for us. It can support certain new customers in new applications with a new business model not considered so far. This will take some time since it cannot be equally well adopted to all products and customers. However, the analyses conducted in the project helped to better understand and prepare the related business. In our context, this depends on the fact whether or not the customer has own network-monitoring facilities. This is particularly true for leasing of certain functionalities – like ALM monitoring-as-a-service – and specific customers.

During the development of the new ALM sensors, we had to look for optimum material for the chassis. Due to lifetime requirements, this turned out to be aluminium. In turn this led to the requirement to request, from the chassis manufacturer, recycled aluminium. So far, the aspect of recycled content in purchased components had not been considered consistently. ADVA is now preparing a process that will, over time, increase the content of recycled material in components where possible and across all product lines. This will be implemented in cooperation with the manufacturing partners.

The disassembly of several active ALM units during the project also provided us better insight, in particular related to the different types of plastic used. This led to complements of our internal design rules that aim at reducing different types of plastic and again increasing recycled content in plastic parts. This scales to all future product lines. Likewise, the ecodesign rules will be frequently updated. First pilot projects already started. Related aspects will be discussed with the plastic-parts manufacturers.

Future packaging, though not the project's primary focus, will also see improvements. During the project, and together with the related manufacturer, we developed for the first time plastic-free packaging that is compliant with the NEBS (a US standard) fall tests. This enables to offer, in the future, more plastic-free packaging and can be extended to other product lines. It also showed that new packaging approaches must be lifecycle assessed since plastic elimination may also bring disadvantages. Therefore, we already decided to extend our LCA activities to all new packaging. Results of this will also be discussed with the related manufacturers. Packaging is also another area where recycled content is considered.

Finally, the remaining area of our future interest is the further development of the UPR10 concept in standardization, across all our product lines and even toward completely different EEE products. This started in early 2023, when we opened the discussion on UPR10 in ITU-T Study Group 5, Question 7. ADVA’s intention is to have this developed as an ITU standard and thus further support optimum-lifetime considerations, again beyond our own product lines.

6. TV sets and displays demonstrator

6.1. Company and product description

The TV demonstration was led by Arçelik and this section provides an overview of the activities, results and findings during the demonstration period.

6.1.1. About Arçelik

See section 3.1.1.

6.1.2. Product description

Arçelik chose a 43-inch flat Grundig TV for the demonstration purposes. The product information is shown below.

Demo Product Features
Brand and name: GRUNDIC SFS000
Ref. code: 43 VLX 7840 BP
Technical information: Picture Features DLTI, DCTI, DNR, Digital Combfilter (3D), Picture Noise reduction
Colour: Black
Dimensions: 62,5 x 23,1 x 97,6 cm
Weight: 9kg unpacked
Voltage: 220-240
Energy Class: A+
Panel Language: Spanish and Turkish
Manufacture location: Turkey – Tekirdağ -Çerkezköy
Sales location: Turkey and EU
Guarantee period: 3 years

Raw Material Information
Plastic back cover: PC + ABS
Plastic front cover: PC + ABS + 10% glass fiber
Plastic midframe: PC + 10% glass fiber
Plastic stands: PC + ABS
Plastic stand holder: PC + ABS + 10% glass fiber
Metal black cover: ECC/EGI (Electrogalvanized sheet)
Metal T-con board cover: DX52 + Z100B
Lens plastic: PC – NAT – I – HB
Main board AV bracket plastic: PC + ABS
Remote control: Plastic or metal
Packaging: EPS + carton

6.2. Demonstration activities

TV set demonstration

Demo leader: ARÇELIK

Baseline	Demonstration activities
• No recycled plastic content	Increase recycled plastic content in TV's back cover
• Product manual in printed form • No QR codes	Certify the recycled content by ICT and make this information available through a QR code in the product
	Use QR codes and blockchain to provide information about materials, components and relevant procedures to all the value chain
• Linear business model (B2C/B2B sales)	Develop a renting/eco-leasing model for B2B market. Demo sites: nursing home in Spain, student dorms in Turkey
	Obtain feedback from B2B and B2C customers via questionnaires
	Capture customer feedback on the use of circular economy business models: living lab experience
• No refurbished product sales • No refurbishment centres outside Turkey • No refurbished spare parts used	Initiate new business line to recover, refurbish and give a second life to used TVs with Emaús in Spain
	Develop dismantling and repair training programmes
	Explore 3D printing potential for TV parts
	Dismantling of products and analysis of business case for recovery and reuse of EoL products' parts
• Recycled plastic bought from external sources	Analysis of the potential to recycle and reuse plastics from EoL TVs

6.3. Demonstration results

6.3.1. Increase recycled content

Arçelik manufactured 100 TV units for the demonstration purposes. The demo product was also provided with QR codes with information about the product and the C-SERVEES project.

TV has different plastic parts that consisted of different raw material and weight, as shown in Table 19.

Table 19. TV's plastic parts

Part	Material	Weight (g)
Plastic Back Cover	PC+ABS	1.635
Plastic Front Cover	PC+ABS+%10GF	350
Plastic Midframe	PC+%10GF	170
Plastic Stands	PC+ABS	280
Others	PC+ABS	130

The demonstration required the redesign, production and testing of 100 units containing 30% recycled PC_ABS in the back cover. They were produced by Arçelik at its electronics plant located in Çerkezköy, Tekirdağ, (Turkey). This is the first time such innovation is applied in Arçelik's TV products.

Figure 41. Back TV panel with recycled content and QR code in the demo TVs.

Continuing on this line, work is being done to introduce up to 60% recycled material for the back cover. Apart from the product back cover, remote TV control using 100% recycled material have been designed, to be used in the entire smart product family.

In line with our environmental policy and strategies, it is critical to ensure that our products comply with the national and international regulations and standards. In scope of this, all plastic raw materials and parts are analysed for any content of restricted substances with X-ray fluorescence (XRF) and Gas chromatography–mass spectrometry (GC/MS) analyses during material approval stage. In addition, parameters that cannot be measured in the factory are sent to the external laboratory.

6.3.2. Obtain customer feedback about eco-leasing models for TVs

Extensive persona studies were carried out to understand how consumers react to new business models such as pay per use or rent model. The information about these studies is described in section 3.3.2. The main insights concerning TVs specifically are highlighted here:

- Arçelik has not come across any rent TV offerings for the B2C market segment from competitors. The rent offerings are dominantly focused in the WM's followed by dishwashers and other major home appliances as well as other small domestic appliances.
- TV offering in the B2B segment proves to be more preferable especially in hotels and dormitories.
- In order to make it more attractive, the TV offering in the B2B- B2C needs to focus more on giving the service as a package to include the TV along with other consumer electronics such as Bluetooth speakers, headphone sets, free subscription to Netflix, Amazon Prime, etc.

During the demonstration, a survey was created to get customer feedback about eco-leasing models. In the content of this survey, besides the product-related information, feedback on the leasing model was received. The questionnaire was shared in Turkish, English and Spanish via QR code, and sent to the facilities where the demo products were being tested (see section 3.3.3).

The survey complemented the results from the persona studies in the previous stage, since it contains the reflections from the current users. Another benefit was the use of the outputs for the feasibility of the rental model. As an example, it was shown that customers prefer the rental period to be at least 3 years.

Critical questions and answers related to the CEBM:

- 39% of users stated that they would rent a refurbished products provided it had the exact same quality and warranty as a new one. 32% declared their preference for a new one.
- The price is the key criterium when considering a rental option, which confirms that correct pricing is essential for this business model.
- The users found that 10-15 euros is reasonable for a monthly fee. They were not willing to pay more than 20 euros.
- 88% declared that their brand perception would rise if they were offered circular business model alternatives such as renting or pay-per-use.

6.3.3. Feasibility study of eco-leasing model for corporate customers

Arçelik studied the viability of introducing a renting/eco-leasing model for their corporate customers, offering the product as well as maintenance services and taking care of the products once the client decides to terminate the contract or requests a substitution or upgrade. The TVs would then be examined to determine the need for repair or refurbishment and given a second life whenever possible, in accordance with circular economy principles.

To carry out the eco-leasing demonstration, TV demo products were sent to selected locations in Turkey and Spain.

In Turkey, 25 TVs were installed in two dormitory blocks on the Bolu Abant İzzet Baysal University Campus. The dormitories run by the university have a capacity of 680 male and 680 female students. Another 22 TVs were installed in Credit and Hostels Institution Dormitories in the Samsung region.

In Spain, 53 demo TVs were installed in Matia Foundation, based in San Sebastian. Matia Foundation has more than 130 years of experience in the provision of social and health services to people with an illness, older people and people with a disability. The provision of services is carried out under a comprehensive and person-centered model based on the principles of autonomy, dignity and personalisation. The TVs were installed in the common areas and TV viewing rooms in 9 different campuses of the institution.

Figure 42. TVs during the demos in Fundacion Matia facilities (Spain) and dorm facilities (Turkey).

A survey was created and shared via QR code to obtain customer feedback from the demo sites, related both to the product and the leasing model. The survey provided the opportunity to compare the results obtained with those of previous persona studies to understand how consumers react to new business models such as pay per use/renting.

The feasibility study of the renting/leasing model was carried out for both the washing machine and the TV products and the results are described in section 3.3.3.

The feasibility study of the TV rent model for both B2B and B2C consumers in Spain and Turkey is based on the following business model in mind:

- The consumers fill in a subscription form via online or call center. Call center calls the consumers for an appointment. The appliances are installed by technicians.
- The consumers are given the option to rent the TV/WM for a 3-year contract with monthly payments of EUR 15 which can be renewed after the term expires.
- The consumers pay a EUR 35 deposit which is returned once the contract expires. If the consumers renounce from the system before the expiry date of the contract, they are required to pay a EUR 70 cancellation fee.
- In order to make the rent model attractive to the customer, the installation, maintenance and technical services are provided free of charge both in Spain and in Turkey.
- The consumers are given the option to prolong their contract after the initial term expires. They are provided with new devices and the previous ones are collected to be refurbished and sold as a second hand product sale with a discounted price.

Differences between the feasibility model for WM and TV categories: The ex factory costs of the selected WM and TV models are almost identical. The TV is a mid segment model which is widely preferred by both the B2B and the B2C segments. The WM is a high segment product. The TV model factors in extra licensing costs such as providing Netflix or a similar entertainment program as a free of charge offering.

As a conclusion from the feasibility studies carried out, there is a positive NPV for the 10 year period. Turkey's NPV is slightly higher despite the increased WACC due to the fact that the labour costs are cheaper as compared to Spain. Examples for the TV set sensitivity studies are provided below:

Table 20. TV set renting model feasibility in Spain and Turkey

Price	Increase in customers	NPV Spain	NPV Turkey
-10%	-10%	-67%	-61%
-15%	-15%	-86%	-78%
-20%	-20%	-98%	-89%
-25%	-25%	Not feasible	-96%
no change	-10%	-51%	-46%
no change	-15%	-66%	-61%
no change	-20%	-76%	-72%
no change	-30%	-91%	-86%
no change	+10%	89%	80%

6.3.4. Customer experience at living labs

To test the acceptance of final user in front of the eco-designed and refurbished products, pedagogic/testing events were carried out with potential customers in Emaús ecocenter in Arrasate (Basque Country, Spain). The objective was to obtain relevant feedback for the project that is being developed in the WEEE recovery line, and this experience is known as a "living lab". The description of the experience, which was carried out jointly for washing machine and TV products, is covered in section 3.3.4.

6.3.5. Use 3D printing for refurbishment operations

During the TV demonstration period, Particula worked in cooperation with Arçelik and Gaiker to develop a methodology to obtain and validate 3D printed TV spare plastic parts (TV stands). Arçelik provided samples from plastic materials used for TV stands and three-dimensional objects in digital format (.stp CAD file). Configurations and several tests were conducted in order to prepare appropriate file formats (.stl) and to determine the most suitable technology for trials and 3D printing TV sets and displays.

Particula conducted several tests with two 3D printers (Prusa i3 MK3 and Zortrax M200). 54 3D-printed models were created with different polymers: PLA, ABS, PETG, rPETG, Facilan C8. 3D printing trials were also conducted with standard raw materials delivered from Arçelik. After the feedback and first testing period in Arçelik, it was concluded that rPET and PETG filament were the most suitable for TV stands production.

3D-printed TV stands - FACILAN material   3D-printedTV stands – rPETG material

Figure 43. 3D-printed TV stand samples and validation testing.

The formulations developed for the 3D-printed samples proved to be too rigid and could not pass the safety tests. The TV stands are critical components since they carry the weight of the TV and thus it is important that they do not break apart. In the tests, it has been concluded that products with weight >7kg could not use these spare parts.

Since the TV stand is the only suitable part for 3D printing in the TV, 3D printer usage for the TV is very limited. With the results obtained, both in terms of cost efficiency and durability of the component, it is not feasible to use the 3D-printing technology for spare parts.

6.3.6. Improve repair and refurbishment operations

Emaús has developed refurbishment processes and carried out trainings for Emaús workers through a collaboration with Telenis, a company dedicated to providing technical services to electrical appliances for Beko in Spain.

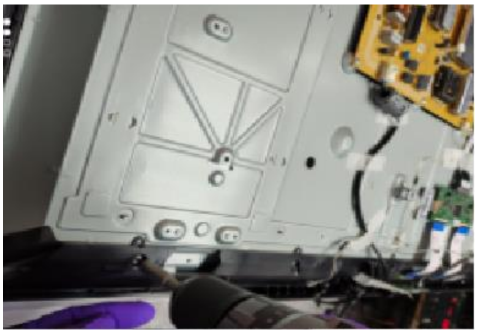
The refurbishment protocols have been established in order to standardize the most common operations and the most profitable ones. Below an extract of the protocol for LED replacement is shown.

1 The TV will be placed in a flat and protected surface to avoid damages to the panel. Unscrew back cover.

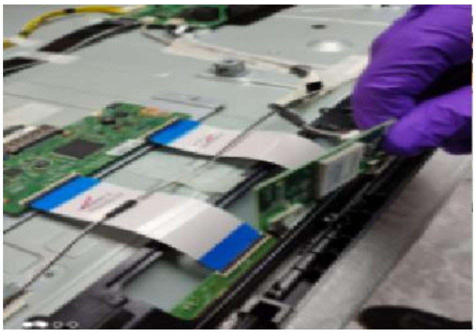
2 Unscrew the main PCB cover and the screws that hide the threads where a wall support would be fixed.

3 Remove back cover. All parts that need to be removed to access the LED bars should be disassembled.

4 Unplug and disassemble the speakers.



5 Unscrew the drivers' protector from display panel.



6 Remove WIFI board from its place and unplug.

Figure 44. Steps from the replacement manual prepared for C-SERVEES refurbishment operations with TVs.

Beko Spain and Telenis organized trainings for Emaús personnel to improve the skills of workers at risk of exclusion that are part of Emaús social programs, facilitating their integration into the labour market.

