Ref. Ares(2020)6555340 - 10/11/2020

Activating Circular Services in the Electric and Electronic Sector

GA NUMBER: 776714

Deliverable 4.2. Demonstration of design & production phase for target products

Acronym: **C-SERVEES**
Project title: **Activating Circular Services in the Electric and Electronic Sector**
Contract Nº: **776714**
Start date: **1st May 2018**
Duration: **48 months**

Deliverable number	D4.2
Deliverable title	Demonstration of design & production phase for target products
Submission due date	M30 – October 2020
Actual submission date	10/11/2020
Work Package	WP4
WP Lead Beneficiary	GAIKER
Dissemination Level	Public
Version	00
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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776714

DOCUMENT CONTROL PAGE

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Version history

#	Reviewer	Comments
00	GAIKER	Document revised by WP leader and TMC

1. Executive Summary

The purpose of this deliverable is to describe the work performed to demonstrate C-SERVEES eco-innovative solutions, previously identified and selected in the exploration of the product-specific CEBMs in WP2, as well as the activities carried out to improve circularity in the design and production phase 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 scope of this document comprises all activities developed within subtask 4.1.1, subtask 4.2.1, subtask 4.3.1 and subtask 4.4.1 of WP4: all four subtasks belonging to the design and production phase for each demonstration.

The first demonstrator is a new version of a recent model of washing machine from Arçelik, where the purpose was to test the potential to include increased content of recycled plastic material in substitution of virgin plastic material.

The second demonstrator is a selected group of high-end A3 printers from Lexmark and several types of supplies (toner cartridges). The aim of this demonstrator is to analyse the potential to introduce design for recycling and design for remanufacture in future models through the feedback provided by recyclers, as well as exploring a potential business model based on the refurbishment of end-of-life devices.

The third demonstrator is a new fibre-optic sensor developed for ADVA's ALM system, a telecommunications equipment whose function is to monitor the stability of the optical fibre signal. The purpose of this demonstrator is to substitute conventional fire alarm systems based on electricity signals with this new fiber-optic sensor offering longer lifetime, increased reliability and sustainable design.

The fourth demonstrator is a new version of a modern TV set from Arçelik where the aim was to test the potential to include increased content of recycled plastic materials substituting virgin plastics.

During the period M7-M21 the definition of the new circular economy business models (CEBMs) was carried out as part of WP2, culminating in four comprehensive CEBMs, one for each of the demonstrator products, including all short, medium and long-term actions to be developed in order to achieve the CE business strategy of each company for the selected product. For the C-SERVEES demonstration purposes, only the short-term actions have been selected since the scope of the project does not permit to test medium and long-term solutions. The list of validated short-term actions for each product-specific CEBM was redistributed and categorised into a shorter list of demonstration activities including the relevant ICT functionalities to be implemented and tested. From these, only the ones belonging to the design and production phase have been included in the present report, understanding that the design process for any product is iterative, with many cycles of prototyping, testing, analysing and refining and this is the first prototype to be tested in terms of circularity improvements for the C-SERVEES demonstrators.

The developed demonstrators and proposed pilot actions and demonstration plans in this document will be considered as preliminary and they may be subject to further revision during the course of the project. Additional testing and refinements may be carried out along the demonstration period until M45 and they will be described and provided in deliverable D4.5 (January 2022).

Content

2. Acronyms and abbreviations

ALM	Advanced Link Monitoring
BAU	Business as usual
B2B	Business to Business
CEBM	Circular Economy Business Model
CE	Circular Economy
EEE	Electric and Electronic Equipment
E&E	Electrical and Electronic
MPS	Managed Print Services
OEM	Original Equimpment Manufacturer
OTDR	Optical time-domain reflectometry
PCR	Post-consumer recycled
PSS	Product Service Systems
REF-CIRCMODE	Circular Economy Business Reference Model
RFID	Radio Frecuency Identification
WEEE	Waste Electrical and Electronic Equipment
WP	Work Package

3. Introduction

This document reports the outcomes of the design and production phase for the four large demonstrations run in the C-SERVEES project. The demonstrations consist of the implementation and testing of the four new product-specific CEBMs developed within the C-SERVEES project, based on a generic reference CEBM for the E&E sector, the REF-CIRCMODE. The aim of the demonstrations is to validate the four CEBMs integrating four basic pillars: eco-design, eco-leasing, improved WEEE management, and ICT services.

This is the second deliverable produced in Work Package 4 of the C-SERVEES project. The first deliverable included an exploration of CEBMs currently applied to the E&E sector, in particular to the four types of EEE selected in the project: washing machines, TV sets, printers and toner cartridges and telecommunication equipment. It also described the four demonstrators, their materials flow charts and the range of key performance indicators that could be included to evaluate the progress of each demonstration. The deliverable ended with an overview of the C-SERVEES demonstrations and a development plan for the demonstrative activities to be carried out.

This second deliverable reports the results obtained for the first set of eco-innovation actions, related to the first stage in the life cycle of the demonstrators: the design and production phase. The specific activities to be carried out for each product were selected during the validation process of the product specific CIRCMODEs (Deliverables D2.2, D2.3, D2.4 and D2.5) in accordance with the manufacturer's priorities and needs.

For the Washing machine demonstration, this stage consisted in the eco-design of a high-end model of washing machine focused on introducing higher amounts of recycled materials. One hundred units were produced by Arçelik, which will be used for the second and third stages of the demonstration.

For the Printer and toner cartridges demonstration, the design and production stage was focused on the analysis of selected high-end Lexmark printers and toner cartridges in order to determine potential eco-design measures to be implemented in future models and preliminary data for the CEBM feasibility. This work was based on the results of the exercises of recycling and dismantling carried out by C-SERVEES partners (Indumetal and Greentronics). Three different high-end printer models and 3 different cartridge models were selected at this stage.

For the ALM demonstration, the fist stage of the demonstration was focused on the development of new eco-designed fire and door sensors (passive units) based on optical fiber technology as part of the current ALM system (network integrity monitorization), aimed to provide long-lasting and efficient substitution for the electric sensors currently used. The number of demonstrator units was initially estimated in 200 ALM units, however it will probable be augmented to 500 sensors (passive units) and around 10 active units in order to be used in the demonstration second stage. Also, the analysis of the ALM active unit was carried out from a dismantling and recycling perspective in order to provide inputs for future releases.

For the TV set demonstration, this first stage has focused on the eco-design of a high-end model of TV set, aiming to introduce higher amounts of recycled materials. One hundred units were produced by Arçelik, which will be used for the second and third stages of the demonstration.

The number of units of each target product proposed for the demonstrations were selected by the respective industrial partners (EEE manufacturers) and stated in Annex I (DoA) of the Grant Agreement, according to the needs derived from the demonstration activities. For the washing machine and TV set demonstrations, one hundred units were considered enough to analyse the production phase from a technical and economical perspective, as well as guaranteeing a sufficient number of units to run the second and third phases of the demonstration (renting/leasing at selected sites in Turkey and Spain, end-user experience in living labs and end-of-life analysis at the recyclers' facilities). For the printer demonstration, the analysis carried out in this first stage was not oriented to the development of new printer models (not feasible in the time frame of the project), thus the number of demonstrators has been decided based on operational parameters and the expected outcome. For this reason, a reduced number of printers and toner cartridges has been used in this first stage, from the 200 printer units and 1000 toner cartridges that were foreseen. For the ALM demo, the focus was on the development of the new passive units (sensors) which will be used in the second stage (distribution and use phase), thus the number will depend on the needs of the demonstration facility where they will be installed (estimated around 500 passive units and 10 active units, as stated above). The analysis of the active units from the eco-design perspective only required of two devices, one ALM-16 and one ALM-64.

4. Washing machine demonstrator

The activities conducted in the design and production phase were derived from the WASH-CIRCMODE short-term actions validated in WP2. The short-term actions were developed into demostration actions to be implementated in WP4. The table below presents the WASH-CIRCMODE canvas sub-components integrating short-term CE actions corresponding to the design and production phase, as presented in D2.2.

Table 1. Validated short-term WASH-CIRCMODE Canvas Key Circular sub-components and their associated Circular Economy Actions relevant for the design and production phase.

WASH-CIRCMODE Canvas Sub-Component	WASH-CIRCMODE validated short-term Circular Economy Actions
WASH_C1.1 Diversify circular activities	WASH_A1.1.1 Increase recycled plastic content in WM parts
WASH_C1.2 Embrace eco-design to ensure products circularity across life-cycle stages	WASH_A1.2.1 Improve durability and reparability
WASH_C1.3 Adopt circular strategies in the production process	WASH_A1.3.1 Enhance the integration of circular strategies into the production process
WASH_C2.3 Introduce and/or expand the use of ICT to foster circular economy	WASH_A2.3.2 Use ICT to enhance washing machines' circularity during the production and end-of-life phases

The following sections provide an overview of the washing machine demonstrator, the product description and related design and production activities. It also provides a description of the ICT functionalities developed to be implemented and tested in the design and production phase of the washing machine demonstration, as well as the description of validation tests performed for the demonstrator products.

4.1. Demonstrator description

Arçelik Overview

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 consumer durables and consumer electronics 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 centers. 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 the market leader with Arçelik brand in Turkey, Arctic brand in Romania, Defy in South Africa and

Dawlance in Pakistan. In 2019, Arçelik's consolidated revenue reached TRY 31.942 million. Arçelik is a publicly traded company and 25% of the shares are free float.

Arçelik operates with the global Beko and Grundig brands as well the remaining 10 local brands that makes up its portfolio. Beko and Grundig are both Arçelik's responsible brands, each with a mission. Beko has partnerships with Unicef and Barcelona football team on promoting healthy living among children and adults. Grundig has a purpose to create awareness on food waste.