Figure 45. Training session on TV refurbishment with Emaús workers

The actions taken have benefited Emaús in terms of improvement of the protocols. Thanks to the actions carried out, the WEEE refurbishment/recovery rate was increased from 3% to 3,5% which is above average.

It has been observed that the washing machine refurbishment process is more suited to the Emaús employees who risk social exclusion instead of TV recovery because of the technical difficulties in TV recovery process. In case of TV refurbishment, procedures of TVs are more meticulous and delicate, taking longer to be refurbished. Certain process guidelines should be followed to prevent accidental discharge. Additionally, special equipment must always be used to prevent the transmission of static electricity when refurbishing electronics. These requirements make operations more complex as some operations require specific knowledge of electronics.

All refurbished TV components such as PCB, plastic covers, plastic stand, led bar, cables, led modules speaker boxes that have been subjected to the refurbishment process have proved to be feasible in terms of profitability, software update being the easiest one.

6.3.7. Analysis of business case for recovery and reuse of end-of-life product's parts and materials

Recovery of TV parts from dismantling operations

Greentronics and Indumetal conducted a technical analysis on the dismantling operations of the demo TVs. Five TVs were sent to Greentronics and two TVs were sent to Indumetal for this analysis. 15 different components/parts were considered relevant for potential use as spare parts:

1	Power cable	9	Loudspeaker
2	Back cover	10	Wi-fi Board
3	Plastic stand bracket	11	Front plastic cover (front frame)
4	Wall mount bracket	12	Display
5	Cable	13	Display plastic frame
6	T-con Board	14	Reflective plastic film
7	Main Board	15	Led Bar
8	PSU (Power Supply Unit)		

Greentronics and Indumetal analysed this list of spare parts and prepared a dismantling procedure for the demo product. The aim was to facilitate the extraction operations of non-damaged spare parts from EoL TVs and to provide expert advice on design-for-recycling or design-for-dismantling measures to Arçelik.

The TVs were disassembled in each location to determine the logical disassembly order of the indicated components and identify them in conjunction with the disassembly manuals. On average, it took 10,5 minutes for Greentronics and 13 minutes for Indumetal to disassemble the full list of components.

A dismantling template was used to analyse the cost of recovering pre-selected TV parts/components based on time/human labour/shipment costs. The template was completed by both recyclers and it is detailed in Figure 46.

	Open Cell	Back Cover	Front Cover	Touch Kit	Mid Frame	Led Bar	Main Board	Led Driver	Bracket	Wi-fi/Bluetooth Board	IR Led Board	Card Board	Ferrit	Hoparlor	On/off switch	OPS	Remote Control	Fasteners (Screw, etc.)	**PSU** (Power Supply Unit)	**Other plastics** (Isolator, Lens Plastic, AC-out Cover, Wall Mount Set, Stand, Stand Bracket, Side AV Bracket, Side AV Label, Source Board Cover, silicon, Tape, Label)	Other Metals	Battery	T-con Board	Cable
TV set 1	NA	X	X		X, broken	X	X			X	X		X	X			X	X	X	X			X	X
TV set 2	NA	X	X		X, broken	X	X			X	X		X	X			X	X	X	X			X	X

	Recycler
Time to dismantle/check parts (mins)*	10,5
Time to pack parts ready for shipment (mins)*	5
Cost to pack the parts (€)*	10
Cost to ship the parts (€)*	50/480
Hourly rate (€)	3,8

Average time per TV part

DATA FOR 1 TV	INDUMETAL
Time to dismantle/check parts (mins)*	13
Time to pack parts ready for shipment (mins)*	21
Cost to pack the parts (€)*	4
Cost to ship the parts (€)*	200
Hourly rate (€)	30

Figure 46. Dismantling template completed by Greentronics and Indumetal

Considering these templates, a comparison (see Table 21) has been done with data provided by Greentronics and Indumetal.

Table 21. Dismantling times achieved by recyclers for the TV set

TV Component Recovery Costs	Greentronics	Indumetal
Time to dismantle/check parts (mins)	10,5	13
Time to pack parts ready for shipment (mins)	5	21
Cost to pack the parts (€)	10	4
Cost to ship the parts (€)	480	200
Hourly rate (€)	3,8	30

As it can be seen in the table above, the two recyclers had very different figures provided with respect to the cost of shipment of components to Turkey and the hourly rates as well as the time to pack parts ready for shipment and the cost to pack the parts.

Arçelik examined the data provided by both recyclers relative to labour and shipping costs are determined that it is not feasible to consider this alternative due to the low chances to recover valuable components at recyclers facilities and transportation costs. However, it could make sense for refurbishment centres located in the recycler's area. It has to be noted that recovering TV components requires more skill and care than washing machine's.

Recovery of TV secondary raw materials from dismantling and recycling operations

Within the TV demo Arçelik has performed a case study on the potential to use recycled plastics from EoL devices outside Turkey. The main objective was to analyse the technical feasibility of reusing ABS or PC-ABS from end-of-life TVs and incorporate the recycled plastic material into new TV parts.

At the beginning of the study, two plastic material streams from end-of-life TV sets were identified as potential candidates for recovery and reuse: ABS and PC-ABS.

Flat TV panels from end-of-life TV sets were collected by Indumetal at their facilities. Since Indumetal receives all kind of brands together and sorting them is an added difficulty, it was decided to use a mix from the flat TV panels in the WEEE stream. The two batches, ABS and PC-ABS (around 35 kg each) were sent to Gaiker to be processed.

In Gaiker, all parts were checked to ensure only ABS and PC-ABS was processed. The process steps were the following:

- Manual sorting: removing stickers, remaining metal pieces, screws etc.
- Shredding: size reduction to about 15 mm.
- Metal separation: elimination of remaining ferrous and non-ferrous particles or inserts using eddy current + magnetic overband.
- Grinding: size reduction to about 8 mm.
- Fines removal: elimination of dust and fine particles by air sifting.
- End-processing: washing, drying, melting, compounding.

Figure 47. Selection of TV parts at Indumetal for recovery of recycled plastics (above) and material flakes and testing specimens obtained (below)

The plastic flakes were also analysed for any content of restricted substances with X-ray fluorescence (XRF) analysis. This analysis showed that the PC-ABS material did comply with the relevant applicable regulations. However, for the ABS material the analysis showed some flakes seemed to have high Bromine content. Although this could be due to just a few processed TV parts containing high Br, it rendered the recycled material unsuitable for utilisation. Thus, the ABS batch was not further processed.

Gaiker then carried out a characterisation of the PC-ABS batch to compare the properties of recycled PC-ABS material obtained from EoL TVs with the properties of virgin PC-ABS used for the Arçelik TVs. The results are shown in the table below.

Table 22. Characterisation of recycled PC_ABS from EoL TV flat panels.

	STANDARD	ACCEPTANCE LIMITS PC/ABS/V0	RESULTS OF RECYCLED PC/ABS
PHYSICAL PROPERTIES			
Density, g/cm^3	ISO 1183	1,2	1,20
Melt Flow Rate, g/10 min	ISO 1133	15 - 27	16
THERMAL PROPERTIES			
Vicat Softening Temperature, /B	ISO 306 /50N	87	94
Heat Deflection Temperature, HDT/A	ISO 75 /1,8MPa	70	80
MECHANICAL PROPERTIES			
Flexural Modulus, MPa	ISO 178	2500	2580
Tensile Strength at yield, MPa	ISO 527	55	47,7
Young Modulus, MPa	ISO 527	2300	3010
Elongation at yield, %	ISO 527	3,5	3

The tests provided positive results and are compliant with Arçelik specs except for mechanical properties such as tensile strength and elongation at yield. These properties can be improved to meet Arçelik's standards by including virgin materials and reformulating. This supports the potential for Arçelik to use recycled PC ABS from recovered TV back covers. However, regulation in Turkey does not allow the import of recycled raw materials, so these operations would have to be done at Arçelik's own WEEE plants in Turkey.

6.4. Environmental, social and economic analyses

Life Cycle Assessment

The environmental impacts were determined using the LCA methodology according to ISO standards (14040/14044). The assessment comprised the whole life cycle of the products, including extraction and processing of raw materials, manufacturing, transport and distribution, use, maintenance (when required) and end of life. The method ReCiPe was used to assess 18 midpoint impact categories, in this summary only four representative ones are shown: global warming (climate change), human health, ecosystems and resource use.

Environmental benefits due to recycling were not added to the total life-cycle environmental impact of the EEE products but they are shown as recycling credits. Additionally, the Material Circularity Indicator (MCI) was determined to assess the circularity of the current products and business models.

Life Cycle Costing

The Life Cycle Costing (LCC) methodology was used to assess all economic costs associated with the complete life cycle of the target product, including internal cost (related to product manufacturing, use and end of life), as well as environmental externalities. The costs of environmental externalities were calculated by monetary valuation of the endpoint environmental impacts (obtained with the LCA).

Social Life Cycle Assessment

The social impacts for the target product were calculated using the S-LCA methodology. In particular, the method and the indicators of the Social Hotspot Database were used. A cradle-to-gate assessment was applied, with 26 social subcategories grouped into 5 categories. The SHDB offers a weighted model that converts the impact values of the social subcategories into aggregate impact values for each social category, which in turn can be aggregated into a single global social footprint for the products (the so-called Social Hotspot Index or SHI).

The results are shown for one hour of the GRUNDIG G43C 891 5A 43” smart-TV set, excluding the use of energy and consumables.

Circular economy actions considered:

- Recycled PC-ABS (30%) back cover – halogen free
- 100% recycled cardboard
- Remanufacturing

Table 23. Main environmental, life cycle costs, and social life cycle indicators for one watched hour of the TV set.

Indicator	Unit	Reference	C-SERVEES	Relative improvement
LCA				
Global warming	kg CO_2 eq	2,19E-02	1,40E-02	36,2%
Human health	DALY	1,23E-07	7,49E-08	38,9%
Ecosystems	species.year	1,44E-10	9,01E-11	37,6%
Resources	USD2013	1,64E-03	1,09E-03	33,6%
Recycling credits	kg CO_2 eq	-1,67E-03	-1,11E-03	-33,2%
Material Circularity Indicator	-	0,37	0,56	52,1%
LCC				Relative reduction
Internal	€	0,042	0,042	0,0%
External	€	0,121	0,115	5,0%
Total	€	0,162	0,156	3,7%
S-LCA				Relative reduction
Labour Rights & Decent Work	Pt	0,12	0,10	13,9%
Health & Safety	Pt	0,15	0,12	20,1%
Human Rights	Pt	0,08	0,07	9,2%
Governance	Pt	0,19	0,17	12,0%
Community	Pt	0,06	0,06	6,8%
Total – Social Hotspot Index	Pt	0,60	0,52	13,5%

All these changes in the materials used reduced the global warming impact category during component, manufacture and at the end of life.

It can be seen how the reuse of part of the product modules for remanufacturing reduces the external cost of the production process by 39% and, to a lesser extent, the end-of-life cost by 5,6%. Therefore, total costs are reduced by 3,7%.

Reusing part of the product's modules for remanufacturing also reduces the social impact of the production process. The reduction of new component from Chine thanks to the remanufacturing reduce social impacts 7-20%.

6.5. Life-cycle validation summary

From the results of the environmental, social and economic analyses of the TV demonstration it can be concluded that for products similar characteristics in terms of composition, use and end of life, it can be reasonable to scale up the demonstrator's results. In addition, the results are expressed on a functional unit basis so that they can be compared with other products using the same functional unit.

The results obtained are credible due to the data quality used. The data used to create the inventory model is as precise, complete, consistent and representative as possible with regard to the goal and scope of the study.

- Primary data was provided by Arçelik from the most recent BoM of the product. The data used for the study is considered to be of the highest precision. Ecoinvent database was the main secondary data source used to model the product system.
- Completeness was judged based on the completeness of both the inputs/outputs per unit process and the unit processes themselves.
- Consistency refers to modelling choices and data sources. The goal was to ensure that differences in results occur due to actual differences between product systems investigated and compared, and not due to inconsistences modelling choices, data sources, characterisation factors, etc.

As shown in the previous validation summaries, an LCA sensitivity analysis on lifetime and use intensity was performed to determine the conditions under which faster or slower changeover of the products may be beneficial under a circular scenario. Sensitivity dependence is the relative variation of the environmental impact with respect to the relative change in the number of units over the lifetime.

The results for the TV demonstrator are shown in the figure below.

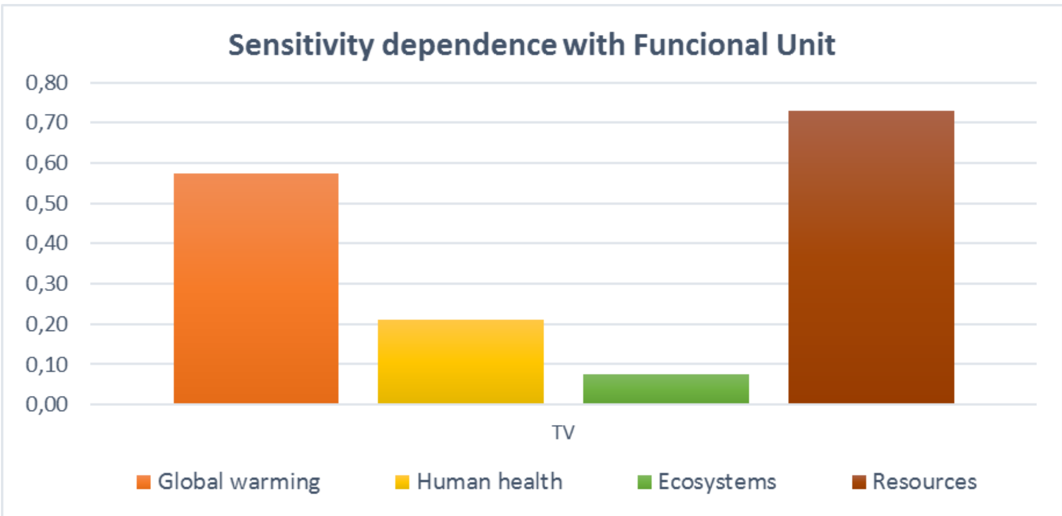


Figure 48. Sensitivity dependence with the change in the number of units during the lifetime of the TV

All values of the SD are less than one, meaning that the relative environmental impacts variation is less than the relative variation of the number of units. Values closer to 0 mean lowest dependence. According to these results, the TV could still further improve its environmental impacts by increasing its lifetime in the future, same as the telecom equipment, which is the only target product that applies a strategy of increasing the lifetime to enhance circularity in the C-SERVEES project.

The limitation of the conducted analysis is that the improvements considered do not focus on the use phase. It can be found that electricity consumed by the TV totally dominates the impacts for the use phase, while the contributions of product distribution and batteries are negligible. It is therefore clear the key role that the increase of renewable sources in the electricity mix can play in the coming years.

6.6. Manufacturer's review

C-SERVEES project supported transition to circular economy business models in Arcelik such as leasing, repairing and second-hand sales. Industrial manufacturing companies, especially in E&E sector are lacking information regarding the full lifecycle of their products and processes as well as of the potential of their products' utilization in different contexts missing opportunities for enhancing their circularity as well as tapping on alternative revenue streams. They are operating production processes according to the linear economy principles and underutilizing technologies that can help the transition to the circular economy. With the circularity concept, they try to lead their way to harmful material independency, recycled and eco-friendly production, while at the same time run their operations in a more cost-effective way. C-SERVEES provided to promote a resource-efficient circular economy model in the E&E sector through the development, testing, validation and transfer of new circular economic business models based on systematic eco-innovative services such as recycling and refurbishing. The household appliances and consumer durable electronics industry in Europe is currently facing the challenge of placing circularity on the European Market, thereby replacing obsolete resource-intensive appliances, hence the imperative need for continuous innovation in the industry. Considering its global production scheme, Arcelik constantly changes its production lines to meet market needs, with a lower resource profile, size, weight, resource consumption, etc. aims to produce a product portfolio that includes extensive customization capabilities regarding features.

One of the most important outcomes was a product with a much lower environmental impact. It enabled us to focus closely on one of our models of television, looking at all aspects of it from design through manufacture to the way it is bought, used and disposed of.

Within the C-SERVEES project, for the first time, 30% recycled plastic content in TV's back cover was used. Post C-SERVEES, we have put this into serial production, but due to import restrictions on recycled raw material from Europe the project was put on hold for some period of time but we worked with the government and other institutions to enable the import of these materials and in the meantime we also worked to increase the recycling capacity of our suppliers in Turkey. With these improvements, we aim to increase recycled content in TV back cover 60% in the future thanks to the contributions of the project. Post C-SERVEES, remote control designs of the TVs completed using 100% recycled material and entered our smart product family.

In the C-SERVEES project for the first time, dismantling of products and analysis of business case for recovery and reuse of EoL products' parts have been experienced. The feedback received from Emaús repairers was that it was fairly difficult to repair TVs because of the delicate LED panels and screws which make it hard to dismantle. Repair of TVs is a burdensome process that requires investments in the repair facility for special recovery equipment as well as trained technicians with necessary skills to recover the products as much as possible.

The results of the living labs showed that consumers were more willing to try the rent and second-hand refurbished TV as compared to the washing machine case mainly because of hygiene reasons. On the other hand, repair technicians were better equipped and more ready to repair washing machines than TVs. This shows that despite the demand from customers, the rate of repair and refurbishment for TVs might not be as high as that of washing machines without adequate investment to provide technicians with the technical know-how and tools needed to refurbish TVs. Therefore, Arçelik's C-SERVEES experience with TV side turned out provide important post project experience on increasing recycled content in the TV and refurbished product business model will be first prioritized on washing machines going forwards. As indicated in the washing machine section, Arçelik will continue to adapt the use of ICT tools for certification of the recycled material from suppliers.

The trial of 3D spare parts did prove to be working for TVs with the current technology but we will monitor the progress of 3D parts going forward.

The recovery of components by a refurbishment company rather than a recycler can add more value considering the complexity of the recycling process and the low chances of recovering viable parts at the recyclers' facilities coupled with the associated high costs. Additionally, due to the logistics costs, it makes more business sense for the sake of circularity overall to invest in infrastructure to increase the number of sites that can recover components in close proximity to manufacturers/repairers.

7. Evaluation of horizontal C-SERVEES tools

The demonstrations in the C-SERVEES project covered the whole life cycle of the products, from the design phase to the treatment of the waste generated when the product entered the EoL phase. The aim was to identify potential areas for improving circularity derived from the exploration of the product specific CEBMs which were translated into specific CE actions to be implemented in each demonstrator.

ADVA, Arçelik and Lexmark, have adopted business-oriented perspectives in order to exploit the project's results. Customer feedback has been gathered through online questionnaires, in-depth interviews and living labs to understand attitudes, expectations and experiences of customers and end-users related to eco-design, eco-leasing, reuse and refurbishment, and purchasing second-hand products. The insights collected were used to define and refine business case scenarios for future exploitation.

The main eco-innovative solutions and services explored in the demonstrations were:

- Eco-design
- Eco-leasing
- WEEE re-use and remanufacturing
- WEEE recycling
- ICT services

Although all of them were explored in each demonstration, the emphasis was different depending on the OEMs strategic circularity goals, perspective and type of product.

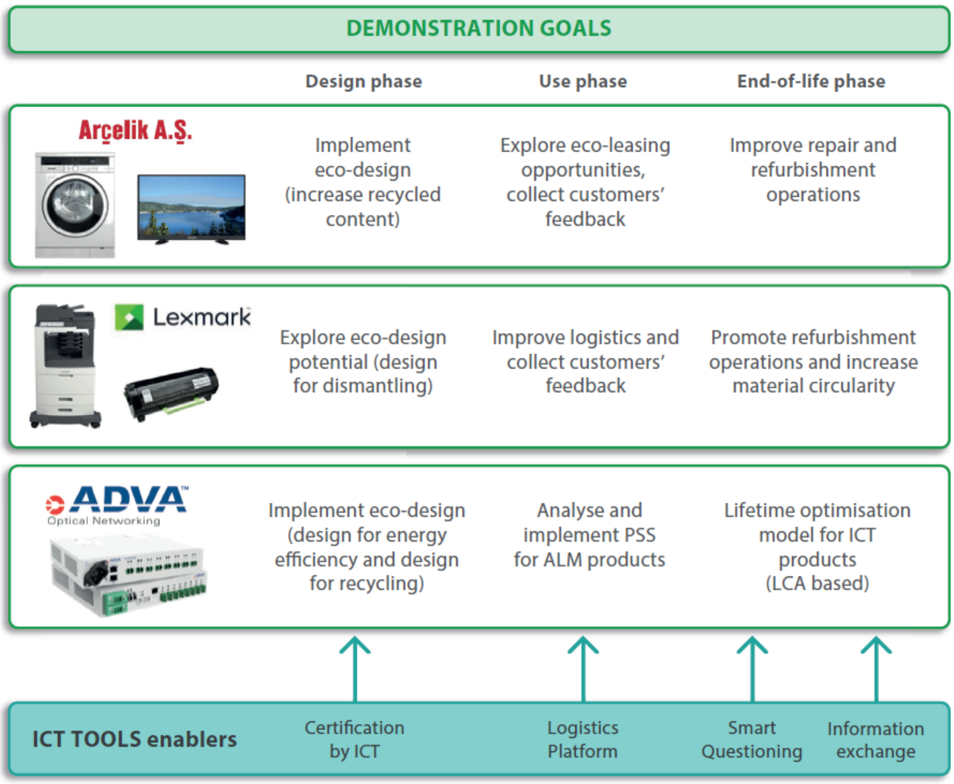


Figure 49. Eco-innovative solutions applied to each product in the demonstrations

7.1. Eco-design of EEE

Eco-design was applied to the four demonstrators with a different approach.

In the washing machines and TVs demonstrations, Arçelik put the focus on introducing **low-impact materials**, increasing the content of recycled plastics in both products (for the TV, it was their first model with recycled PC_ABS). The products used during the demonstration (100 washing machines and 100 TVs) were manufactured according to this goal and the recycled content was certified using the ICT tool developed by Circularise.

Eco-design applied to WM and TVs was focused on incorporating recycled plastic materials since, compared with metallic materials, they are more difficult to recycle and compared with minerals (glass on door window or concrete on counterweight), consume more non-renewable resources. The plastics are the only option for small parts with complex geometries and their substitution by 100 % recycled materials can contribute to reduce impact significantly. In practice, less than 25% of the washing machine is made of plastics, which limits the application of recycled materials. In the C-SERVEES washing machine, up to 23% of recycled plastic content was used (considering plastic scrap besides postconsumer plastics), although this accounted only to 2% of recycled content of the total weight. For this reason, the associated saved impact resulted to be low (lower than 0.3 % across all impact categories). Added to this are the difficulties to find high grade recycled plastic which complies with manufacturer’s technical standards. It was concluded that there is still need for action in order to increase the quality of secondary raw materials, such as improving sorting and cleaning of the waste plastics and including compounding to reach the required physicochemical and mechanical properties in the recycled plastics.

In the printer and toner cartridges demonstration, eco-design was explored focusing on the potential for **easier disassembly and recycling** of components in printers, although these proposals could not be implemented in new products during the demonstration period. They will be considered by Lexmark for future model designs. The feedback for this future eco-design was provided mainly by recyclers, who identified options to maximize value which can be generated out of the end-of-life product by harvesting parts to be reused by OEMs. While it is concluded that recycling or dismantling “as is” doesn’t generate value, it seems there is a path to generate value by developing specific instructions and giving access to it through an ICT tool to recyclers. In terms of feedback, the recyclers suggested that to facilitate dismantling operations an independent modular construction of subassemblies would be preferred, as well as quick fastening systems and using a colour code for those parts that should be prioritised for recovery.

Finally, in the ALM demonstration the focus was on design for **energy efficiency and longevity**. Similar to other equipment with long lifetime and 24/7 always-on use mode, the ALM system’s environmental impact is dominated by the use phase. This use-phase dominance requires persistent focus on best-possible energy efficiency. During the demonstration new eco-designed passive sensors were produced, namely fire door sensors and sprinkler sensors for the ALM system, to substitute conventional electric sensors. As for the active unit, eco-design was explored to improve the EoL phase with the recycler’s feedback, mapping the components for easier disassembly (aluminium, plastics, steel, electronic boards, electric wires). The findings of the project will influence future releases of the ALM system and possibly other product lines as well. This will happen primarily via the Design for Environment

(DfE) Guide, which is an ADVA-internal eco-design guide that is integrated in the product lifecycle process. A new version of the DfE Guide was released during the C-SERVEES project including updated and new instructions, based on conducted recycling studies, to improve both design and EoL phases.

Moreover, in this demonstration the eco-design was applied by ADVA at a high-level to produce **guidelines for lifetime optimisation of ICT products**, extensible to any E&E product. These guidelines consider the environmental impacts caused by production, use and end-of-life of a given EEE and their concept, development and application are detailed in section 7.7.

7.2. PSS and eco-leasing

Product Service Systems represent a business model innovation to drive a shift from traditional business offerings that focus on manufacturing products to an integrated system of products and services which are jointly capable of fulfilling specific customers' demands while at the same time generating value. Hence, decoupling business success and economic growth from pure product sales.

In particular, eco-leasing – the long-term rental of a product that, once the end of its useful life is reached, undergoes a combination of remanufacturing and recycling processes to prolong their useful life or else become a source of secondary raw materials– is a PSS-type of business model that has been widely considered as a solution to eliminate waste and drive the transition to a circular economy.

PSS and eco-leasing were analysed most in-depth in the ALM demonstration, where different PSS were considered for the ALM, one of them being a leasing model (see section 5.3.3). Although this analysis was conducted for two ADVA products, the ALM and the TeraFlex, the conclusions were generalized to certain extent to non-ICT-products.

First, if functional obsolescence or energy efficiency are not critical, positive effects of product reuse and parts reuse can become relevant. In turn, this may make an eco-leasing model more attractive because EoL treatment may provide higher positive credits. This must however be confirmed with LCA.

Second, for EEE products with high yields in their EoL treatment (due to less or slower obsolescence of their components), eco-leasing can also get more attractive since those products generate some revenue or allow cost and material savings at EoL.

It has been concluded that monetary EoL difference between leasing and selling the product including take-back is negligible. The EoL yield is independent of the PSS as long as take-back at EoL is mandatory. Therefore, PSS that consist of selling products with maintenance and EoL take-back do not have disadvantages as compared to leased products. This also means that eco-leasing should primarily be considered for financial reasons (e.g., avoidance of day-1 investment for the customer). In terms of environmental performance, other PSS with EoL take-back are equally good.

The results from this comprehensive analysis have activated ADVA's interest towards implementing a PSS for the ALM and other products in their portfolio. This will comprise all major aspects that are feasible for ICT products – increasing maintenance services and take-back, providing leased products or even leased functionalities.

In the washing machine and TV demonstrations, eco-leasing has also been explored from a financial perspective in order to create a potential new business line to be adopted for B2B customers. The involvement of a non-governmental organisation (NGO) authorised to perform preparation for reuse operations creates findings that can be replicated across Europe for the Arçelik brands, e.g. the reuse of currently discarded EEE products in a social economy environment.

7.3. WEEE reuse and remanufacturing

The potential to reuse, refurbish and remanufacture the products has been explored in all of the C-SERVEES demonstrations, but most in particular it has been the focus of the printer and toner cartridges demonstration. Indeed, Lexmark's main aim was to expand their Managed Print Services (MPS) with more circular options by promoting the refurbishment business. Three main issues were identified as critical: cost, customer acceptance, and logistics. In the washing machine and TV demonstrations, reuse and refurbishment were key elements in the CEBM developed by Arçelik in collaboration with Emaús to initiate a new business to prolong the useful lifetime of their products. For the ALM products, reuse is limited due to the particularly long lifetime of the devices and the functional obsolescence of their parts. The ALM demonstration has focused on developing specific guidelines for lifetime optimisation of ICT devices, with consideration for reuse and spare parts reutilisation.

Promoting refurbishment activities requires availability of spare parts. This may be problematic when faced with older devices or unforeseen conflicts affecting the supply chain. Obtaining second-hand parts from WEEE managers and recyclers could be a solution, and this possibility has been explored in the Lexmark and Arçelik demos in collaboration with the recycler partners. In the printer demonstration, several aspects were analysed, from the selection of the priority printer models and list of target spare parts, availability at the recyclers' facilities, ease-of-extraction, how to ensure quality of the components, and the cost-benefit assessment. The results showed that this business case could drive a positive financial outcome, assuming the recyclers received Lexmark printers in their WEEE streams, which may be a major challenge. It also led to several eco-design proposals to ensure the target parts and components were easily accessed inside the printers, and to the development of an improved dismantling manual.

Customer acceptance was explored in the Lexmark demo by means of targeted interviews and experiences with refurbished printers at selected customers' locations. The outcomes showed that customers were generally not much concerned with cosmetic issues, as long as the performance was good. In the case of washing machines and TVs, customer feedback was obtained from surveys and living lab experiences. Customers approved of having more circular options available such as refurbished products for sale, although there were concerns about the durability and the way in which the previous use was made.

The outcomes of the demonstrations point out several limitations for the economic feasibility of the reuse business: i) the collection scheme for end-of-life EEE, which currently does not support reuse operations, ii) the logistics costs to ship recovered parts or components and iii) the availability of preparation for reuse centres and qualified personnel to carry out the refurbishment and repair operations.

7.4. 3D printing

One of the roadblocks identified in C-SERVEES for the success of reuse and refurbishment CEBMs was cost related, as customers expect refurbished products to be much cheaper than brand new ones (up to 50%), which is more than a challenge assuming same product performance. As has been mentioned, one of the potential cost saving areas was related to recovering spare parts from EoL E&E products. The other was using 3D printing to produce spare parts on demand, avoiding the need for large orders and associated shipping costs as well as storage costs.