Arçelik is a subsidiary of Koc Holding in Turkey. Koc Holding is Turkey's conglomerate, making up 9% of Turkey's total exports, 9% of Turkey's R&D expenditure, consolidated revenue equal to 8% of Turkey's GDP. Koç Holding is a Fortune Global 500 Company.

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.

Recycled PET Tub:

The first in its industry. Recycled PET bottles are used together with PP in washing machine drums. From 2017 when the project started until the end of 2019, more than 30 million PET bottles have been recycled.

The innovation has been extended to other Koc Group Companies. Recycled PET bottles are now used in air conditioners in Arçelik LG (Arçelik-LG joint venture that produces air conditioners in Turkey) as well as in TOFAŞ (Koc Holding car company).

Recycled PET bottles are also used in Arçelik's demo washing machines in the C-SERVEES project.

Recycled Waste Fishnets and Textiles in Oven Parts:

Upcycling and using waste fishnets and waste textiles in oven parts, Arçelik recycled more than 7 tons of waste fishnets and textiles and used these in more than 200.000 oven parts.

Bio-Fridge:

Arçelik has created a unique bio fridge combines bio plastics and bio PU insulation. The bio PU is made of soy and the bio plastics are made from corn. The fridge has eggholders from waste eggshells. This project is expected to be in serial production as of December 2020.

Microfiber Filter:

Arçelik is working on a washing machine and dryer with a filtration system to filter microplastics. The filters have capacity to filter more than 90% of microfibers that are washed away from synthetic clothes. These microplastics get into the systems of sea creates and thus the food chain. The micro plastics are everywhere from the air we breathe to the water we use. The product is expected to be in serial production as of Q2 2021.

Arçelik WEEE Recycling Plants

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, we saved a total of 299 GWh of energy since 2014 until the end of 2019, the equivalent amount of energy almost 36 million households would use in one day. Through recycling, we 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.

Demo Product description

In this section, the Grundig Washing Machine demonstration will be described.

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

Brushless Motor Technology

Our washing machine range features brushless motor technology. Brushless motor offers the following advantages:

- Extended motor life
- Increased mechanical action ratio
- Better torque and speed characteristics
- Uniquely patented unbalanced load detection

Raw Material Information

- Tub: Leo-PET (include 10% recycled PET bottle in the formula)
- Detergent box group (expect 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: Aluminum
- Drum: Stainless Steel

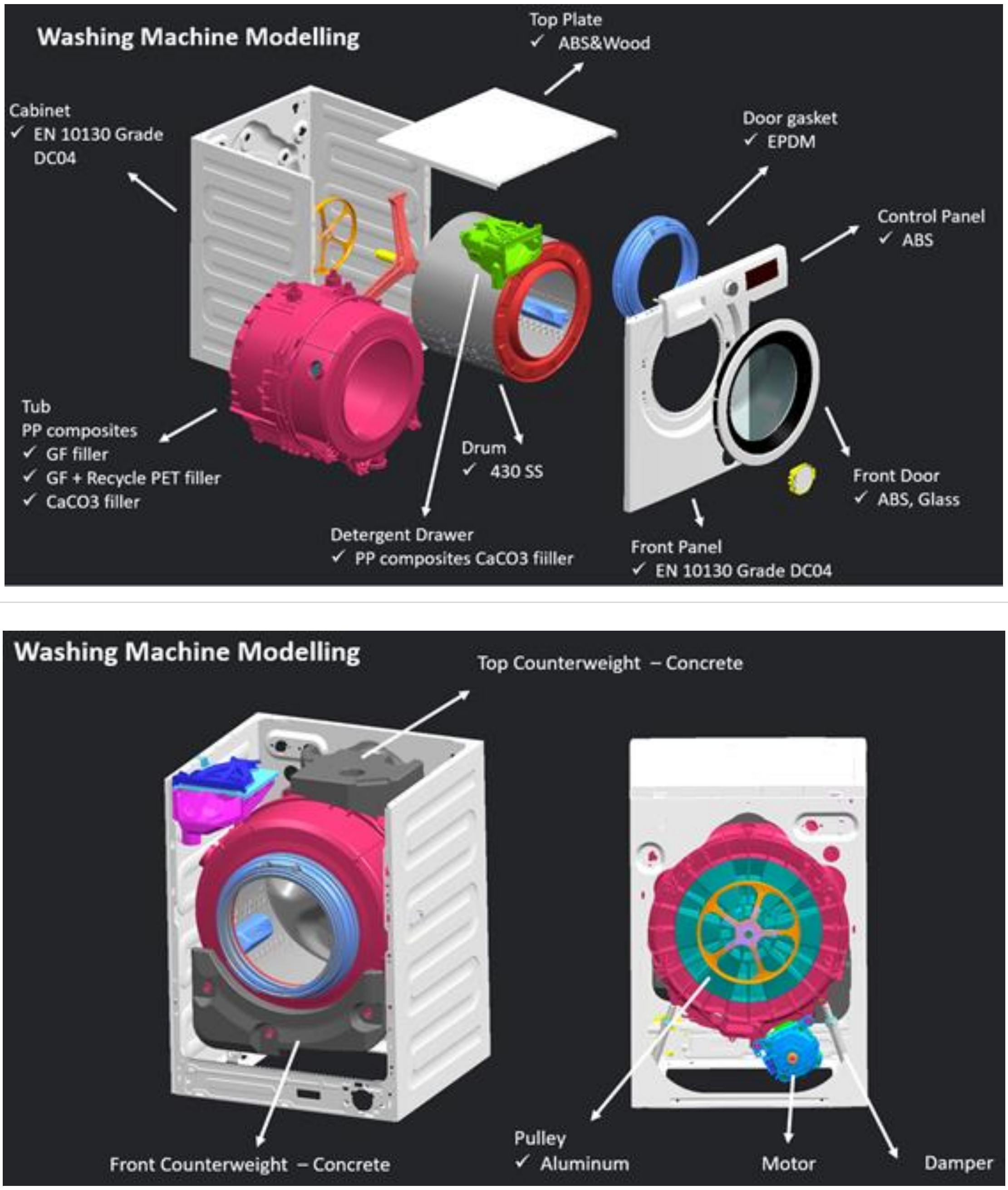


Figure 1. Washing machine general parts and components

Recycled Content Details

We increased our washing machine recycled content up to 10% for C-SERVEES Project (without accounting for scrap content). Reycled PET formula (which is explained 4.2.1) was used for the first time in a 1200 rpm washing machine tub's raw material, for the C-SERVEES demonstrator.

Table 2. % recycled content information for reference and C-SERVEES demo product

Recycled Material Type	Reference product with scrap	Demo product with scrap	Reference product w/o scrap	Demo product w/o scrap
Recycled content_plastic	7,68	7,95	7,68	7,95
Recycled content_metal	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%

Goals of the Washing Machine Demonstrator

The main objective was to implement eco-design in the washing machine by increasing the recycled plastic content in target components and decreasing the use of raw plastic materials (as per agreed in action 'WASH_A1.1.1 Increase recycled plastic content in WM parts'). Additionally, tracing of recycled content would be enabled via the ICT tools developed in the project (ICT-based certification), as per the agreed in action 'WASH_A2.3.2 Use ICT to enhance washing machines' circularity during the production and end-of-life phases'.

The percentage of recycled plastic in different parts will be traced by means of QR codes. These QR codes will be integrated in the product so that consumers can access information via app about the sustainability and circularity of the demonstrator.

Specific objectives of the design and production phase are:

- Target 1: using 10% recycled PET in tub
- Target 2: using 63,5% recycled PP (eco-PP) in detergent box group (except drawer) and inner cover
- Target 3: using blowing agent to decrease the amount of PP used in detergent box group (except drawer) and inner cover
- Target 4: new panel design

4.2. Eco-Design of the Washing Machine

High amounts of plastic raw materials are used in Arçelik product groups. If alternative recycled plastics are used into these plastic raw materials, there is a high potential for cost saving. At the same time, strong environmental savings can be achieved by using recycled raw materials instead of using virgin materials that will result in ensuring less use of petroleum resources and utilising waste in a value-added manner. Different types of polymers are recycled from different waste sources, and also material studies are required to achieve final product specifications.

In this project, environmentally friendly products that reduce carbon dioxide emissions will be created with the help of processing and recycling plastic waste generated in different industries.

4.2.1. Recycled PET TUB

The tub is the dynamic part in a washing machine and requires high mechanical and temperature resistance.

34% glass fiber reinforced PP composites are preferred in high speed washing machine tubs due to their high mechanical properties. Recycled PET Tub formula showed that similar mechanical properties can be achieved by removing glass fiber from the composite and adding PET flakes.

The flakes obtained from PET bottle waste are thinned and extended at optimum temperature during the material preparation process and turned into micro-fibrils. These fibers can increase the mechanical properties of the composite thanks to their high length/width ratio. PET micro-fibers support the raw material of the tub with reinforcing fibers in an innovative way, creating a high-performance material for the washing machine tub.

PET flakes, whose cost is much lower than glass fiber, elongate during extrusion and form a fiber form. These particles with high length/width ratio provide high mechanical properties to the composite. Thus, an improvement can be achieved for the tub raw material without any significant change in mechanical properties.