3D printing was explored in the washing machine, TV and printer demonstrations. The ALM demonstrations, as noted previously, did not focus on the reuse and refurbishment operations. Selection of suitable parts for 3D printing proved to be challenging in all demos. Covers and generally visual parts were excluded due to manufacturer's cosmetic specifications precluding the finishing of the 3D printed parts. Other plastic parts or components were discarded due to complex geometries or technical specifications requiring smoothness, mechanical properties, etc.

In the end, a component of the liquid detergent container, the siphon, was selected for the washing machine trials. In the TV, the stand was the most suitable part. For the printer, a deflector was chosen. In all three cases, different polymer materials and finishings were tested. However, none of the selected parts passed the validation tests at the manufacturers' labs. In the case of the washing machine, clogging and swelling or cracking was observed during initial washing cycles. For the TVs, the stands did not pass the mechanical balance and safety tests. In the case of the printer, results from functional tests did not support the use of these parts for intensive printing. Polishing of the parts could solve some of the technical problems, but the associated costs did not support that option.

Other, less visible or non-functional parts could be appropriate for 3D printing. This was demonstrated in the printer demo, where Lexmark successfully implemented 3D printing for packaging parts in their refurbishment centre. The lower technical and aesthetic requirements, the higher chance of achieving a cost-efficient business case.

7.5. WEEE recycling

C-SERVEES approach to improve current WEEE treatment practices was to enable a close and/or open loop recycling of plastics and other critical materials present in WEEE from an eco-design perspective: product design for recycling, including design for easy disassembly, new dismantling guidelines and information sharing via ICT tools. The demonstrations have explored the potential to reuse plastics in a close-loop scenario: through the collaboration with recyclers and by means of improved dismantling manuals, specific polymer fractions were separated and processed to obtain secondary raw materials of certified quality that the manufacturers could incorporate into new product parts. Dismantling of plastic components before shredding results in a high quality of post-consumer plastics compared to post-shredder (BAU) recycling. The economics of this selective dismantling were also analysed, since manual operations can substantially increase the economic value of the separated fractions, but this increased value needs to compensate for the additional costs incurred in the dismantling.

In the washing machine demonstration, PP from the detergent boxes was recovered and characterised for its physical and mechanical properties. Even though not all of them were compliant with Arçelik specifications, the material showed potential to be improved and reformulated. Arçelik has its own recycling plants in Turkey and can collect EoL products to be dismantled, so this activity could be replicated.

In the same way, ABS from flat panel display type TVs was recovered and processed to obtain recycled ABS flakes which were characterised according to Arçelik's specifications. In this case, the parts processed had to be checked for the presence of halogens to avoid restricted elements that can be present as flame retardants in some formulations. These should be identified before shredding to avoid contamination of the batch. For this reason, recycling ABS from the TV panels is less viable from a technical and economic point of view.

In the printer and toner cartridges demonstration, ABS and PC_ABS from printer parts and toner cartridges parts were recovered, processed and analysed following Lexmark's instructions. Although the physical and mechanical properties were compliant, the presence of impurities in some batches (glass, metal or rubber inserts) hindered the application of the secondary raw materials. Only the ABS from cartridges passed all the tests, since the cartridge parts were composed exclusively of plastic. New toner cartridges containing 20% recycled ABS were manufactured as a result of this activity.

7.6. ICT tools

Three different ICT tools were used as support for the demonstration activities, developed by partners Circularise, Rina-C and Soltel. Although developed independently, the tools were integrated into a common C-SERVEES ICT platform, where the different functionalities were tested across the four demonstrators: certification of recycled content by ICT, Smart Questioning, reverse logistic optimisation and secure information exchange among the various actors in the supply chain.

7.6.1. Integrated ICT Platform

The C-SERVEES project entailed the development of a collection of integrated ICT tools that provide a) information about sensitive product material data with content guarantees from material suppliers, b) public or centrally collected data and c) logistics data of the circularity process.

The three integrated software solutions enable customers to supplement sensitive digital product passport originating from the source of the material with the practical opportunity to collaborate on the less sensitive data and add logistics assessments. All in all the system tackled

a) the questions on recyclability and sustainability of materials
b) the re-manufacturability/ reuse/ service models/ repairability of products
c) the logistical feasibility and sustainability of circularity processes
d) the circularity and sustainability of products

The demonstrations showed that the certifiable use of recycled or sustainable materials or business models has an important marketing value that encourages sustainability. Furthermore, the possibility to assess material compositions, disassembly and 3-D printing manuals and logistics feasibility parameters enhanced the interest of companies to continue working on this topic. ICT tools as providers of circularity supporting data have been found to be an enhancing factor of circularity.

7.6.2. Circularise Blockchain platform

The ICT Platform developed from scratch in the C-SERVEES project focuses on the safe provision of any type of data about the product, its quality/ safety/ compliance criteria, its chemical composition and chain of custody. The decentralised blockchain system created for this purpose had the special functionality to pick up the material- or component-specific data directly from the specific material suppliers with the related proof of data correctness.

The technology was used for the types of circularity practises where the use of data can either increase the possibility for circularity or the economic value for the companies. This resulted in two types of demonstrations with the industry partners:

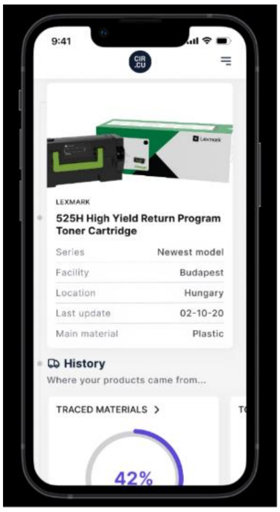
Providing certification of sustainability (e.g. exact proven recycled material content) to unlock customer segments that require certified sustainability

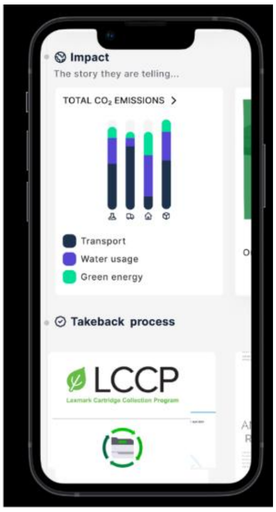
The certification of recycled content by ICT was demonstrated in three out of four C-SERVEES demonstrations: washing machine, TV and printer and toner cartridges.

In the WM and TV demos, an external material supplier (Covestro) was identified which could provide a) the recycled material, b) the certificates or audit report from a third-party auditor identifying the material as recycled at the supplier stage. In the printer demo, the recycled material was obtained during the project activities as described in section 4.3.6. For this reason, purchase orders and shipment documents stating exact quantities and batch numbers were employed instead of external certificates.

All the participants were onboarded on the Circularise Web App. The OEM received a personalised dashboard in order to receive tokens from their supplier, certifying the material as recycled. Furthermore, Circularise created a personalised page on the mobile app showing the product properties upon scanning of the QR-Code.

The material supplier then received a purchase order over the specific amount of material to be supplied, tokenised and shipped to the part manufacturer. The recycled material is supposed to be audited by a third-party expert and verified/certified in its nature of secondary raw material. This certificate specifies the amount or recycled content in the material. The document should be uploaded by the supplier and an equal amount of recycled content tokens would be created for the amount of material produced in this certified production batch. The tokens resembling the part of material supplied to the manufacturer are sent via blockchain to the manufacturer's account. The token transfer through the blockchain makes it verifiable, immutable and prevents double-spending. This means that token transfers are recorded forever, cannot be changed or tempered with and tokens cannot be multiplied or transferred twice.





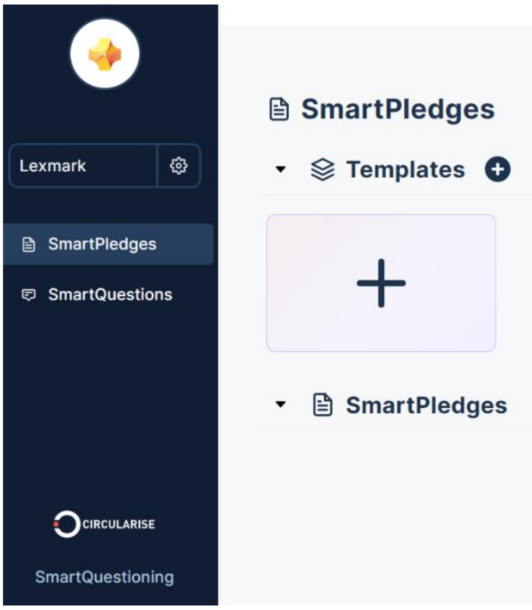
Providing data that increase the end-of-life value of material and components and therefore its likelihood to be re-introduced to the supply chain

Traceability and supply chain due diligence is increasingly becoming mandated by regulation, e.g. via EU directives for Digital Product Passports, Eco-Design principles, and Supply Chain Due Diligence to name a few. Similar regulatory demands are expected to be developed in other regions – notably Japan and the US. Providing verifiable end-to-end data will be critical to an organisation's future licence to operate. The challenge is that today's data systems are not digitized, decentralised, updatable and connected. Sharing data in a secure and encrypted manner that maintains confidentiality whilst providing transparency of data is a challenge.

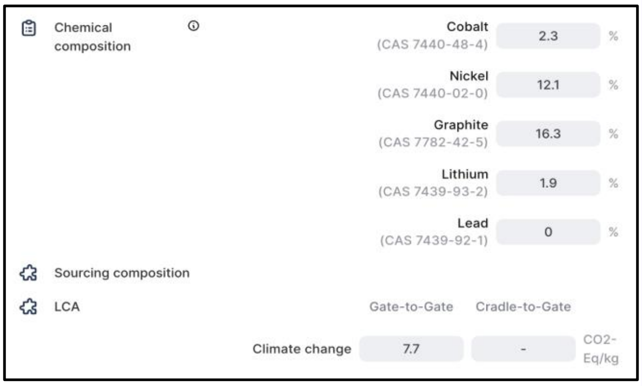
Supply chains often deal with data that needs to remain a secret. This includes trade secrets on processing steps, business deals or the composition of materials. Normal encryption methods rely on trust and central parties. With our solution, however, data is communicated decentrally via blockchain and zero-knowledge cryptography. This makes it immutable and trustworthy while also avoiding the central storage and encryption that can be broken with enough resources. While it is hard to protect privacy and confidentiality on public blockchains, it is not impossible. Circularise solved these challenges by creating a patent-pending 'Smart-Questioning' technology to exchange information securely and anonymously using zero-knowledge proofs (ZKP).

Circularise creates a network of suppliers where inquirers can share questions and relevant value chain members can provide answers. Stakeholders thereby receive certified answers to their material questions from data stored decentrally on blockchain from across the whole supply chain. This supports the advancement of circular strategies such as product lifecycle management e.g. take-back, reuse, refurbishment, remanufacturing, recycling to recover resources. Within such processes a core unique selling point is that companies who use Circularise retain full control over their own data.

The demonstration of the Circularise Smart Question Technology was conducted in a similar fashion for the washing machine, TV and printer and toner cartridges demonstrators. First, Circularise and the OEMs identified the product components and the suppliers for each of them, who were either onboarded on the Circularise system or represented by an account manager from the OEM knowledgable about the component and its exact composition. The suppliers or representatives then each created a smart pledge containing the exact chemical composition of the component on the Circularise system. This smart pledge was then transformed into an encrypted link to the original composition data. This reflects the chemical composition to be safely communicated.



The second step was the quantification of the material created. The chemical composition of the material had to be linked to actual physical material that is being supplied to the OEM. When selling or sending the final product, the OEM sends the digital asset as well. The customer, refurbisher, repairer or recycler can then access the data of the product via the smart question technology to find out what materials



are prevalent in the product and how the material flow of the whole supply chain is constituted. The smart questioning technology enables the sharing of specific answers to pressing questions in the repair or recycling process without sharing the full material information.

The developed software and the resulting demonstrations were highly successful. By end of 2022, Circularise has a registered patent on its Smart Question technology, a venture capitalist investment, further EU funding and a company size that has grown from 5 to 36 people. The C-SERVEES project has been absolutely vital for the further existence and commercial success of Circularise with resulting commercial pilot projects e.g. with Porsche. Arcelik, the first demonstrator of the C-SERVEES project has become a commercial client of Circularise, which emphasises the success of the C-SERVEES project in creating circular economy business models.

7.6.3. Logistic Platform

Product recovery is an emerging business area which shall be attractive from both an economic and environmental point of view. Several points contribute to the success of this action, such as costs, time and safety for disassembling products, availability and costs of raw materials, disposal costs of end-of-life products and, last but not least, logistics and transport costs and related GHG emissions for reverse logistics which represent key points to make the process competitive compared with the one which involves only primary materials.

The efficient and planned management of the reserve logistics for the recovery of products once they are no longer be used by the consumers allows to:

- save transport costs,
- reduce GHG emissions due to transport,
- contribute to reduce final cost of the product,
- increase attractiveness of reused/second-hand materials, and
- increase environmentally responsible behaviour.

In this context, the Logistic Platform, developed by RINA Consulting in the scope of C-SERVEES Project, aims to ensure a sustainable transportation of the WEEE (Waste from Electrical and Electronic Equipment) among the stakeholders of the logistic chain to enable the re-use of the recovered materials and to re-insert them in the process. The tool allows to compare transportation routes of existing supply chain with new potential scenarios including end-of-life products and recovered materials as potential nodes of the supply chain. The most sustainable routes and combination of trucks are identified with the aim of:

- minimizing the total distance covered by trucks to minimize CO2 and other main pollutants' emissions
- minimizing travel costs related to the total driven kms and travel time needed to reach all the nodes of the chain

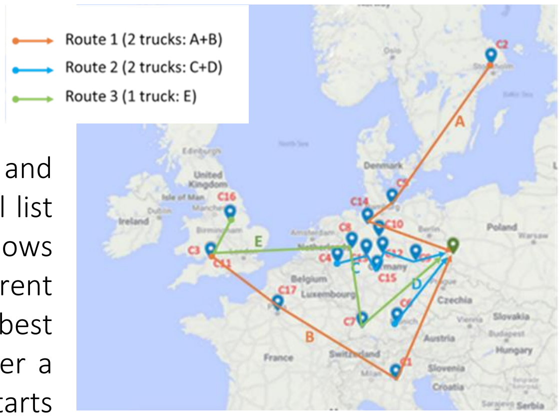
thus making logistics more cost-effective and sustainable. In this sense we can say the tool enables closing the loop for the EEE value chain.

The main core of the tool is the Best Routing Algorithm developed in the scope of the project to support the User in the identification of the of the most sustainable routes (for which ones the tool evaluates the CO_2 and the main pollutant emissions) and combination of trucks per each scenario implemented in the platform. The goal is to reduce the environmental impact of the transport and in this way the algorithm is able to combine two factors:

- the optimization of the route planning by defining the best sequence of nodes of the supply chain and the shortest path between two nodes of the chain; and
- the identification of the appropriate number of trucks according to loading constraints but also aiming at minimizing the total driving distance covered by trucks to connect all the stakeholders involved.

The Logistic Platform has been developed according to some of the needs of the business models (e.g. foster the re-use of recovered materials, improvement of the end of life product logistics, assessment of the supply chain environmental benefits,..) which are validated in the scope of the project through demonstrations in different use cases dealing with target products belonging to different EEE categories.

After a testing phase of the algorithm, the tool has been used within the Lexmark demo on printers and within the Arçelik demos on TV and WM. In all the demo cases no baseline is available since both companies are still not implementing the reverse logistics for these products which are not return back to the production site. However, the industrial partners were interested in simulating this scenario to identify a possible logistic chain and evaluate its environmental impact.



The Lexmark demo included 4 companies where end of life printers could be collected and shipped back to the production site in Poland to be disassembled to recover components. Companies are in UK, France and Germany and final destination in Poland. The full list of options proposed by the Logistic Platform shows about 15 alternatives which consider different company order and number of trucks. The two best routes (which are very similar in results) consider a multi-stop path and only one truck; the route starts in UK, then France and Germany. The worst route, instead, divides the logistic chain in 3 sections and therefore foresees the use of three trucks with an increase of kms and of environmental impact. In terms of km and therefore CO_2 and pollutants emissions the best route registers about 40% of emission savings which implies also a reduction of time and costs.

Comparison between single shipments and consolidated scenarios

17 pick-up locations	Single shipments to Zary	Best consolidated solutions to minimize CO2 TOTAL	Best consolidated solutions according to the availability of printers TOTAL
Total CO2 (kg)	10822	4414	6541
Total distance (km)	14036	5725	8484
Total delivery time	6 days 5:15:18	2 days 15:32:22	3 days 20:18:05

A different solution has been instead proposed by the platform in the Arcelik demo where, due to the location of the warehouses, some located north and some south of the production site, it is more convenient dividing the route in two sections and therefore using two trucks to reduce kilometres and emissions. Also in this case savings of the best routing compared with the worst are about 30-40%.

The Logistic Platform, as it is today, is totally tailored on the C-SERVEES project information and data made available in the C-SERVEES project, but the core of the tool which is represented by the developed algorithm could be also applied as main elements of a stand-alone platform able to support industrial companies, not only operating in the E&E sector, in planning and optimizing the transport routes to collect products/materials but also to distribute their products.

In this case, specific developments and customisations could be needed to the input forms to adapt the Logistic Platform to the needs of the customer companies, but the core algorithm could be integrated to achieve the company' s targets and to increase sustainable logistics concept based on transport planning.

7.6.4. Information Exchange Platform

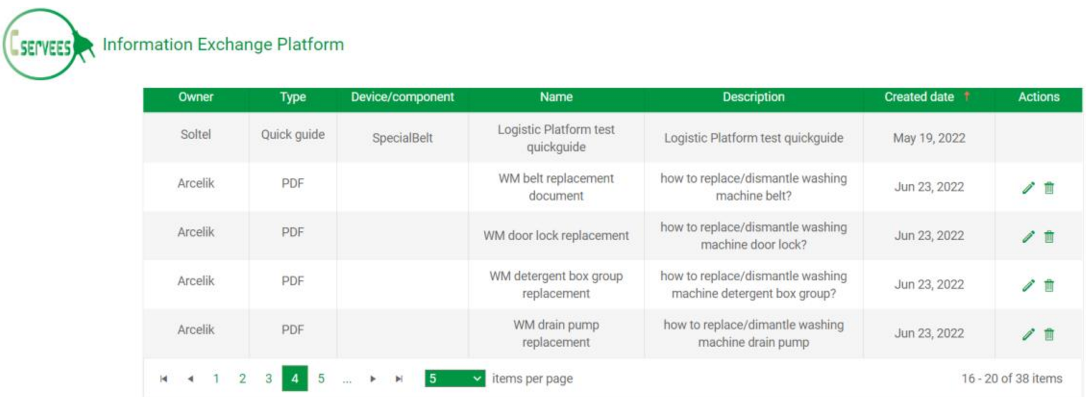
The Information Exchange Platform (IEP) is a tool conceived within the scope of the C-SERVEES project, developed to facilitate communication between the different actors involved in the recycling and reconditioning processes, thus supporting the implementation of the circular economy business models defined within the project. With this premise, the Information Exchange Platform has the following main objectives:

- Allow users to discover other stakeholders and actors of the previously mentioned processes.
- Connect with them in order to initiate new collaborations and partnerships.
- Establish new communication channels both inside and outside the platform.
- Enable the useful exchange of information through the different functionalities available in the application.

To achieve these points, the tool has different areas, each of them focused on offering the user the appropriate functionalities. Thus, the Information Exchange Platform has the following main areas:

- Manufacturer list (List of partners)
- Documents repository (List of documents)
- Recipes repository (Quick guides)
- Forum

The two main demonstrations have been carried out with partners Lexmark and Arçelik using printers and washing machines respectively as main products. In both cases the conclusions reached were similar, with the document repository proving to be very useful, allowing users to share information with different partners in a simple and efficient way.



Owner	Type	Device/component	Name	Description	Created date	Actions
Soltel	Quick guide	SpecialBelt	Logistic Platform test quickguide	Logistic Platform test quickguide	May 19, 2022	
Arcelik	PDF		WM belt replacement document	how to replace/dismantle washing machine belt?	Jun 23, 2022	
Arcelik	PDF		WM door lock replacement	how to replace/dismantle washing machine door lock?	Jun 23, 2022	
Arcelik	PDF		WM detergent box group replacement	how to replace/dismantle washing machine detergent box group?	Jun 23, 2022	
Arcelik	PDF		WM drain pump replacement	how to replace/dimantle washing machine drain pump	Jun 23, 2022	

1 2 3 4 5 ... 5 items per page 16 - 20 of 38 items

Owner	Type	Device/component	Name	Description	Created date ↑	Actions
Lexmark	PDF		CX725 User's Guide	Lexmark CX725 Series User's Guide Safety information, applications, features, printing, copying etc.	May 5, 2022	

During the several days in which the application was tested, users reported on several occasions the ease of use of the application and its simplicity, which is the flagship of the development of the information exchange platform. Different use cases were carried out and different scenarios were tested in which it was detected that the application could be of great interest. The main use cases tested included:

- Connection between the producer/manufacturer (Lexmark/Arçelik) with a new potential collaborator (new user).
- Exchange of information between different users: technical documents, user manuals, etc.
- Resolution of doubts through the forum

The rest of the scenarios tested using functionalities integrated in the application did not show remarkable results, demonstrating, among other things, that the integration between the three platforms is not an outstanding or user-friendly functionality, being the least valued feature during the demonstration phase.

While it is true that the demos were conducted in the same way for all products, it could be detected from the early stages that for the use cases in which the product needed to be repaired or reconditioned, the application provided greater value to the user, with the step-by-step guidance functionality becoming the main attraction for the user in these cases. This was especially the case in the demo with Arçelik and Emaús regarding the washing machines, due to the refurbishment work that the latter carry out in their social work. Lexmark, on the other hand, found in this functionality the ideal tool for the repair of some printers, but more importantly, the configuration or tuning of the printers.

In conclusion, the work team linked to the information exchange platform determined, after the feedback obtained from the other partners, that the main functionalities with potential to be developed, exploited and evolved were those related to the sharing of information (step-by-step guides, forum, document repository). Due to the great variety of cases and realities that have been taken into account within the C-SERVEES project, simplicity plays a particularly relevant role when trying to create a common and practical tool. In this sense, the IEP tries to do what the user expects of it in the simplest but most solid way possible.

7.7. EEE lifetime analysis

7.7.1. Context of the lifetime analysis

For certain products, considerable use-phase extension may not make sense because of the environmental use-phase impact. This is true, e.g., for certain classes of Information and Communication Technology (ICT) equipment, namely equipment that is accommodated in the networks and data centres, i.e., infrastructure equipment, and that is operated in a 24/7 always-on mode [14]. The related electronic products show strong use-phase dominance in lifecycle assessments (LCA) [15], which has an impact on their optimum lifetime or the CE aspect of longevity. These products may also require ecodesign that primarily focuses on energy efficiency rather than CE, since energy consumption is driving the use-phase impact.

The aim of this chapter is to derive a *classification figure* for separating products with clear use-phase dominance, e.g., ICT infrastructure equipment, from those with less use-phase impact, e.g., end-user equipment like laptops. This can be used for guiding ecodesign, for total-lifetime carbon-emissions optimization and for product classification in future regulations and policies. As such, the classification figure also supports the Do-No-Significant-Harm principle of the EU Taxonomy Regulation [16].

Hereinafter, the methodology of the classification figure is described. This includes an assessment of gaps in existing standards related to environmental requirements and assessment specifications for electronic or ICT equipment, a short description of LCA and the relevance of the global warming potential (GWP), and the derivation of required parameters like emission factors. Subsequently, the usefulness of the developed classification figure is verified in several case studies.

7.7.2. Methodology

Knowledge gaps

Several standards define environmental requirements and assessment specifications for electronic or ICT equipment, e.g., [17]-[24]. These are complemented by references on electronics-equipment eco-design, e.g., [10]-[13], [25]. References [17]-[20] describe LCA, [24] is on eco-design, and [21] describes lifecycle management. Some of these references explicitly address CE and hence the aspect of longevity ([10], [18], [23]).

These references lack any guidance leading toward optimum product lifetime, e.g., with regard to **total-lifetime emissions**. This may lead to attempts of lifetime extension, as mentioned in the introduction. What is missing in these references is a clear and easily applicable classification and evaluation of the most relevant environmental impacts of electronic products in an attempt to answer the question: *shall electronic equipment be replaced by newer, more efficient products with the goal of total-lifetime environmental-impact reduction, and if so, when?* This includes the identification of the most relevant electronic-products lifecycle phases and the associated impact, e.g., emissions.

The missing classification could guide regulation requirements in order to avoid any adverse effects. Similarly, it can also be used to guide eco-design.

In order to derive meaningful results, such a classification should consider the total product lifetime including all relevant lifecycle phases and associated environmental impact.

Moreover, it should be applicable to a broad range of electronic and electrical equipment and be flexible enough to be adopted to different use cases (e.g., using average grid-mix electricity vs. renewable electricity).

Simplification toward GWP

When calculating optimum lifetime of electronics equipment, suitable measures are required. Here, the LCA midpoint parameter of global warming potential, GWP, is used. Due to global warming and the urgently required actions to reduce carbon emissions, GWP is considered the most important LCA midpoint impact category today.

On the other hand, circular economy is primarily considering general resource depletion and the associated waste generation [26], [27]. This covers fossil resources and thus, indirectly, emissions. In addition, and more importantly on the long run, it also covers other abiotic resources, including critical raw material. However, these depletion midpoint parameters are correlated with the GWP to good extent.

For the electronic devices, typical use-mode and lifetime data was used. For infrastructure ICT equipment, this is based on experience with our customers' networks.

Parameter extrapolation

In order to derive lifetime electronic-products' GWP, use mode (average usage per time) and lifetime need to be known. Moreover, since potentially long future periods are considered, the development of the average electricity emission factors and of the energy efficiency must be extrapolated into the future.

This research used two sets of globally averaged emission factors (EF) that are extrapolated up to 2050. The first set assumes a linear decline in the average EF toward 100% renewable energy (RE) in 2050. The second EF set is more aggressive than the first one. It reaches 100% RE in 2044. Even faster approach toward 100% RE is not seen realistic today on a global scale. The second EF set is used for sensitivity analysis.

In addition to the average EF, we also consider the case where renewable energy is used exclusively. Then, a non-zero emission factor of EF_{RE} = 0.04 kg CO_2e/kWh for renewable energy is used. For calculations with RE only, this emission factor stays constant over time.

The RE emission factor considers complete lifecycle electricity emissions. It is an average over a large range of differences in technology, local resource conditions and methodological approaches for assessment [31]. For example, lifecycle GHG emissions are in the range of 7-56 g CO_2e/kWh for wind energy and 5-217 g CO_2e/kWh for photovoltaic.

The next parameter that is relevant for calculating GWP into the future is the development of the gain in energy efficiency in electronics. This is a relevant parameter for infrastructure ICT gear, but also for TV sets and other electronics equipment. The problem is that this gain started saturating since total efficiency is approaching some fundamental physical limits [34]. At today's pace, any gain in efficiency will come to a stop in around two decades, given that no disruptive new technologies will be found. In the last two decades or so, the yearly gain in energy efficiency for main classes of ICT infrastructure equipment (switches, routers, WDM transmission gear) was in the range of 14% [34]. Therefore, we assume non-linear decrease of the yearly efficiency gain from 14% in 2020 toward almost zero in 2050.

Product classification

In order to fully generalize our analysis and the consideration if and when products should be replaced by more efficient successors, we define the following **U**se-phase-over-**P**roduction-phase **R**atio UPR_{10} for the GWP:

$$UPR_{10} \coloneqq \frac{\text{GWP of the first 10 years in the use phase}}{\text{GWP of the production phase}} \qquad \text{(Eqn. 1)}$$

UPR_{10} is the ratio of 10 years use-phase GWP and the production GWP according to LCA. Note that the first 10 years in use shall be considered since over time, the use-phase GWP decreases due to improving emission factors. We consider 10 years of use to allow certain averaging of the emission factors and sufficient time for successor product generations to be developed.

UPR_{10} does depend on the applicable emission factors. Due to the fact that emission factors for grid-mix electricity and renewable energy develop differently, UPR_{10} cannot be normalized to the emission factor. Instead, it has to be calculated for different emission factors separately.

7.7.3. Results

GWP and LCA

In Figure 50, two LCAs for the *TeraFlex* system are shown. TeraFlex is an example of coherent WDM (wavelength-division multiplex) transport equipment, i.e., equipment that simultaneously uses multiple different laser wavelengths for optical-fibre long-distance Internet-traffic transport [36]. It hence belongs to ICT infrastructure equipment. TeraFlex is based on high-performance chip sets (ASICs, application-specific integrated circuits) for conducting the necessary digital data processing. Since these chip sets lead to relatively high power consumption, and since the use mode is 24/7 always-on, the system is dominated in GWP and other mid-point LCA parameters via power consumption by its use phase. Despite relatively high absolute power consumption, TeraFlex is one of the most *energy-efficient* WDM systems, where energy efficiency is rated in W/Gbps (electrical power consumed per throughput in gigabit-per-second transported).

The LCAs were calculated for average EU electricity grid mix and 100% renewable energy, respectively. This is relevant since the related emission factors have high influence on LCA. Considering emission factors for renewable energy is relevant to compile meaningful results for the period up to 2050 and beyond, when Carbon neutrality is targeted.

In the upper part of Figure 50, the TeraFlex LCA is shown for average EU grid-mix electricity. All midpoint categories shown are dominated by the use phase via use-phase energy consumption.