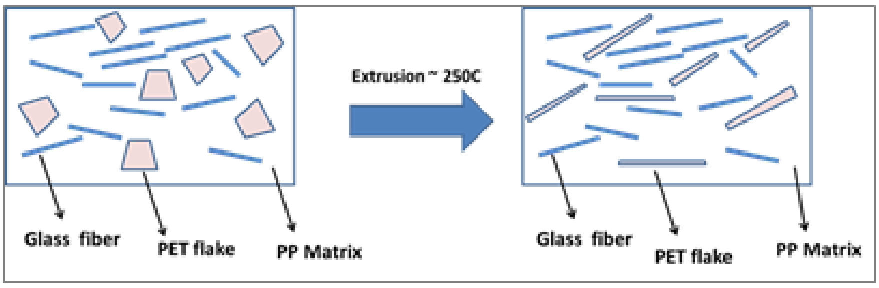


Figure 2. Extrusion process description

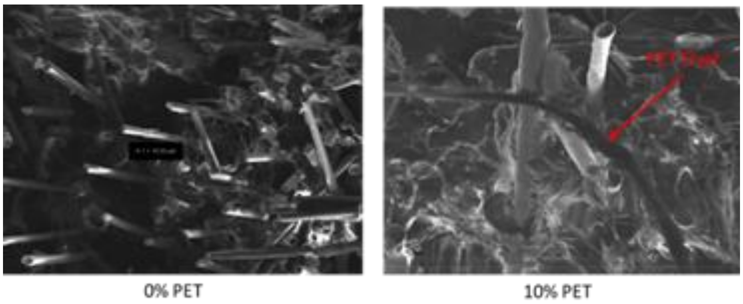


Figure 3. Image of using PET fiber instead of glass fiber under microscope

Formulation studies were carried out in Central R&D – Material Laboratory and the interactions of plastic production process parameters were analyzed. Aging and approval tests were carried out and mass production approval was obtained for the raw material. All certificates were obtained indicating that there are no undesirable chemicals in the raw material (Reach-RoHS-PAH certificates). During the project process, the products of many PET recycling companies were evaluated and the right partners for mass production were determined.

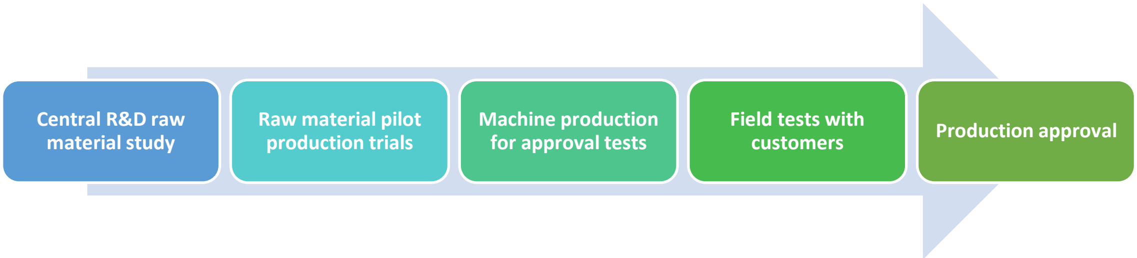


Figure 4. Diagram: Steps of Recycle PET Tub Study

4.2.2. Eco-PP

ECO PP compounds were developed from recycled PP sources and material approval tests were carried out.

Figure 5. Recycled PP sources

Formulation studies were carried out in Central R&D – Material Laboratory and the interactions of plastic production process parameters were analyzed. Aging and approval tests were carried out and mass production approval was obtained for the raw material. All certificates were obtained indicating that there are no undesirable chemicals in the raw material (Reach-RoHS-PAH certificates).

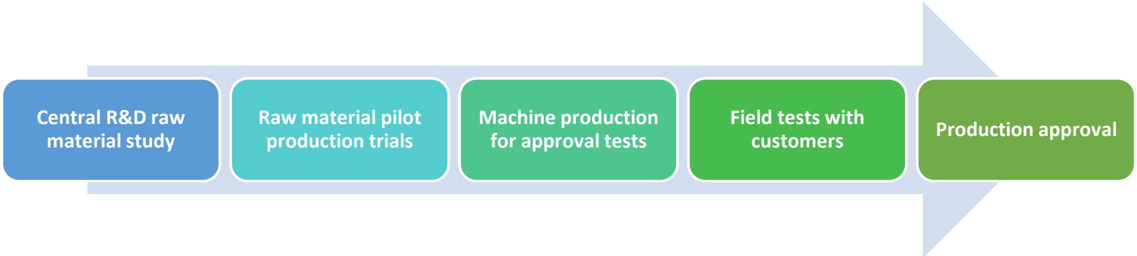


Figure 6. Diagram: Steps of Eco-PP Study

4.2.3. Blowing Agent Usage in Plastic Parts

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 the innovative foaming method called blowing agent, it is possible to develop eco-friendly parts and products by reducing plastic raw materials and energy consumption.

With the help of bubble structures, the density of the material has been reduced and results in using less raw material. During the process, with the effect of foaming, the hold down pressure and hold down duration of the injection moulding process are reduced. Thus, reducing the cycle times supplies energy savings. Environmentally friendly foamed parts are produced without changing the performance and aesthetic perception of the parts.

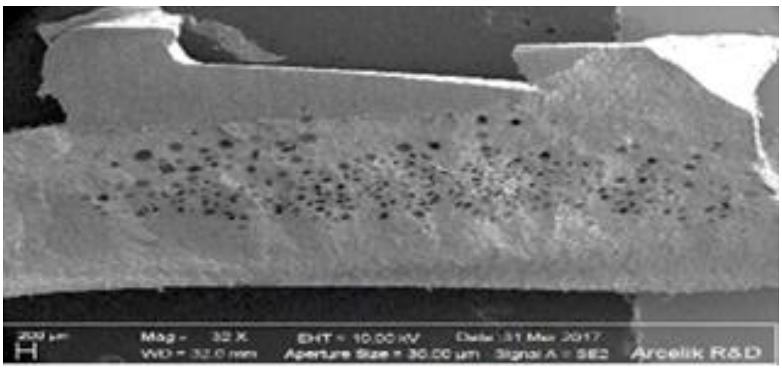


Figure 7. Washing machine's inner cover image (with blowing agent)

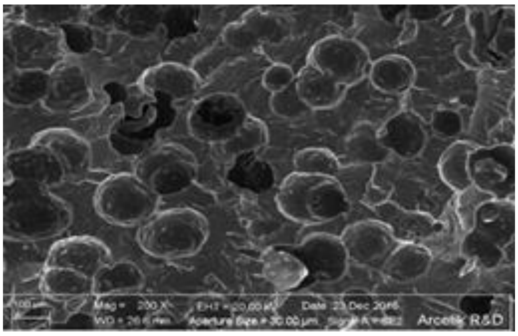


Figure 8. Bubble image with high magnification

Formulation studies were carried out in Central R&D – Material Laboratory and the interactions of plastic production process parameters were analysed. Part and mold design criteria were determined for the foaming of plastic parts. Plastic part designs were studied and the part/mold designs were updated with "Moldflow Foaming Module" analyses.

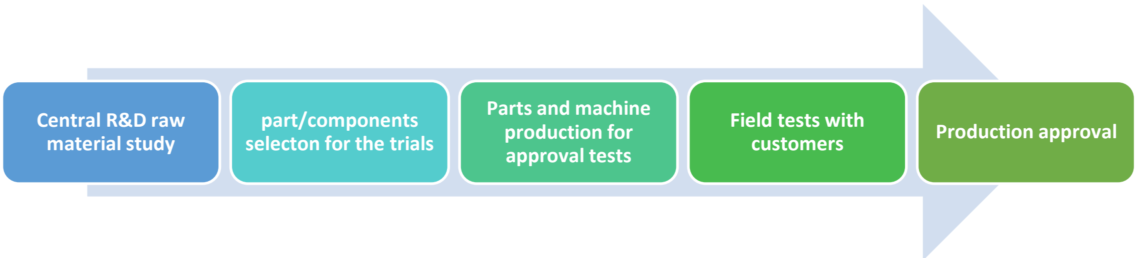


Figure 9. Diagram: Steps of Blowing Agent Study

During the pilot production phase, specific process parameters were studied for each part (inner cover, detergent box, detergent box cover, detergent box cover body). The weight of the parts and cycle times were minimised.

The produced parts were taken to the Quality and R&D tests and their test processes were completed. Foamed parts were tested for transportation, mechanical endurance, etc. In addition to this, Reach-RoHS and PAH certificates were obtained.

Figure 10. Washing Machine Parts (detergent box group and inner cover)

Environmental Benefits of Blowing Agent

- Productivity increased by reducing the process cycle times by ~ 25%.
- ~10% weight reduction achieved in plastic parts.
- Less plastic usage and lower CO_2 emission

These benefits are in accordance with action 'WASH_A1.3.1 Enhance the integration of circular strategies into the production process' and they also contribute to Arçelik's sustainable environmental policies.

4.2.4. New Panel Design

Spanish and Turkish language has been used on the same panel for the C-SERVEES demonstrator.

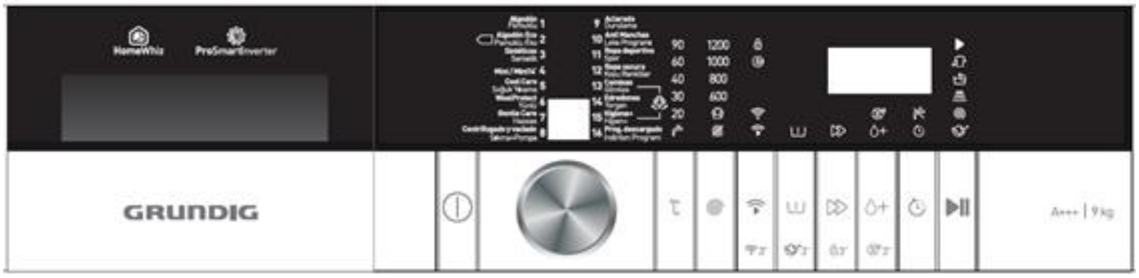


Figure 11. C-SERVEES Demo product front (control) panel

New QR Code Label and C-SERVEES Label Design

We prepared new labels for C-SERVEES demo product.