Note that abiotic resource depletion (ARD) has a result similar to GWP. ARD is regarded an important midpoint parameter in the CE context.

When renewable energy is used, things change but use phase is still mostly dominant, see the lower part of Figure 50. The reason is that we use a non-zero emission factor of EF_{RE} = 0.04 kg CO_2e/kWh for renewable energy as described earlier.

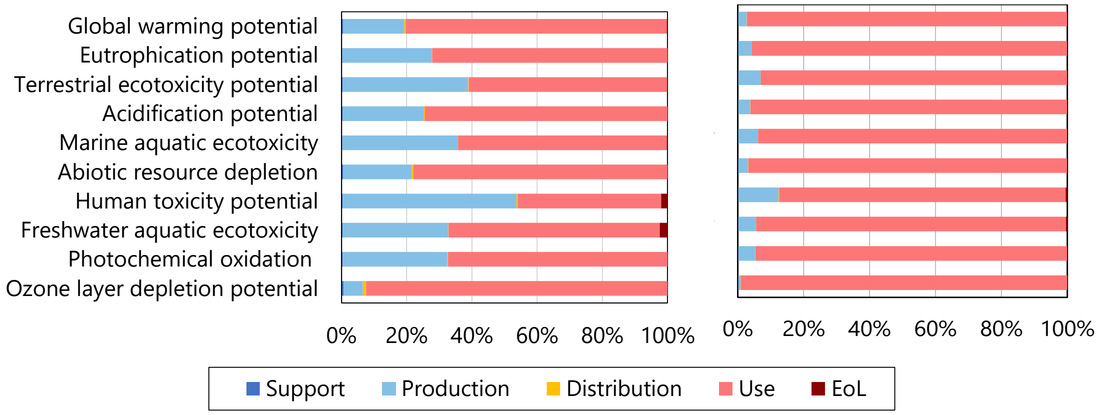


Figure 50. LCA for the TeraFlex system. Left: renewable energy. Right: grid-mix electricity.

Also for the case of using renewable energy, ARD performs similar to GWP. This confirms that GWP is a valid measure for lifetime optimization. The correlation between GWP and ARD holds for all ICT-equipment LCAs we conducted so far.

Following the use phase, the next important lifecycle phase is the production phase. The other phases can be neglected, their total aggregated impact on any of the midpoint parameters is clearly <5%.

Results similar to WDM equipment can be shown for Ethernet switches and IP routers [28], [29].

Parameter Extrapolation

The extrapolated, linearly declining emission factors are shown in Figure 51. Both variants approach carbon neutrality between 2044 and 2050.

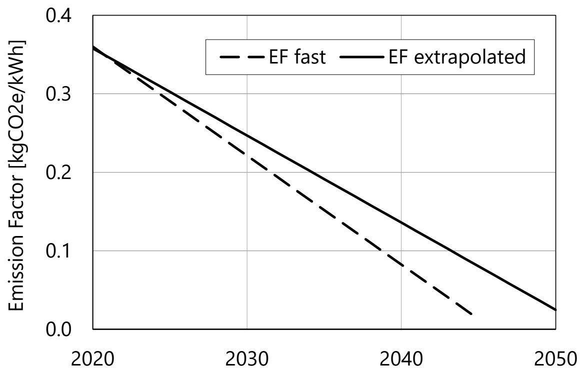


Figure 51. Extrapolation of emission factors. The EF variant comprises faster declining values.

The extrapolated emission factors can be used for any long-term emission calculation.

The extrapolated, non-linearly declining development for electronics and electrical products energy efficiency is shown in Figure 52.

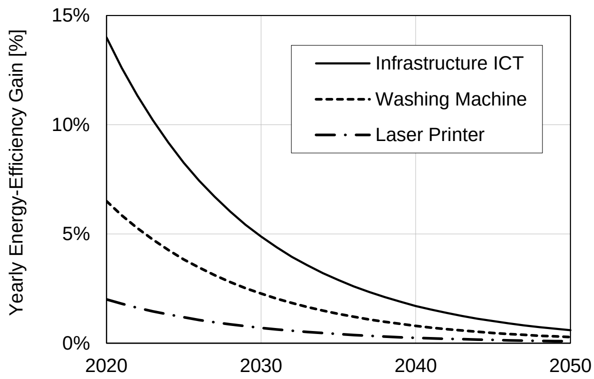


Figure 52. Extrapolation of yearly gain in EEE energy efficiency.

The method leading to Figure 52 can be used to calculate the improvement in efficiency that a successor generation of a piece of equipment can offer in the long term (e.g., over 10 years). This improvement depends on absolute time since it is decreasing over time. The different equipment classes have different efficiency development. The underlying data for laser printers was taken from manufacturers.

Product Classification

We now calculate the time after which electronic (ICT) products should be replaced by more efficient successor products in order to minimize total-lifetime emissions in dependence of UPR_{10}. This is done by varying UPR_{10} across a large range and identifying if and when there is a *GWP crossover point in time* between these two scenarios: no product replacement versus replacement. For any replacement scenarios, production GWP of successor generations is considered.

In the upper part of Figure 53, this crossover is shown as a function of UPR_{10} for the case of extrapolated emission factors as per Figure 51. The crossover time shows hyperbolic character. Below $UPR_{10} \approx 2$, there is no crossover anymore, it moves toward infinite duration.

For $UPR_{10} > 20$, the crossover is within the first year. Significantly higher UPR_{10} values are unlikely since this would require products with *very* high power consumption but low production GWP. In this part of the curve, it is clear that products must be replaced if more efficient successors are available.

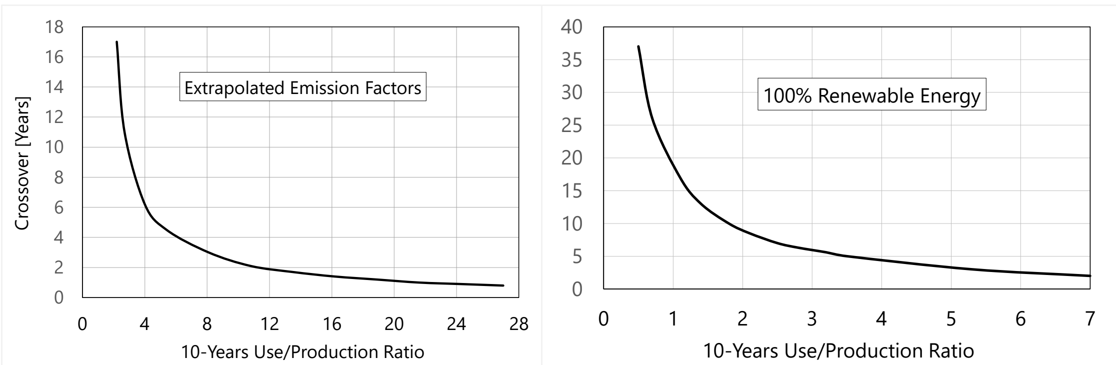


Figure 53. Crossover time toward total net-positive emissions for emission factors extrapolated up to 2050 as a function of the UPR_{10} (left). Crossover time toward total net-positive emissions for EF_{RE} = 0.04 kgCO_2e/kWh for 100% renewable energy as a function of the UPR_{10} (right).

We repeated the crossover calculation for 100% renewable energy. The result is shown in the lower part of Figure 53. Not surprisingly, the crossover time shifted upward, and with 100% RE, no UPR_{10} values above 7 were reached. *However, even when using 100% RE, the principle characteristic does not change. For products that are particularly energy consuming in the use phase, replacement after a certain point in time makes sense in terms of total resulting GWP*. This holds for small non-zero emission factors for RE.

For simple product classification, the crossover UPR_{10} value that separates the replacement from the no-replacement domains needs to be known. This value cannot be derived precisely in general since there are dependencies on UPR_{10}, on absolute time and on emission factors, as well as unknown development cycles of successor products. However, the crossover UPR_{10} value that separates the replacement domains can be approximated.

The approximation is done by fixing the production GWP *or* the use-phase power consumption and varying the other of the two parameters to the value where the two scenarios (replacement, no replacement) yield the same GWP. The crossover UPR_{10} then simply is the ratio of the two resulting parameters as per Eqn. (1).

Then, for the **extrapolated emission factors** of Figure 51, a value of **$UPR_{10\ \mathrm{Crossover}} \approx 2.5$** results. This is in line with the upper part of Figure 53. There, $UPR_{10} \approx 2.5$ is the range where the crossover-time curve most massively changes in slope. Note that, compared to [14], the value for $UPR_{10\ \mathrm{Crossover}}$ has been lowered from 4 to 2.5, following more recent analyses. The new value covers a broad range of energy-efficiency development.

The $UPR_{10\ \mathrm{Crossover}}$ calculation is repeated for the case of running the equipment with 100% renewable energy. Now, **$UPR_{10\ \mathrm{Crossover}} \approx 1$**. Again, this is in line with the bottom part of Figure 53, where $UPR_{10} \approx 1$ is the range where the gradient of the curve clearly changes. The smaller the emission factors are, the more the crossover point moves toward higher power consumption relatively to the production impact.

The $UPR_{10\ \mathrm{Crossover}}$ calculations must be adapted to other emission factors that the respective equipment might see in its future use phase.

In general, products with UPR_{10} clearly below 2.5 (grid mix) or clearly below 1 (RE), respectively, do not require replacement. Products with UPR_{10} clearly above 2.5 (grid mix) or clearly above 1 (RE), respectively, do require it. Products with UPR_{10} near the crossover values 2.5 (grid mix) or 1 (RE), respectively, should be analysed in more detail to identify the optimum replacement scenario.

Similar considerations hold for the preference on energy efficiency in eco-design. Products with high UPR_{10} require consideration of energy efficiency first, followed by circular-economy consideration. For products with small UPR_{10}, it is vice versa.

UPR_{10} may have an **influence on the choice of the most-suitable product-service system** (PSS) [1] as the supporting CE business model. In cases of very high UPR_{10}, it may be beneficial to select a PSS that supports (improvements of) operational efficiency, namely energy efficiency. In turn, certain PSS can have a strong influence on UPR_{10}. In particular, PSS that aim at substantially improving product utilization, e.g., by better sharing, may also lead to substantially increased lifetime energy consumption, thus increasing UPR_{10}. In these cases, it should be checked whether the respective products need to be replaced because of energy-consumption reasons after certain periods.

7.7.4. Case studies

In this chapter, we demonstrate the usability of the UPR_{10} for several products: two infrastructure ICT products (ALM, TeraFlex), a flat-panel TV set / monitor, a washing machine, ICT data-centre equipment, and a refrigerator. Where applicable, we vary utilization to show the resulting impact.

Infrastructure ICT Products

In the first case study, we analyse the total-lifetime GWP for TeraFlex, which was already introduced earlier. TeraFlex has a UPR_{10} **of ~27**. This indicates that this system should be replaced after a certain period of time for reasons of energy-efficiency and lowering total-lifetime emissions. Therefore, we investigated the optimum replacement period for TeraFlex. In general, an optimum replacement period for real products cannot be derived. The main reason is that unrealistic assumptions regarding the availability of successor products must be made, which likely are not met by reality. However, a good approximate answer can be given.

First, we assumed grid-mix electricity and its development of the emission factors as per Figure 51, extrapolated case. The result for TeraFlex is shown in the upper part of Figure 54, where we show **total resulting lifetime emissions**. It is obvious that replacement is advisable for a product like TeraFlex.

Three scenarios are shown: no-replacement, replacement every 8 years and a replacement scheme that is close to optimum. This shows that regular replacement, e.g., every 8 years, becomes less efficient over time. Faster replacement at the beginning might be better for products with very high UPR_{10}, but toward 2050, it performs worse. For TeraFlex, close-to-optimum replacement is achieved after 4, another 4 and 8 years, respectively. The curves are flattening over time due to improving emission factors according to Figure 51. The curves for the replacement scenarios are even flatter due to better energy efficiency of the successors.

The saturation of efficiency gain, together with emission factors that are improving over time, lead to the fact that replacement becomes less frequently necessary over time. In addition, efficiency gain becomes smaller with faster replacement.

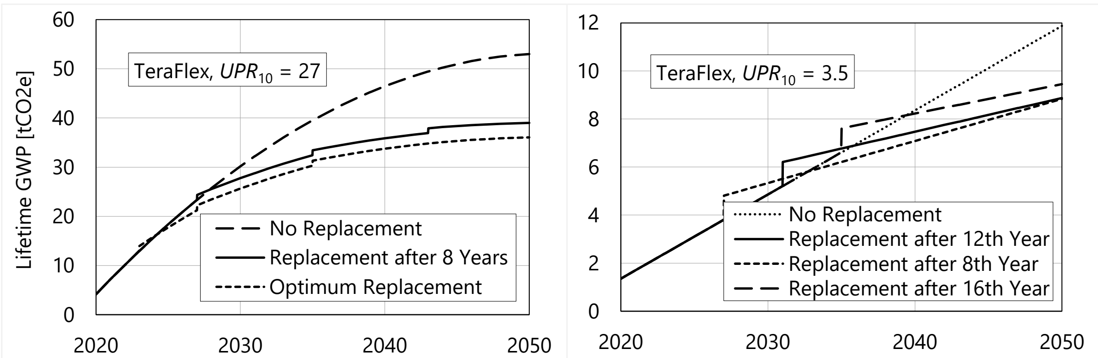


Figure 54. Optimum replacement cycle for TeraFlex, compared to replacement after every 8 years and to no replacement at all. Note the high UPR_{10} of TeraFlex for grid-mix electricity (left). Optimum replacement for TeraFlex, when using 100% renewable energy. Note that UPR_{10} of TeraFlex changed compared to using grid-mix electricity (right).

We also approximated optimum TeraFlex replacement when using 100% renewable energy, see the bottom part of Figure 54. Due to the low emission factor, only one replacement should take place in the period up to 2050. For TeraFlex, optimum replacement when using RE (with non-zero emission factor) should take place after 8…12 years.

We kept the production emissions constant, over time and with changing emission factors. This is not fully exact, but prediction how production LCA changes with changing emission factors is difficult. Production GWP certainly will get better over time, but the extent is unclear. We regard this a secondary effect which does not have significant influence on our results for products with high UPR_{10}. Note that keeping the original high production GWP does penalize the more frequent replacement of products. For TeraFlex, the crossover point in time would only come even earlier.

Next, we calculated two scenarios – one replacement vs. no replacement – for the ALM64. The ALM, Advanced Line Monitoring, is an infrastructure, fibre-monitoring system. It can either supervise ICT service-providers' fibre plant or, by installing fibres in buildings, various parameters in these buildings. Technically, the ALM is an optical time-domain reflectometer [37]. It permanently monitors fibres for their integrity, therefore the use mode again is 24/7 always-on. Moreover, the ALM is designed for lifetime in excess of 10 years, therefore, its energy consumption is relevant. The LCA of the ALM shows use-phase dominance. The use phase caters for 55-90% of the different midpoint parameters when using grid-mix electricity.