- QR Code Label
- C-SERVEES Label (it includes H2020 project information)

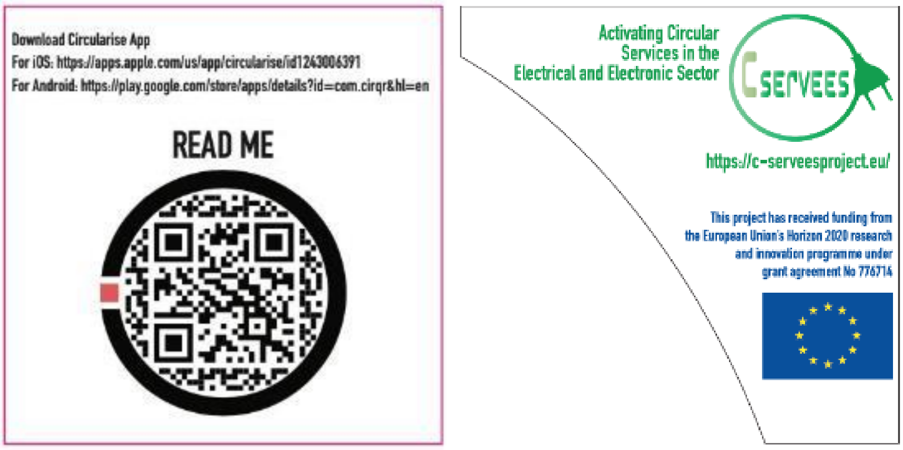


Figure 12. C-SERVEES Demo Product Labels

4.3. ICT functionalities

The C-SERVEES project contains an interacting combination of three different types of ICT tools by the companies Circularise, Rina-C and Soltel. Based on the needs' assessment within WP2 and WP3, the ICT tools of Circularise have been chosen for the first demonstration with Arcelik.

Circularise tools offers a blockchain-based transparency solution to provide absolute proof for the circular economy, sustainability and recycling practices of manufacturers at any stage of the supply chain. Circularise enables value chain transparency without disclosure of datasets or supply chain partners. The solution uses decentralised, encrypted data to track material and product characteristics, e.g. whether, and which proportion of recycled materials have been employed.

The functionalites demonstrated

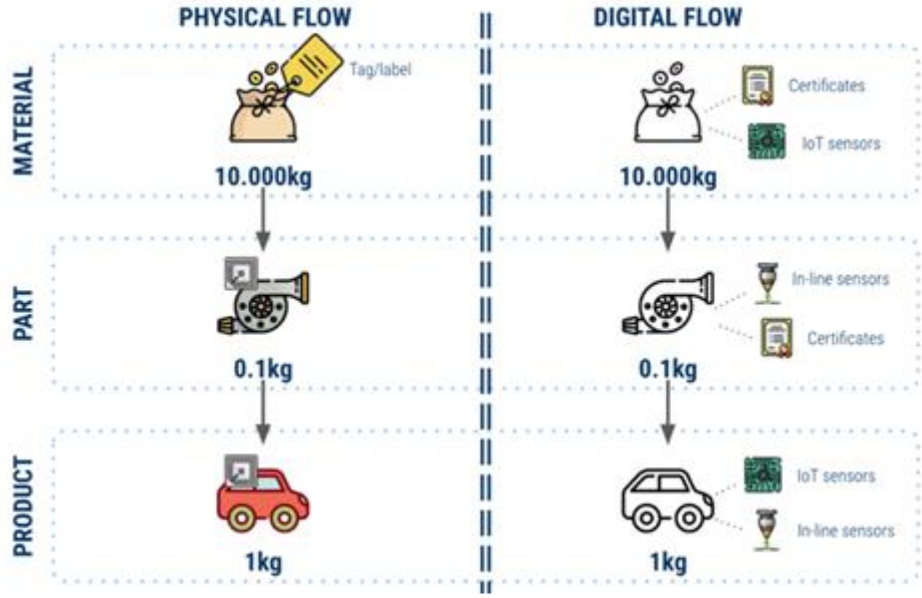


Figure 13. Tokens representing recycled content moving parallely on Circularise System

Circularise creates a digital world that resembles the physical supply chain, but also includes all information that is needed to proof the sustainability of that supply chain. For every kilo of certified recycled material, it creates one token. This quantification of the quality criteria "recycled" then makes it possible to transfer this proof, the token, along the supply chain and to the brand owner to proof that the material is recycled. This impedes greenwashing and makes sustainable material usage a proofable quality critieria that creates value for the brandowner and proof for the customer. 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. Customer expectations for transparent supply chains and sustainable product is increasing. This encourages material manufacturers to produce recycled material and brand owners to purchase certified recycled material.

The demonstration process

The identification of component and recycled material supplier

Arcelik chose a product component suitable for the addition of secondary raw material. Arcelik and Circularise then identified a material supplier (Covestro) 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. This required the certification based on an audited production batch of recycled material at Covestro and the identification of the specific amount of it purchased by Arcelik.

Onboarding of the supplier and Arcelik on the Circularise system

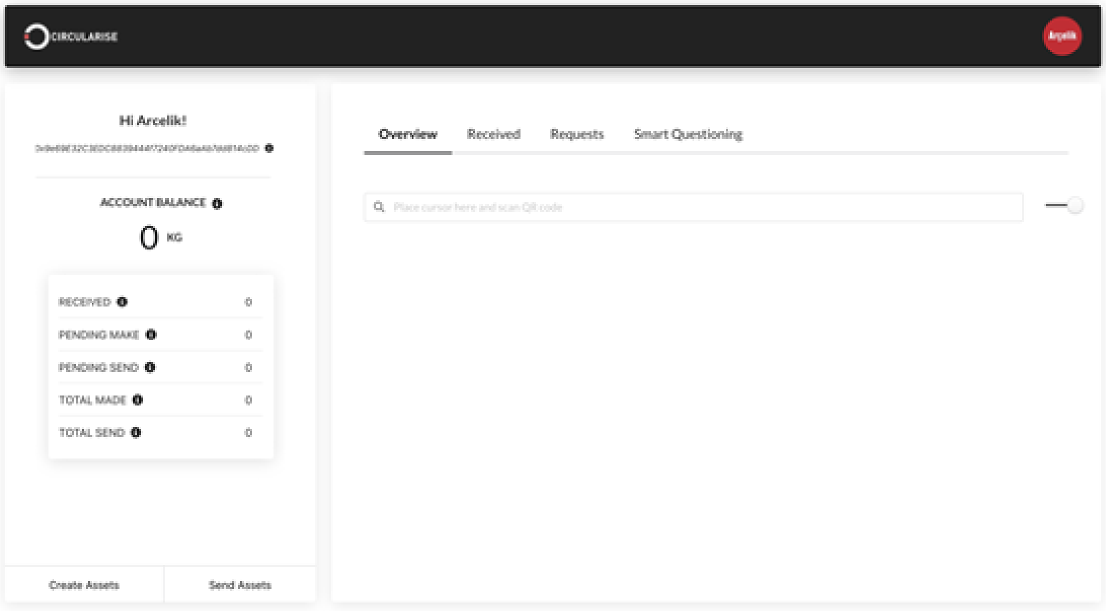


Figure 14. Arcelik Dashboard on the Circularise Web Application

Arcelik and the material supplier were onboarded on the Circularise Web App. Arcelik was provided with a QR-Code (see Figure 12) for the front cover of the washing machine. Arcelik 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.

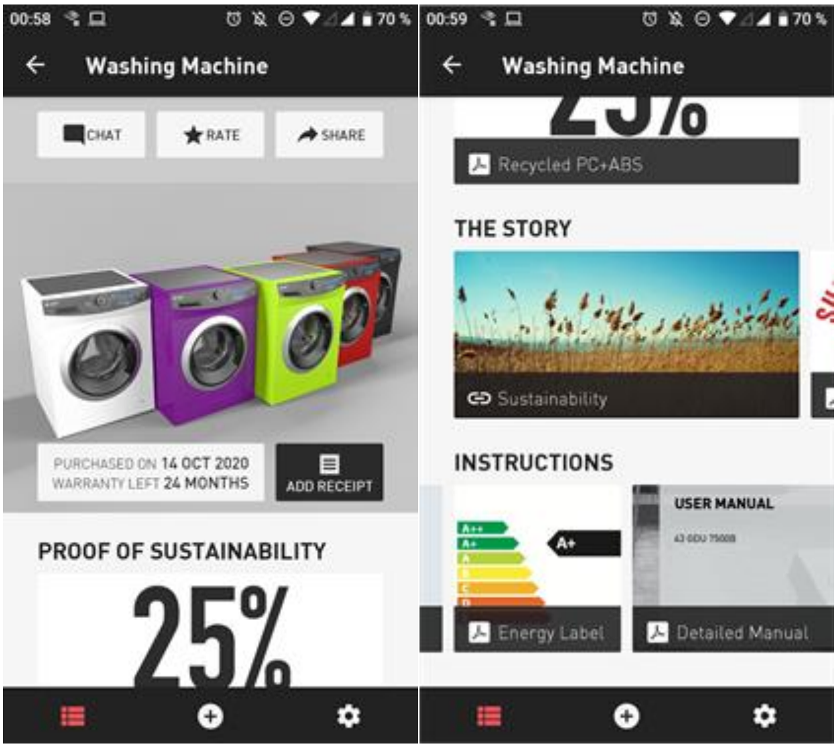


Figure 15. Product in the Mobile App (percentage or recycled content tbc)

<u>Tokens creation</u>

Covestro then received a purchase order over the specific amount of material to be supplied, tokenised and shipped to Arcelik. The recycled material was audited by a third-party LCA-expert and verified/certified in its nature of secondary raw material. This certificate specifies the amount or recycled content in the material. The document was going to be uploaded by the supplier and an equal amount of recycled content tokens was going to be created for the amount of material produced in this certified production batch. The tokens resembling the part of material supplied to Arcelik were then going to be sent via blockchain to Arcelik's account. This process allows an anonymous but verifiable blockchain transaction. The tokens created for the specific amount of produced recycled material based in the quantifiable certificate are then Split between the different customers of Covestro. Arcelik was going to receive the tokens resembling the exact amount of purchased material. The token transfer through the blockchain make it verifiable, unmutable and prevents double-spending. This means that token trasfers are recorded forever, cannot be changed or tempered with and tokens cannot be multiplied or transfered twice.

<u>Challenges encountered and solution found</u>

In the production process of the demonstration products, the recycled material supplied within this pilot had to undergo a quality and security check by Arcelik. The material did not pass the test specifically for the material requirements for washing machine, while the TV production did not face such issues. As a result, the tokens could not be transfered. As a result, Arcelik used recycled material from one of their usual suppliers and completed the production of the demonstration washing machines successfully without certified recycled material (i.e., using recycled material with no third-party certification).

<u>Mitigation</u>

Arcelik and Circularise are currently in communication with the supplier of the recycled material eventually used. If the supplier is able to provide certification or third-party audits which can be clearly linked to the material used and specifies its recycled content, it can be added to the demonstration. This would then result in an onboarding of the supplier as well as the token creation and transfer. As a result, the Arcelik account on the Circularise system (see dashboard in Figure 14) would receive the certifying tokens of the exact amount of material used.

4.4. Validation Tests

Arçelik produced 106 washing machine demo products at the beginning of April 2020.

Product SKU: 7150341600

Product Serial Numbers: 2004400002-2004400108

Figure 16. C-SERVEES demonstrator production in Arçelik WM Production Facilities

Thermoplastic and elastomer raw material approval process (testing) is followed by Central R&D. Their test process includes below tests and controls:

- Density
- Met flow rate
- Ash content
- Tensile strength at yield
- Elongation at yield
- Tensile modulus
- Izod impact strength
- Flexural strength
- Flexural modulus
- Aging tests (for different solutions)

After the completion of raw material approval process, product testing stage is started. All approval processes may continue more than 2 years. 400+ test methods are applied for washing machine approvals. Product test groups are listed at below:

- Performance Tests (Energy Labeling and Noise Tests)
- Abnormal Conditions Tests (humidity, tempertaure, high/low voltage)
- Software Control Tests (program following, software check-list etc)
- Algortihm Control Tests
- Safety Tests (EMC etc)

- Standart Compliance Tests (VDE, TSE, UL, glow wire, needle flame, ball pressure etc)
- Dynamic Group Tests
- Mechanical Tests
- Life Tests
- Transportation Tests
    - Vibration Test
    - Drop Test
    - Inclined Plane Crashing Test
    - Overturn Test
    - Others (stacking, pressing etc)
- Quality Tests
- Audit Tests
- Component Tests for each component (heater, pump, front door, top plate etc)

4.4.1. Blowing Agent, Leo-PET, Eco-PP Validation Tests and Approval Process

After the completion of raw material approval process, product testing stage is started.

For the tub's raw material approval (Leo-PET), dynamic group tests, mechanical and life tests and transportation tests were performed in R&D Lab.

The produced parts, namely the inner cover and detergent box group, were controlled with transportation tests for the demo production. Blowing agent and Eco-PP raw material were used for these parts.

Figure 17. Pictures and inner cover and detergent box pictures after transportation tests

4.4.2. Covestro PC/ABS raw material validation tests

Covestro was initially selected as provider of recycled material to increase the recycled content of the washing machine for the demonstration. Covestro PC/ABS raw material includes 30% recycled content. We tried to use this raw material for the washing machine demo products' PCB holder parts to increase the recycled content (See Figure 18).

Glow wire testing requirements for home appliances are specified in IEC 60335-1. Glow wire testing is performed by heating an element to a pre-determined temperature. The heated element is referred to as the glow wire. The sample to be tested is fixed in place and tissue paper is positioned directly below the sample. After reaching the pre-determined temperature, the element is then pressed into a sample material under a set force 1N for 30 seconds. If ignition occurs, recordings are made to note the duration, flame height, and if drips of the material ignite the tissue paper. Glow wire testing can be performed on both end products and raw material test plates. The glow wire test is defined by the IEC 60695-2-11 standard. The results of this test will be either pass or fail at given temperature. Passing the test requires that the samples does not ignite or self-extinguishes within 30 seconds after removal of the heated element.

We performed this standard compliance tests for the Covestro raw material and the test failed at 750-850 ºC. Due to this failed test result, we did not use this raw material for the C-SERVEES demo product.

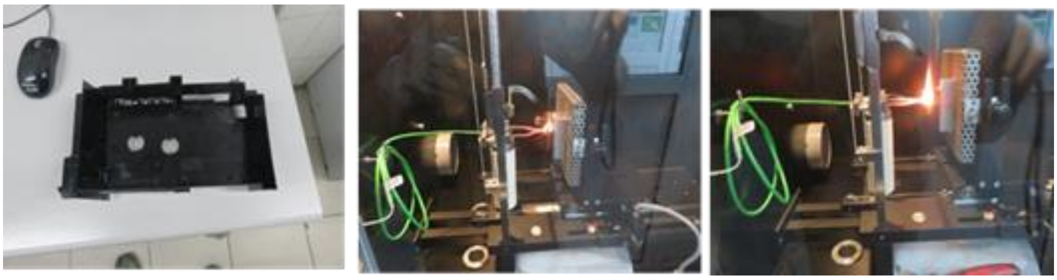


Figure 18. PCB holder pictures after glow-wire test

5. Printers and laser toner cartridges demonstrator

The activities conducted in the design and production phase were derived from the PRINT-CIRCMODE short-term actions validated in WP2. The short-term actions were developed into demostration actions to be implementated in WP4. The table below presents the PRINT-CIRCMODE canvas sub-components integrating short-term CE actions corresponding to the design and production phase, as presented in D2.3.

Table 3. Validated short-term PRINT-CIRCMODE Canvas Key Circular sub-components and their associated Circular Economy Actions relevant for the design and production phase.

PRINT-CIRCMODE Canvas Sub-Component	PRINT-CIRCMODE validated short-term Circular Economy Actions
PRINT_C1.1 Diversify circular activities	PRINT_A1.1.2 Improve the refurbishment and/or dismantling processes
	PRINT_A1.1.3 Provide information about printers to LEXMARK recycling partners
PRINT_C1.2 Embrace eco-design to ensure products circularity across life-cycle stages	PRINT_A1.2.3 Use materials that recyclers can easily and profitably recycle
PRINT_C1.7 Implement and/or enhance practices and tools to track materials and components	PRINT_A1.7.2 Use ICT tools to improve tracking of printers' current location and status
PRINT_C2.1 Devise competitive financing models and cost saving by using and/or purchasing fewer components and obtaining materials reused or recycled from other sources	PRINT_A2.1.1 Further improve recyclable materials in printers
	PRINT_A2.1.2 Learn from recyclers what materials can be recycled better or more profitably to use more of them instead of low-recycle value or efficiency materials
PRINT_C2.3 Introduce and/or expand the use of ICT to foster circular economy	PRINT_A2.3.1 Use ICT to improve information sharing across the supply chain
	PRINT_A2.3.2 Use ICT to improve tracking of printers' current location and status
PRINT_C7.3 Introduce and/or enhance products or services that will improve sustainable consumption patterns and respective intangible benefits	PRINT_A7.3.1 Explore the potential of eco-design to enhance printers' durability
	PRINT_A7.3.2 Leverage the use of WP3 ICT tool to improve printers' circularity
PRINT_C9.2 Introduce and/or enhance manufacturing and sales processes to account for costs associated with the end-of-life and second life of materials, components and products	PRINT_A9.2.1 Explore the potential of eco-design measures costs related to the refurbishment process of printers

The following sections provide an overview of the printer and toner cartridges demonstrator including the description of the products and the activities carried out. It also provides a description of the ICT functionalities to be developed and tested during the demonstration period, as per agreed in ‘PRINT_A7.3.2 Leverage the use of WP3 ICT tool to improve printers' circularity’. Since this demonstation does not include the development of new products as is the case for the rest of the C-SERVEES demonstrations, the eco-design for the printer and toner cartridges is derived from the exploration of potential improvements based on the collaboration with recyclers, in order to obtain feedback to implement design for durability and design for recycling in the demonstration products. This is in accordance with actions ‘PRINT_A7.3.1 Explore the potential of eco-design to enhance printers' durability’ and ‘PRINT_A9.2.1 Explore the potential of eco-design measures costs related to the refurbishment process of printers’ as well as ‘PRINT_A1.1.2 Improve the refurbishment and/or dismantling processes’.

5.1. Demonstrator description

Lexmark devices are built to last longer than 7 years, that means fewer raw materials and less energy is needed to produce and distribute devices to the market, and less waste as a result. We call it planned durability. All Lexmark devices feature industrial metal frames, which are much sturdier than other devices in the market made with plastic, and durable in even the most demanding environments. We also carefully consider material selection, using innovative processes created by our engineers to recover post-consumer recycled (PCR) plastic from empty toner cartridges and to pelletise the PCR for integration into new parts. Currently, reclaimed PCR plastic is incorporated into nearly 60 Lexmark supplies components at a level up of to 100% PCR plastic. We offer the highest number of printer models and supply items with significant PCR content in the industry - currently four times more than our nearest competitor. In fact, beyond 90% of Lexmark products include PCR content. The Unison™ print system - with a separate toner and imaging unit design and a high-yield fuser - maximises the longevity of these components and delivers long-term reliability, ultimately saving time and money, and reducing environmental impact.

Since the fastest growing, printing-as-a-service business model of Lexmark called MPS is more profitable with longer lasting devices, Lexmark has a genuine interest to design printers, options, supplies and service parts to last as long as possible.

The Lexmark Cartridge Collection Program has been operating for almost 20 years, which represents a significant investment into circular processes to the company so that cartridges can be collected and reused the highest number of times. The collection of empties and full reverse logistics process generates a significant financial cost.