The lifetime GWP of the two grid-mix-electricity ALM scenarios is shown in Figure 55.

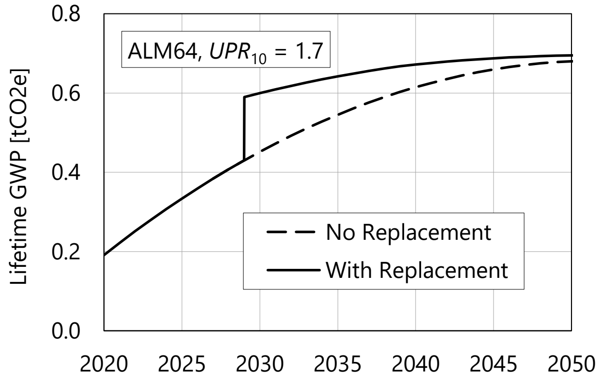


Figure 55. Lifetime GWP for two ALM64 scenarios for the use of grid-mix electricity.

In the first scenario, the ALM is installed in the respective infrastructure and remains there. In the second scenario, the original ALM is replaced, after 10 years, by a successor product with better energy efficiency according to Figure 52. Again, both curves are flattening over time due to improving emission factors, and the curve for the replacement scenario is flatter due to improved energy efficiency of the successor. However, the two curves never cross. This means that the ALM *should not be replaced* due to improvements in energy efficiency. It also proves the concept and threshold parameters related to UPR_{10}, since for grid-mix electricity, the ALM64 has $\boldsymbol{UPR_{10}}$ **= 1.7**, which indicated that it should not be replaced for reasons of improving energy efficiency.

In turn this means that the ALM should be (and is) designed for longevity, potential parts reuse and finally recycling.

In

Table *24*, relevant parameters for the ALM and TeraFlex are summarized.

Table 24. GWP parameters of the ALM64 and TeraFlex

	ALM64	TeraFlex
Power Consumption	10 W	1000 W
Use Mode	24/7 always on	
Typical Lifetime	8 years	
Production GWP	160 kgCO_2e	1.0 tCO_2e
UPR_{10} Grid Mix	1.7	27
UPR_{10} 100% Renewables	0.04	3.5

Flat-panel TV / Monitor

The next product example for proving the UPR_{10} concept is a flat-panel TV / monitor from the project partner Arçelik. This is an example of end-user ICT equipment, not infrastructure equipment. The production GWP of this device, according to its manufacturer, is 226 kg CO_2e. We started our analysis with an average power consumption of 6.1 W, which equals an average utilization of 2.5 hours per day. In that case, $\boldsymbol{UPR_{10}}$ **= 0.73** results, which clearly indicates that no replacement for reasons of energy-related emissions should be done. This is confirmed in the upper part of Figure 56.

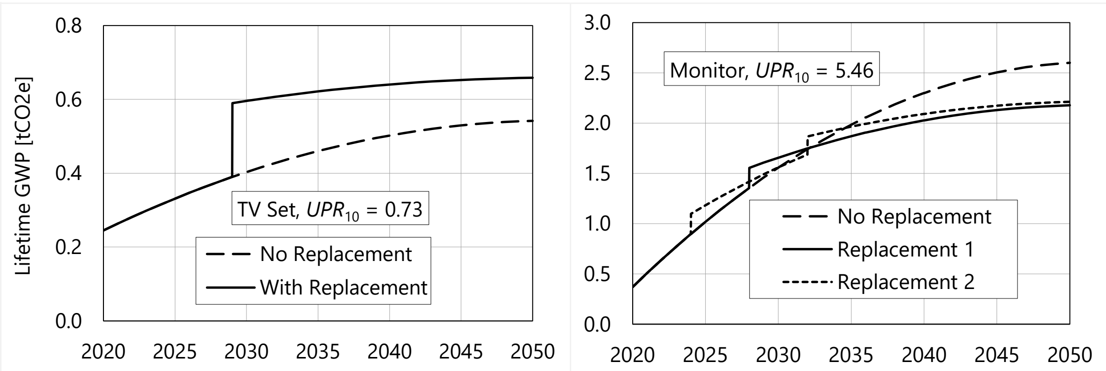


Figure 56. Lifetime GWP for flat-panel display. TV mode with 2.5 hour daily usage and UPR_{10} = 0.73 (left). Monitor mode with 18 hours daily usage and UPR_{10} = 5.46 (right). Average grid-mix electricity was considered.

The utilization of 2.5 hours per day is relatively small, it may be seen in many private households. However, very similar flat-panel technology is also used in commercial applications, displaying information over much longer daily periods. We changed the daily utilization up to a value of 18 hours per day. This changes average power consumption to almost 46 W, which increases $\boldsymbol{UPR_{10}}$ to 5.46.

This indicates that the device should now be replaced for GWP-optimization reasons, which is confirmed in the lower part of Figure 56. Here, we also investigated two replacement scenarios. As can be seen, the use phase is now so dominant that even a second replacement at least needs to be considered.

The increase of the daily utilization and its impact on GWP optimization is an example of the PSS discussion at the end of section 5.3.3.

Washing Machine

We extended our case studies on UPR_{10} to non-ICT end-user equipment, here, a typical washing machine, again from project partner Arçelik.

As duty cycle for this machine, a typical single medium-sized household usage was taken. With production GWP, according to the manufacturer, of 355 kg CO_2e and average lifetime power consumption for such a duty cycle of 16.9 W, $\boldsymbol{UPR_{10}}$ = 1.39 results. This indicates that the machine should not be replaced for reasons of energy efficiency improvements. This is confirmed in Figure 57, top part.

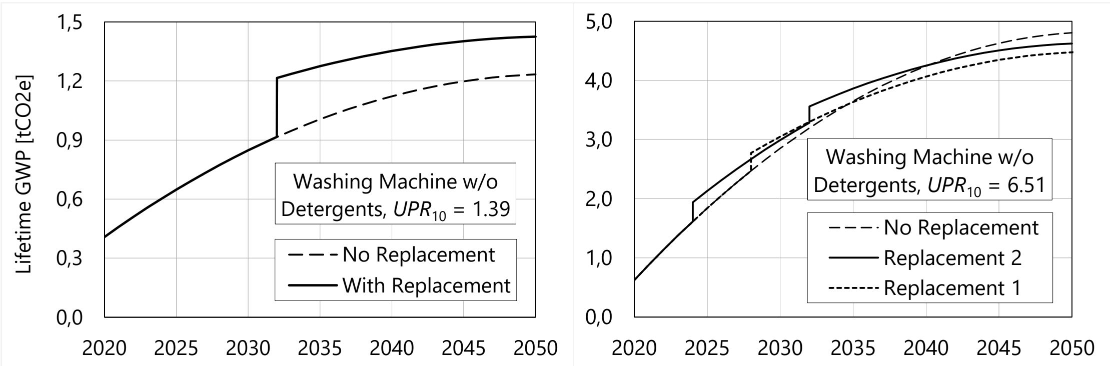


Figure 57. Lifetime GWP for a washing machine. Left: typical single-household utilization. Right: utilization increased by 5X, e.g., through sharing in multi-dwelling unit.

When increasing the utilization, e.g., by sharing in multi-dwelling units, by a factor of 5, $\boldsymbol{UPR_{10}}$ = 6.51 results. This increased UPR_{10} indicates that also for washing machines at (very) high utilization, replacement should be considered. This is confirmed in Figure 57, bottom part, where again two different scenarios for replacements are shown.

The increase of the daily utilization and its impact on GWP optimization further confirms the PSS discussion at the end of section 5.3.3.

Data-centre devices

In order to further verify the lifetime classification via UPR_{10}, we repeated the analysis for two devices from the data-centre space that were not associated with C-SERVEES.

The first device is a storage platform for up to 84 hard-disk drives. Its production GWP is 5.0 tCO_2e, target lifetime is 10 years, and average power consumption is 1690 W. From this, $\boldsymbol{UPR_{10}}$ = 9.12 for grid-mix electricity results. This clearly indicates that the storage platform should be replaced somewhere after the target lifetime for reasons of energy efficiency improvements. This is confirmed in Figure 58.

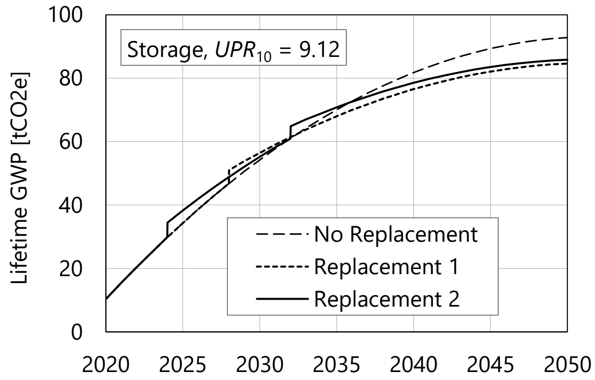


Figure 58. Lifetime GWP for a storage platform [41]. Two replacement scenarios indicate that the device should be replaced when more efficient successor units become available.

We used somewhat slower efficiency gain here. This considered the effect that efficiency gain of hard disk drives is assumed to be slower than the one of semiconductors as shown in Figure 52. Nonetheless, a clear indication of replacement for reasons of energy efficiency and related emissions can be derived.

For the storage platform being operated with 100% renewable energy, UPR_{10} = 1.18 results. This is very close to the threshold value for renewable energy, thus detailed analysis is advisable anyway. In this case, it would lead to a replacement recommendation that is far beyond the typical lifetime of a server in a data centre.

The second device is a high-performance server with maximum configuration of two 28-core CPUs and three GPUs [42]. Target lifetime of this device is four years, production GWP is 4.3 tCO_2e, and power consumption is 308 W, respectively. This translates to UPR_{10} = 1.94 for grid-mix electricity. The lower use-phase impact results from the average utilization (100% load: 10% of the time, 50% load: 35%, 10% load: 30%, idle mode: 25%). The small UPR_{10} indicates that the device should not be replaced and could hence be given longer lifetime. This is confirmed in Figure 59.

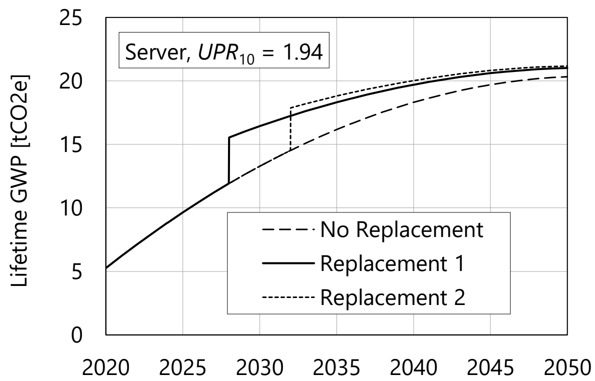


Figure 59. Lifetime GWP for a server.

Again, we used somewhat slower efficiency gain here, compared to the one of semiconductors as shown in Figure 52. This considers that the server can be equipped with hard disk drives and that CPU efficiency scaling has already slowed down significantly [43], [44].

Refrigerator

The final example of non-project-partner EEE is a Class A+ Electrolux ERB3105 refrigerator [45]. Average continuous power consumption of this device is 22.1 W. Production GWP is stated as 256 kgCO_2e, which leads to ***UPR***$_{10}$ = 2.33 for grid-mix electricity. This suggests that no replacement for energy-efficiency reasons is recommendable. This is confirmed in Figure 60.

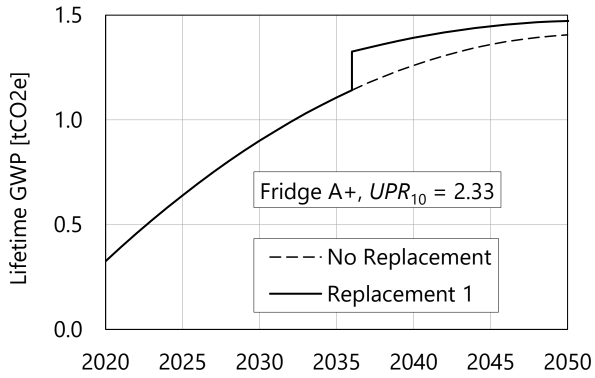


Figure 60. Lifetime emissions of Class A+ fridge [45]

In [46], an increase of the energy efficiency for refrigerators of 60% in 25 years is stated. This equals a yearly efficiency gain of ~10.5% in 2020, which then decreases year over year until it reaches almost zero in 2050. Like in the other EEE cases, it is assumed here that without any new, still unknown, disruptive new developments, the efficiency gain must come to a stop somewhere in the future because any physical processes (like cooling in this case) cannot undercut certain lower energy bounds determined by physics.

A Class A+ refrigerator obviously is efficient enough not having to be replaced for efficiency reasons. This is in line with [45]. However, this is not true for a scenario where the Class-A+ refrigerator replaces an *old* device with high power consumption. Such a scenario is shown in Figure 61. Here, on old device with power consumption of 35 W is replaced by the Class-A+ refrigerator. This increases ***UPR***$_{10}$ to 2.69 for grid-mix electricity for the old device, indicating that the old device should be replaced.

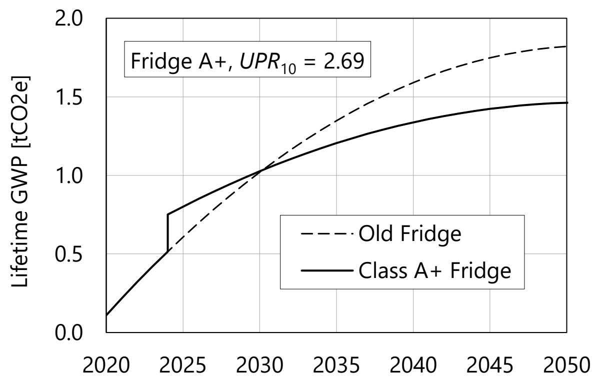


Figure 61. Lifetime emissions of Class A+ fridge replacing old fridge

It can clearly be seen that old devices should be replaced, which again confirms usability of *UPR*$_{10}$ and the threshold values provided earlier!

7.7.5. Discussion

A product classification figure UPR_{10} has been defined that allows simple differentiation between EEE products that require replacement by more efficient successors after certain time in order to minimize lifetime emissions and those where this is not the case. This is confirmed by several case studies described earlier.

UPR_{10} relies on correct assumptions regarding relevant parameters it uses. This primarily relates to the restriction to the GWP, the electricity emission factors and the improvement of energy efficiency.

The restriction to GWP is valid as long as the GWP and ARD results in LCA behave similarly. For ICT infrastructure equipment, we never found a strong deviation from that requirement in all LCAs that we conducted across our complete portfolio. For completely different equipment classes, it should be checked that GWP and ARD show similar LCA behaviour. This check should be repeated after certain periods, e.g., 10 years. This considers that over the next decades, GWP should get less relevant on the way toward carbon neutrality, whereas resource depletion may become more relevant. Beyond 2050, GWP may then have to be replaced or complemented in the UPR_{10} calculation by ARD.