5.1.1. Printer 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. The models selected are shown below:

- A low-end Multifunction, Color Lexmark OEM A4 printer CX510

Figure 19. Lexmark OEM A4 printer CX510

- A high-end Multifunction, Monochrome Lexmark OEM A4 printer: MS812

Figure 20. Lexmark OEM A4 printer MS812

- A high-end Multifunction, Color acquisition A3 printer: X950

Figure 21. Lexmark A3 printer X950

5.1.2. Supplies description

The demonstrator includes the printer supplies, which was also investigated in order to determine how to improve the recycling process and overall circularity of the LCCP.

During this first stage of the demo 3 different categories of supplies – which were shipped to recyclers and dismantled for component salvage as well as plastic resin recovery (a project that Lexmark placed on hold years ago) - were investigated. The selected models are representatives of the various product architecture and design/material found in a Lexmark cartridge. As mentioned before, almost 3000 cartridge units out of the 10.000 units expected to be processed have been used for the design and production phase.

Today's recycling process consists of crunching the entire products (no pre-dismantling) under controlled atmosphere and then sort out the various materials

For the purpose of the demo, remaining toner from these units have been vacuumed to avoid partner procuring special vacuuming system/device just for the purpose of this demo, would recycler received and want to process laser cartridges from their collection flow, recyclers should ensure proper equipment/safety measures are in place to handle remaining toner

To vacuum remaining toner without damaging the products, few parts were dismantled at Lexmark manufacturing location where such special vacuuming system is in place

The three different models selected are shown below:

- MS/MX Toner Units. A Toner Unit is mainly made of a plastic container with a multitude of plastic and metal parts to ensure the toner is properly distributed to the imaging unit

Figure 22. MS/MX Toner Unit

- C95x Bottle. A bottle is similar to a Toner Unit but this one is made of different raw material than the MS/MX Toner Unit, reason why it was selected

Figure 23. C95x bottle

- MS/MX Imaging Unit (PIRATE IU). An Imaging Unit contains most of the electrophotography system of a laser cartridges and is the most complex type of cartridge in Lexmark product portfolio

Figure 24. MS/MX Imaging Unit

Goals of the printer and toner cartridge demonstration

The global objective was to examine and propose potential improvements to the LEXMARK laser printers and toner cartridges in terms of material circularity and recyclability (design for circularity, design for recycling). The target products selected by LEXMARK were analysed from the recycling point of view considering the following aspects:

- Ease of disassembly
- Recovery of components
- Value of recovered materials
- Hazardous or toxic materials
- Material compatibility for recycling

The exploration of these aspects will allow Lexmark to adopt strategies to improve effectiveness and cost-benefit of the refurbishment operations and to achieve the goal of providing E2N printers in their circular offerings. Lexmark has already put great efforts into designing its products to achieve a longer lifetime, but with the help of the C-SERVEES project, the intent is to increase durability and circularity even more by:

- Collecting information from recyclers and other partners on design improvement to ease the dismantling operation as well as the recycling process and make it "affordable":
    - to reach valuable parts for the OEM more easily and in a cost-efficient way
    - to minimise components that create difficulties or could cause harm during the recycling/dismantling process
    - to use raw material that have a higher value on the recycled material market so recyclers can generate value out of them
- Working with plastic molding companies on designing products that could incorporate Post Consumer Recycled materials from many different sources, as the quality of such materials are often varying.
- Potentially incorporating parts that can be printed with 3D printing (not yet formalised)

Printer models were selected to cover the widest possible scale of Lexmark's product portfolio, at the same time of minimising the effort needed from the recycler's side.

The following quantities were processed during the first stage of the demonstration:

- Cartridges: 2716
- Printers: 18

5.2. Eco-Design of the printers and toner cartridges

Lexmark elected to get the physical demo ran by 3 parties to provide an outcome as comprehensive as possible. The 3 parties being the 2 recyclers from the C-SERVEES Consortium, namely Indumetal located in Spain and Greentronics located in Romania and a Lexmark manufacturer named Syncreon based in Poland.

The 3 parties were asked to proceed with the same exercises after receiving the documentation from Lexmark with instructions on how to perform these exercises, which is summarised here below.

During the first stage of the demo, the 3 parties performing the following 3 exercises were asked to provide details concerning measurement times, energy consumed, human resources required etc., and to provide feedback on encountered difficulties, suggested design improvement, as well as monetary benefit resulting from the Exercise.

5.2.1. Description of the exercises

The following exercises were derived from the PRINT-CIRCMODE short-term actions shown in Table 3, especially, 'PRINT_A1.2.3 Use materials that recyclers can easily and profitably recycle', 'PRINT_A2.1.1 Further improve recyclable materials in printers' and 'PRINT_A9.2.1 Explore the potential of eco-design measures costs related to the refurbishment process of printers'.

Printers:

Exercise #1:

- Taking one of each printer model and performing regular recycling on it without the use of any supporting materials, documentation
- This exercise was drafted specifically for the recycler to be used as a baseline, Syncreon being a manufacturer, this exercise was not relevant to them

Exercise #2:

- Taking one of each printer model and perform disassembly on them without the use of any supporting materials, documentation
- Purpose of this one being to get an outcome mainly on the product design

Exercise #3:

- Taking one of each printer model and perform disassembly on them with the use of the supporting materials, documentation (service manual: manual issued by Lexmark for the purpose of servicing the printer during its lifetime) that were provided by Lexmark

- Purpose of this exercise was to drive the party to access certain parts/subassembly which could be recovered with no damages for the purpose of being ultimately reuse

Supplies:

Exercise #1:

- Taking a certain number of supplies from all 3 categories and performing regular recycling on them
- This exercise was drafted specifically for the recycler to be used as a baseline, Syncreon being a manufacturer, this exercise was not relevant to them

Exercise #2:

- Taking a certain number of supplies from all 3 categories and perform disassembly operation on them
- Purpose of this exercise was to drive the party to access certain parts/subassembly which could be recovered with no damages for the purpose of being ultimately reuse

Expected outcome:

Recyclers and partners taking part in the exercise to provide information on the design of printers and supplies to reach greater efficiency during disassembling and/or recycling of the products:

- To provide higher quality recycled material for the PCR material market at the end of the recycling process
- To consume less time during the disassembly process
- To reduce the number and type of components that slows, contaminates, endangers the recycling procedure

5.2.2. Technical analysis of the recycling and dismantling operations

An analysis of the general results obtained from the Exercises has highlighted the following aspects:

- Disassembling printers without any prior knowledge is often less time consuming than using the provided service manuals: printer design already supports the easy disassembling
- The market price of mixed plastic is very low (0.01 €/kg) if the recycler wants to sell it on the market

- The market price for sorted material is much higher, as an example for ABS, used for most of the Lexmark housing products market price is 0.21 €/kg sorted ABS waste while virgin ABS price fluctuates between 2 and 3 €/kg
- Without considering the cleaning, grinding, transportation procedures the difference is at least 10-fold in favor of the sorted ABS waste, however the estimates will have to be recalculated for PCR ABS
- The highest value of a certain type of plastic is for the original manufacturer of the product
- The highest cost of the dismantling operation is generated when cleaning the dismantled parts (6:1 ratio compared to the dismantling process). This cleaning being required in case the parts will be reused as spare parts, as an example. In case of recycling, the cleaning phase is not required
- There is an hiatus of such grinding services on the market that could pelletise the recycled ABS plastic into 8-9 mm pieces, that the plastic molding supplier could handle and create newly molded plastic elements
- For an easy dismantling operation, an independent modular construction of subassemblies is recommended
- From the construction the subassemblies/parts that must be recovered to have to carry a color code both with fastening system
- Using fast fastening systems
- The repetitiveness of operations leads to reduced working hours, so the specialization of the worker on a type of printer, increases efficiency and productivity

5.2.3. Cost and price analysis of the recycling and dismantling operations

To build a sustainable system, besides the environmental aspects, business aspects must be strongly considered, therefore a cost and market analysis was performed for the operations defined in 5.2.1 and analysed in 5.2.2.

The associated costs of recycling and dismantling were calculated considering the time, the energy consumption and the required human resources to perform the operation.

Recycled material market prices were provided by Greentronics.

Dismantled part prices – where applicable – were provided by Lexmark based on the current demand.

Results were calculated using the cost of dismantling, the price of the recycled materials on the second-hand raw material market or the prices Lexmark is willing to pay for certain good quality, dismantled parts.

5.2.3.1. Printers

Exercise #1 (BAU recycling operation):

- The first number shown for each product below is the dismantling cost incurred by the recycler to dismantle the products
- The second one is the benefit the recycler can get out of the various fractions resulting from the exercise
- The third one is the net between above two

  - CX510: 9.5 €/device (market price: 6.16 €/device) – Sum: -3.84 €/device
  - MS812: 14.26 €/device (market price: 5 €/device) – Sum: -9.26 €/device
  - X950: 41.5 €/device (market price: 30.3 €/device) – Sum: -11.2 €/device

Exercise #2 (dismantling without support)

- The first number shown for each product below is the dismantling cost incurred by the recycler to dismantle the products
- The second one is the price Lexmark pays today for the various recoverable spare parts
- The third one is the net between above two

- CX510: 10.33 €/device (purchase price: 10.16 €/device – 1 part) – Sum: -0.17 €/device
- MS812: 16.65 €/device (purchase price: 101.55 €/device – 14 parts) – Sum: 84.9 €/device
- X950: 46 €/device (purchase price: 39.7 €/device – 3 parts) – Sum: -6.3 €/device

Exercise #3 (dismantling with service manual)

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

5.2.3.2. Supplies

Exercise #1 (BAU recycling operation)

  - 95X Tube: 0.0284 €/unit (market price: 0.0025 €) – Sum: -0.026 €/unit
  - Pirate Imaging Unit: 0.237 €/unit (market price: 0.091 €) – Sum: -0.14 €/unit
  - MS/MX Toner: 0.283 €/unit (market price: 0.18€) – Sum: -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)

It can be concluded that dismantling devices provide more value for the printers, as complete parts and components result in higher value to the original manufacturer than the potential selling price of the secondary raw material on the recycled material market.

On another hand, for cartridges, as of today, very few parts are qualified by Lexmark to be reused in the manufacturing of cartridges, potential opportunities here to be determined.

5.2.4. Summary of actions for further testing and development

- A special dismantling manual should be created for those products that have higher value when dismantled than recycled (it is the case of high-end devices)
- An easily identifiable color coding could be developed for faster identification of components or materials OR alternatively a QR-coding / RFID marking of parts with higher value could be applied which would drive focus and care from the recycling operator
- Either purchasing a grinding machine that could produce 8-9 mm ABS flakes from the recovered plastic ABS housing OR search for alternative solutions – the business case is currently being revised taking into account the lower demand due to Covid-19
- As per Indumetal, the volume of processed printers for above exercise and especially exercise 1 should be higher since, it is not feasible to treat them alone in the standard recycling process. A standard batch for recycler's mechanical process is around 100 tons of material. So, considering the transportation costs there might be an extra round with Indumetal to complete Exercise #1 – if it can provide valuable information for the project
- Analyse opportunities to re-use more recovered parts in the cartridge manufacturing

5.3. ICT functionalities

The long-term goal is to have a network supported with an ICT solution:

- That supplies high quality PCR material as close to the production as possible
- That automatically signals the producer when a product and/or a higher value component ends up at their facility

- That calculates the time, distance, costs of shipping back such material, component or product to the producer or suppliers of the producer – to be able to calculate when it becomes profitable to initiate transportation based on the continuously updated purchasing price of the supplier or producer for that certain material, component or product
- That the members have full control over, minimizing the risks of counterfeit materials entering the system using a distributed ledger technology (private blockchain) – enabling traceability of products, components and recycled materials.

Using QR-codes for products, bigger components and using other tracing methodology for smaller components and materials.

For the project the following exercises were planned to be carried out in order to improve the information on products to authorities, customers, recyclers etc., in accordance with 'PRINT_A1.7.2 Use ICT tools to improve tracking of printers' current location and status', 'PRINT_A2.3.1 Use ICT to improve information sharing across the supply chain' and 'PRINT_A2.3.2 Use ICT to improve tracking of printers' current location and status'.

1. Refurbished printers will receive a QR code sticker that upon scanning would direct the user to a site where the following information will be made available:
    a. The % of the changed parts in the printer
    b. All product and process certifications (like Energy Star, Blue Angel, EPEAT, ISO, etc.)
    c. Hazardous material and chemical of concern information (RoHS, REACH)
    d. The warranty information for the printer
    e. Technical specifications
    f. Life Cycle Assessment data
    g. Other data based upon the feedback obtained from authorities, NGO's, customers, recyclers
2. Newly manufactured cartridges will have a sticker consisting similar information as for 1.
3. Refurbished, remanufactured cartridges will have a sticker consisting similar information as for 1.

The demonstration of the ICT functionalities mentioned above has been discussed and agreed with Circularise and will be undertaken as part of the second and third demo stages: distribution and use phase and end-of-life phase.

6. ALM products demonstrator

The activities conducted in the design and production phase were derived from the ALM-CIRCMODE short-term actions validated in WP2. The short-term actions were developed into demostration actions to be implementated in WP4. The table below presents the ALM-CIRCMODE canvas sub-components integrating short-term CE actions corresponding to the design and production phase, as presented in D2.4.

Table 4. Validated short-term ALM-CIRCMODE Canvas Key Circular sub-components and their associated Circular Economy Actions relevant for the design and production phase.

ALM-CIRCMODE Canvas Sub-Component	ALM-CIRCMODE validated short-term Circular Economy Actions
ALM_C1.1 Diversifying circular activities	ALM_A1.1.1 Design for longevity
	ALM_A1.1.2 Design for recycling
ALM_C1.2 Embrace eco-design to ensure products circularity across life-cycle stages	ALM_A1.2.1 Reduce energy consumption in the use phase
	ALM_A1.2.2 Eco-design approach in production and Design for Recycling
ALM_C1.3 Adopt circular strategies in the production process	ALM_A1.3.2 Improvements to own production
ALM_C2.3 Introduce and/or expand the use of ICT to foster circular economy	ALM_A2.3.3 Provide information about materials and disassembly for recyclers
ALM-C7.3: Introducing and/or enhancing circular products or services that will improve sustainable consumption patterns	ALM_A7.3.1 Implement eco-design strategies across the life cycle of ALM products and the subsequent reduction of energy use
ALM-C9.1: Mitigating against any possible additional costs associated with end-of-life activities	ALM_A9.1 Reduce cost of packaging disposal
ALM-C9.2: Introducing and/or enhancing manufacturing and sales processes to account for costs associated with the end-of-life and second life of materials, components and products	ALM_A9.2.1 Reduce costs by design for recycling

The following sections provide an overview of the ALM demonstrator including the description of the products and the activities carried out. It also provides a description of the ICT functionalities explored and the feasibility of their implementation in the demonstrator. The exploration of potential improvements for the ALM unit is also included, based on the collaboration with recyclers, in order to obtain feedback to implement design for longevity and design for recycling in the demonstration products. This is in accordance with actions 'ALM_A1.1.1 Design for longevity' and 'ALM_A1.1.2 Design for recycling', as well as 'ALM_A9.2.1 Reduce costs by design for recycling'.

6.1. Demonstrator description

In this chapter, the ALM (Advanced Link Monitoring) demonstrator will be described. The ALM is part of ADVA's portfolio of telecommunications systems. As such, it belongs to the ICT (Information and Communications Technology) sector. Previous to go ahead reading this report, to better understand some of the conclusions shown in this section of the ALM products demonstrator, it would be recommended to read the Annex of this report where it can be found an analysis of the environmental impact of the ICT sector since this is crucial in understanding to what extent circular economy (CE) can be applied to certain classes of ICT equipment and what the ALM demonstrator can show.

6.1.1. ADVA and the ALM demonstrator

6.1.1.1. ADVA and our demonstrator goals

About ADVA

ADVA is headquartered in Munich, Germany, and has 35 locations globally. The company has significant operations in Germany, Poland, England, Israel, China and the USA. The global presence is shown in Figure 25.

Figure 25. ADVA's global presence

Between 2017 and 2020, the headcount was around 1,900 employees, and total revenue was in the range of EUR 500-600 million.

ADVA is a global provider of open networking solutions with 25 years of experience in:

- Cloud interconnect – Solutions based on wavelength division multiplexing (WDM) technology to deliver scalable bandwidth for access, metro and long-haul networks. This includes high levels of programmability and monitoring / supervision.
- Cloud access – Carrier Ethernet access and network functions virtualization (NFV) solutions that enable communication service providers to deliver software-defined, differentiated and performance-assured wholesale, mobile-backhaul and business-access services.
- Network synchronisation – Primary reference sources (atomic clocks) and distribution solutions to deliver accurate and scalable time and frequency synchronisation for mobile network infrastructure, utilities, financial services, distributed databases and metrology.
- Fibre monitoring – Solutions that monitor fibre quality and integrity, including tapping, without interfering with the customer traffic. Since a couple of years, these solutions are extended to more general fibre sensors.

The demand for these solutions is fuelled by the global ICT trends 5G (6G), IoT / M2M, edge computing, HPC / big data, and HD video streaming.

The revenue split by technology roughly is cloud interconnect 64%, cloud access 30%, network synchronisation 5%, and fibre monitoring 1%.

ADVA's products

ADVA develops, manufactures and sells solutions for a modern telecommunications infrastructure. This comprises fibre-optic transmission technology, Ethernet access technology and solutions for network virtualisation. It further includes solutions for network synchronisation and monitoring, and the required software to operate and monitor the products and the related networks. It thus covers significant parts of ICT's core and access networks, as shown in Figure 26.

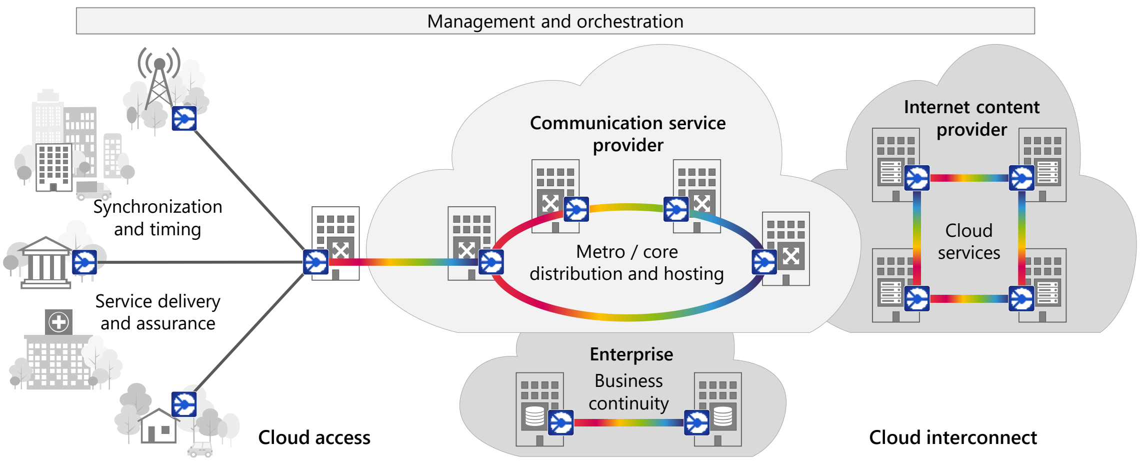


Figure 26. ADVA products in telecommunications networks

Fibre-optic transport

Optical fibre is the optimum physical medium to transmit large amounts of data over long distances. The bandwidth-distance capabilities of fibre by far exceed those of any other physical medium such as copper or wireless technologies. Therefore, fibre-optic transport is the foundation for all high-speed networks. It is based on WDM (wavelength division multiplexing). With WDM, multiple data streams are transmitted simultaneously over a single pair of optical fibres by modulating, per direction, each stream onto an individual wavelength (i.e., colour) of laser light. Every wavelength (more than 100 in total) carries different applications such as voice, video, data or storage traffic. Combining (i.e., multiplexing) these wavelengths at one end of the fibre, transmitting them over distance and then separating (i.e., de-multiplexing) them at the far end maximises the fibres' capacity and makes transmission more efficient. As network infrastructure, WDM systems typically have long lifetime, which frequently exceeds 10 years.