For the UPR_{10} calculation, we used extrapolated grid-mix and 100%-renewables emission factors. The extrapolated EF are in line with the B2DS scenario of the IEA [30] and the RCP2.6 scenario of the IPCC [31], that is, relevant climate-change scenarios that support less than 2°C global warming compared to the pre-industrial state. For renewable energy, we used a non-zero EF. This is in line with the IPCC [32]. It also considers the fact that producing renewable energy is never carbon-neutral unless compensation techniques or techniques like CCS (carbon capture and storage) are used [33].

Regarding the development of the energy efficiency of electronic products, we used data from the last two decades and extrapolated it considering fundamental physical limits (the SNL limit, [38], [39]). The resulting extrapolation is regarded correct for many classes of ICT equipment and similar electronics. For other equipment classes, similar extrapolation should be conducted.

Given correct input parameters, UPR_{10} clearly indicated if products should be replaced by more efficient successors. Subsequent lifetime-GWP calculation can then identify when the replacement should take place, i.e., product lifetime optimized with regard to GWP can be derived.

Only when UPR_{10} falls into the transition range between the replacement options ($UPR_{10} \approx 2.5$ for average grid-mix emission factors, $UPR_{10} \approx 1$ for RE), a more detailed analysis of the respective product is necessary.

In those cases where substantive lifetime extension is no option, energy efficiency, as the relevant environmental parameter, should be as good as possible. For certain product classes, standards for energy-efficiency ratings exist which can then be applied for further assessment. For ICT equipment, Telecommunication Equipment Energy-efficiency Ratings (TEER) exist, e.g., [40].

Usage of UPR_{10} is relatively simple, e.g., compared to conducting full lifecycle assessments since only the production-phase GWP and use-phase GWP (i.e., the power-consumption specification plus emission factor and use mode) need to be known.

The concept of UPR_{10} is also regarded novel. It resolves the ambiguity that the exclusive consideration of LCA even in cases of clear use-phase dominance still leaves.

UPR_{10} can have relevance for future regulations. This is particularly true in case such documents regulate quota for reuse, lifetime extension or similar concepts for electronic equipment. In order to prevent environmental harm, certain product classes must be exempted from such regulations. With the help of UPR_{10}, these product classes can be clearly identified.

Since early 2023, UPR_{10} is also being discussed in ITU-T (Study Group 5, Question 7) for future standardization.

7.7.6. Conclusion

Circular economy aims at reducing raw-material consumption and waste generation through the concept of longevity. However, lifetime may be limited, for certain electronic products, by use-phase energy consumption and the efficiency gain that is to be expected by successor products. This effect is time-dependent since both, the efficiency gain and the electricity emission factors that are to be applied decrease over time.

For the related product classification, the use-phase-over-production-phase GWP ratio UPR_{10} has been defined. For certain EEE products, it clearly indicates that replacement for reasons of increased efficiency and reduced emissions is advisable. This can even be true for the case of using renewable energy.

For such products, continued work toward better energy efficiency is required. The resulting lifetime GWP optimization may contradict generic CE requirements for longevity and the respective eco-design efforts. However, in particular as long as average emission factors are clearly above the ones for renewable energy, the product discrimination enabled by UPR_{10} should be applied in order to avoid net-negative CE rebound effects on global warming, as required in the EU Taxonomy Regulation's Do-No-Significant-Harm principle. This is particularly true for potential new regulations. These must apply similar electronics products discrimination. Products with very strong use-phase dominance, like TeraFlex, must be allowed to be taken out of service for reasons of energy-related emissions, even if they could be re-used for extended periods from the viewpoint of functionality. Of course this means that at their end of life, these products have to be recycled to the best-possible extent.

8. References

[1] L. Kjær et al., “Product/Service-Systems for a Circular Economy: The Route to Decoupling Economic Growth from Resource Consumption?” J. Indust. Ecology, Vol. 23, No. 1, 2018, pp. 22-25. DOI: 10.1111/jiec.12747.

[2] A. Tukker, “Eight Types of Product-Service Systems: Eight Ways to Sustainability? Experiences from SusProNet,” Bus. Strat. Env., Vol. 13, 246–260, 2004, DOI: 10.1002/bse.414

[3] International Financial Reporting Standard, issued standards, IFRS 16 Leases, available online: https://www.ifrs.org/issued-standards/list-of-standards/ifrs-16-leases/

[4] https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en

[5] K. Grobe (2018) Wavelength Division Multiplexing. In: Encyclopedia of Modern Optics 2nd edition, vol. 1.

[6] K.Grobe, “Simplified LCA-based optimum EEE lifetime analysis,” CARE Innovation 2023, Vienna, May 2023

[7] K. Grobe, “Improved Sustainability in Wavelength-Division Multiplexing Network Elements,” Electronics Goes Green 2016+, Berlin, September 2016

[8] K. Grobe, “Environmental Challenges on Photonics Equipment,” 18. ITG-Fachtagung Photonische Netze, Leipzig, May 2017, https://ieeexplore.ieee.org/document/7988096

[9] S. Verbrugge et al., “Modeling operational expenditures for telecom operators,” in Proc. Conference on Optical Network Design and Modeling (ONDM), pp. 455-466, February 2005, DOI: 10.1109/ONDM.2005.1427028

[10] Paul Vanegasa, Jef R. Peetersa, Dirk Cattryssea, Paolo Tecchioc, Fulvio Ardentec, Fabrice Mathieuxc, Wim Dewulfa, Joost R. Dufloua, “Ease of disassembly of products to support circular economy strategies,” Resources, Conservation & Recycling 135 (2018) 323–334, doi.org/10.1016/j.resconrec.2017.06.022

[11] Siru Sihvonen, Jouni Partanen, “Eco-design practices with a focus on quantitative environmental targets: An exploratory content analysis within ICT sector,” Journal of Cleaner Production 143 (2017) 769-783, doi.org/10.1016/j.jclepro.2016.12.047

[12] A.S.G. Andrae, M. Xia, J. Zhang and X. Tang, “Practical Eco-Design and Eco-Innovation of Consumer Electronics—the Case of Mobile Phones,” Challenges 2016, 7, 3; doi:10.3390/challe7010003

[13] A.R. Balkenende, C.A. Bakker, “Developments and Challenges in Design for Sustainability of Electronics,” Transdisciplinary Lifecycle Analysis of Systems, doi:10.3233/978-1-61499-544-9-3.

[14] K. Grobe, “Energy Efficiency Limits to ICT Equipment Lifetime,“ 23. VDE ITG Workshop Photonische Netze, Leipzig, Germany, May 2022.

[15] K. Grobe, D. Stanaityte, “More Lessons Learnt from WDM LCA,” CARE Innovation 2018, Vienna, Nov. 2018.

[16] Taxonomy: Final report of the Technical Expert Group on Sustainable Finance, Technical Report, EU Expert Group in Sustainable Finance, March 2020

[17] Recommendation ITU-T L.1410: "Methodology for environmental life cycle assessments of information and communication technology goods, networks and services". www.itu.int/rec/T-REC-L.1410-201412-I.

[18] ETSI ES 203 199 V1.3.1 (2015-02): Environmental Engineering (EE); Methodology for environmental Life Cycle Assessment (LCA) of Information and Communication Technology (ICT) goods, networks and services

[19] ISO 14040 (2006): "Environmental management – Life cycle assessment – Principles and framework".

[20] ISO 14044 (2006): "Environmental management – Life cycle assessment – Requirements and guidelines".
[21] International Telecommunication Union. L.Sup5: "Life-cycle management of ICT goods". www.itu.int/rec/T-REC-L.Sup5-201412-I.
[22] ETSI TR 103 476 (V1.1.1): "Environmental Engineering (EE); Circular Economy (CE) in Information and Communication Technology (ICT); Definition of approaches, concepts and classification figures".
[23] International Telecommunication Union. L.Sup28: "Circular economy in information and communication technology; definition of approaches, concepts and classification figures". www.itu.int/rec/T-REC-L.Sup28-201610-I .
[24] ECMA-341 (4th Edition): Environmental Design Considerations for ICT & CE Products, Dec. 2010
[25] Ab Stevels, "Adventures in EcoDesign of Electronic Products: 1993-2007," ISBN/EAN: 978-90-5155-039-9
[26] Ellen MacArthur Foundation, The butterfly diagram: visualising the circular economy (ellenmacarthurfoundation.org)
[27] The Circularity Gap Report 2021, online: www.circularity-gap.world/2021#downloads
[28] Cisco Corporate Social Responsibility Reports 2018, CSR-Report-Our-Story-2018 (cisco.com).
[29] Cisco Corporate Social Responsibility Reports 2019, CSR Report 2019 (cisco.com).
[30] OECD/IEA, "Energy Technology Perspectives 2017," ISSN: 2079-2603, ISBN: 978-92-64-27597-3, 2017
[31] IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.
[32] IPCC, "Energy Systems. In: Climate Change 2014: Mitigation of Climate Change," 2014.
[33] M. Bui et al., "Carbon capture and storage (CCS): the way forward," Energy & Environmental Science. 11 (5): 1062-1176, 2018. doi:10.1039/C7EE02342A
[34] K. Grobe and S. Jansen, "Limits to exponential Internet Growth," EGG2020+, September 2020
[35] L. Kjær et al., "Product/Service-Systems for a Circular Economy: The Route to Decoupling Economic Growth from Resource Consumption?" J. Indust. Ecology, Vol. 23, No. 1, 2018, pp. 22-25. DOI: 10.1111/jiec.12747.
[36] K. Grobe (2018) Wavelength Division Multiplexing. In: Guenther, R. and Steel, D. (eds.), Encyclopedia of Modern Optics 2nd edition, vol. 1, pp. 255–290. Oxford: Elsevier.
[37] Viavi Reference Guide to Fiber Optic Testing, Volume 1, comms.viavisolutions.com/Fiber-Optics-Test-Guide-Volume-1-vi96906
[38] Victor V. Zhirnov et al., "Limits to Binary Logic Switch Scaling—A Gedanken Model," Invited Paper, Proc. IEEE, Vol. 91, No. 11, pp. 1934-1939, Nov. 2003.
[39] Victor V. Zhirnov et al., "Minimum Energy of Computing, Fundamental Considerations," in: ICT – Energy – Concepts Towards Zero – Power Information and Communication Technology, dx.doi.org/10.5772/57346.
[40] ICT Ecology Guideline Council, "Ecology Guideline For the ICT Industry," 2021, www.tca.or.jp/information/pdf/ecoguideline/guideline_eng_9.pdf
[41] OneStor SP2584 Extensible Storage Platform (ESP) Product Life Cycle Assessment (LCA), Seagate data sheet. Available online: https://www.seagate.com/files/www-content/global-citizenship/en-us/docs/lca-summary-onestor-sp-2584s-20150309.pdf
[42] Life Cycle Assessment of Dell PowerEdge R740, Report produced June, 2019. Available online: https://corporate.delltechnologies.com/content/dam/digitalassets/active/en/unauth/data-sheets/products/servers/lca_poweredge_r740.pdf

[43] J.L. Hennessy and D.A. Patterson, “A New Golden Age for Computer Architecture,” Contributed Article, Communications of the ACM, Vol. 62 No. 2, Feb. 2019, pp.48-60

[44] K. Rupp, “42 Years of Microprocessor Trend Data,” Feb. 2018, available online: https://www.karlrupp.net/2018/02/42-years-of-microprocessor-trend-data/.

[45] S.A.F.E. Schweizerische Agentur für Energieeffizienz, Bundesamt für Energie (BFE), Ökobilanz Kombi-Kühlschrank Electrolux ERB3105, online: https://treeze.ch/fileadmin/user_upload/downloads/Publications/Case_Studies/Miscellaneous/steiner-2005-Kuehlschrank_Graue_Energie_1.0.pdf

[46] Energieinstitut Vorarlberg, Ökologisch optimale Lebensdauer von Weißware, online: https://www.energieautonomie-vorarlberg.at/zoolu-website/media/document/1216/LCA+Wei%C3%9Fware+Projektbericht_2016_12_20

9. Main conclusions and recommendations

The C-SERVEES demonstrations have shown how new CEBMs can be implemented in the Electric and Electronic sector, and how ICT tools can contribute to support this implementation and promote sustainable production and consumption patterns.

Final conclusions and recommendations derived from this work are summarised below:

- → There is a need to analyse EEE regarding their CE characteristics and limitations before making recommendations for their reuse/replacement/recycling. Generic, across-the-board recommendations are not desirable.
- → Results from in depth PSS analysis of ICT equipment show that not all PSS make sense. Material recovery yield at end-of-life is a determining factor when choosing a PSS. If this yield is limited through, for example, obsolescence, the PSS do not differ too much. If meaningful services can be offered, e.g. operating the equipment, leasing does seem to make sense.
- → ICT solutions offer the possibility to provide useful information via QR codes, for example the percentage of recycled material used in the product. This can help communicate a company's sustainability actions to their clients.
- → ICT solutions also enhance the repair and refurbishment operations, increasing the recovery of products. A QR code can be used on specific components with information about the material composition, which is useful at the repair/dismantling/recycling stage.
- → In the business-as-usual scenario, recyclers do not receive WEEE in good condition. This reduces the potential to recover spare parts. Therefore, from a circularity perspective, it makes more sense for repair companies to have special operations to work on the recovery of components before the product becomes waste.
- → A digital dismantling manual would help recyclers be more efficient while dismantling printers and recovering parts to be sold to OEMs; this was proved by the demonstration to be cost efficient. Assuming the industry moves forward with QR code usage, dismantling instructions could be linked to QR codes on the product.
- → Reverse logistics is shown as a major challenge today: how to locate used products and bring them back to a refurbishment plant at a competitive cost, given that the client expects the refurbished product's price to be significantly lower than a brand-new product is key.

The following table presents an overview of the main exploitable results achieved by the four large scale demonstrators:

Table 25. Main aspects explored in the demonstrations, classified according to the potential for future exploitation

Washing machine demo	Printer and toner cartridges demo	ALM system demo	TV set demo
Eco-leasing model for B2B WMs	Printer parts recovery and reuse with ICT tool support for data sharing	New optical sensors for the ALM system	Eco-leasing model for B2B TVs
Business line for refurbishment of used WMs outside Turkey	Use of secondary plastic materials from end-of-life printers and toner cartridges	Lifetime optimisation for ICT products: UPR_{10} ratio	Business line for refurbishment of used TV outside Turkey
3D printing of spare parts	3D printing of non-functional parts	Generalisation of UPR_{10} to EEE + PSS optimisation: DSS for EEE products	3D printing of spare parts
Use of ICT tools to certify recycled content	Levers for refurbishment operations: cosmetic issues acceptance		Use of ICT tools to certify recycled content
Use of ICT tools to support EoL activities	Use of ICT tools to support EoL activities	Disassembly guidelines for ICT products	Use of ICT tools to support EoL activities

++ Good results | + Potentially good | +/- Unconclusive | - Negative results

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