Ethernet

Ethernet is the dominant OSI-Stack Layer-2 data-link protocol for today's networks, supporting virtually all communication applications. ADVA provides Ethernet transmission and demarcation solutions for fibre-based networks used to interconnect enterprises and mobile-network base stations with carrier networks. Features include aggregation, synchronisation, monitoring, encryption, and virtualisation. Ethernet access systems also have lifetime that often exceeds 10 years.

Software

Software is relevant in networking technology. On the one hand, network operation and monitoring are automated by means of intelligent software. This simplifies network control and maintenance. On the other hand, more and more network functions are virtualised (network function virtualisation, NFV). With NFV, the tight coupling between hardware and software in network elements is dissolved, and individual network functions can be developed independently of the underlying hardware. In certain applications, NFV can help reducing energy consumption and greenhouse gas emissions.

Information security

Information security – integrity, authentication and confidentiality – is getting more relevant. This is reflected, e.g., by the EU NIS Directive. ADVA is offering three security packages under the brand name ConnectGuard. These enable lowest-latency state-of-the-art encryption on the photonic layer, the Ethernet layer or the IP layer.

Synchronisation

Reference clocks that deliver highly precise frequency and time-of-day information are crucial to the effective transmission of digital signals in several network domains. Especially in mobile networks, the availability of highly accurate synchronisation and timing information is mandatory for the network-capacity increase. ADVA offers synchronisation technologies under the brand name Oscilloquartz.

Monitoring

Fibre monitoring helps to guarantee fibre integrity and to supervise complex fibre plant, even if the respective fibres are not yet lit by active gear. This enables, for example, certain service-level agreements. With the Advanced Link Monitoring (ALM) product line, ADVA offers a monitoring solution based on optical time-domain reflectometry (OTDR). The solution comprises several different passive fibre sensors.

ADVA's current business

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%).

So far, the majority of ADVA's business is linear (integrating and selling products, no take-back). The clear 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 apparently are ADVA products. Any take-back and recycling obligations in most cases are followed by the resellers or OEM partners.

The majority of ADVA's customers buy products together with maintenance contracts, which can be regarded an entry-level PSS (product-service system). 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.

In the recent years, ADVA implemented a number of take-back, refurbishment and recycling processes especially in the UK and in our main site in Meiningen, Germany.

The CE processes in the UK were implemented for two large customers. They include take-back, refurbishment and recycling. (Reverse) logistics are optimised in cooperation with a logistics provider, using his geographically dispersed logistics infrastructure. The processes are extended to third-party equipment (the latter being recycled). Supported by optimized reverse logistics, this covers 4-digit product-unit numbers per year (installed base is in the range of 100,000-200,000 units).

In addition to the customer-specific processes in the UK, ADVA implemented a refurbishment / parts reuse / recycling process for any equipment sent back to the main site (logistics hub) in Meiningen, Germany. An overview is shown in Figure 27.

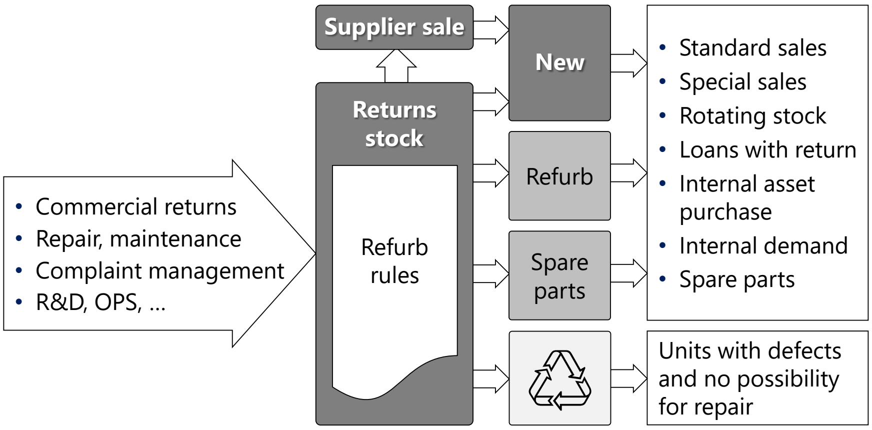


Figure 27. The Supplier Sale analysis and reuse process implemented in Meiningen, Germany

All equipment sent back is analysed for potential components reuse and refurbishment. Systems or components without a possibility for reuse are professionally recycled by a contract WEEE recycler located close to Meiningen, which also minimises truck-roll mileage. Depending on the degree of reuse potential, the components are sold back (supplier sale, new) or get into respective stocks for new, refurbished or spare parts. This also helps extending the use of components that have reached production stop. The portion of equipment sold back to their suppliers, relative to total purchasing volume, is in the range of 1-2%.

Goals of ADVA demonstrator

ADVA follows two main goals with the demonstrator. The first goal is to prove results of a more structured analysis aiming at improving CE business. The second goal is to analyse in particular product-service systems (PSS) in more details and have a first example (beyond the PSS of selling products with maintenance contracts) implemented, supported by the project.

The first goal is about proving an analysis that goes beyond what ADVA did so far. Within the company, there were several approaches to CE, see Annex 1. The products have certain features in favour of CE, e.g., long lifetime or modularity. However, CE business so far was relatively small. The analyses in WP2 showed several ways of potentially improving this business. The questions remain whether these are feasible, or if formerly identified (see **CE Challenges**, page. 111) or new hurdles toward more CE business persist. In this sense, the demonstrator aims at showing if existing limits to CE can be overcome.

The second goal refers, more specifically, to the analysis of different PSS and a first successful implementation. ADVA does sell products together with maintenance contracts, and the products are modular and have supportive monitoring functions. However, so far, no PSS beyond this have been implemented. There are open questions in particular regarding the migration phase toward more sophisticated PSS and how these PSS have to be calculated and implemented in order not to disrupt business.

6.1.1.2. The ALM system in more detail

The ALM (advanced link monitoring) system was originally developed for cost-efficient monitoring of access fibre plant. Background is that, unlike long-haul fibres (which are always used because of their cost), access fibres sometimes are not yet in use. In addition, access most often takes place in urban areas where there is relatively high risk of fibre failures because of civil-engineering work. In order to guarantee service-level agreements, and to identify failure causes, access-fibre monitoring is a frequent requirement. A typical application for monitoring radio-access-network (RAN) fibres is shown in Figure 28. The active ALM unit is accommodated, together with the associated passive couplers and the mobile data unit/control unit in a central office. The access fibres most often are shorter than 20 km.

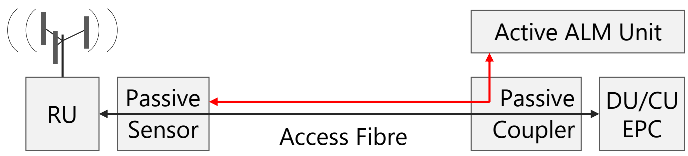


Figure 28. Application of an ALM in radio-access-network monitoring. RU: radio unit. DU: data unit. CU: control unit. EPC: evolved packet core.

The active ALM unit is connected to the access fibre via a passive wavelength-selective coupler. The monitoring wavelength is chosen such that it does not interfere with payload wavelengths on the same fibre. At the fibre end, a passive sensor (or reflector) is used. This allows detecting several different events and is discussed in more detail below.

The basic principle of the ALM is optical time-domain reflectometry (OTDR) [37]. It is explained in Figure 29.

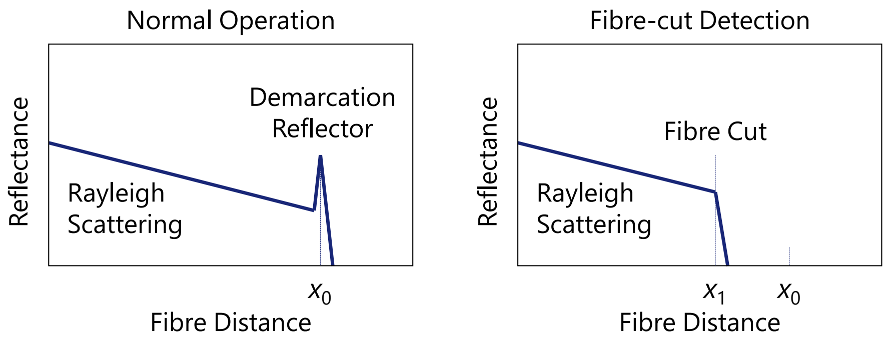


Figure 29. ALM working principle.

In OTDR, pulsed light is sent into the fibre that is to be monitored. It is reflected back to monitoring device both, continuously by Rayleigh Scattering in the fibre, and at any events and defects in the fibre. In the left part of Figure 29, a demarcation reflector is provided at the fibre end at location x_0. It produces a strong reflection peak, which can be calibrated during installation of the ALM. Distance resolution along the fibre is done via light-pulse runtime-delay/location conversion (which is the basic OTDR principle). If an event occurs, e.g., a fibre break, see right part of Figure 29, no pulsed-light power is reflected behind the event, and the location of the event can be detected.

The ALM normally uses a demarcation reflector. This has certain advantages:

- The reflector provides clearer, less ambiguous results.
- With reflector, one can clearly identify the high reflection peak at the end of the link during installation, which is an indication at the link is intact.
- With reflector, any event detection is significantly faster. A standard OTDR (which does not use dedicated reflectors) needs 15 to 30 seconds to do a complete OTDR trace and is less accurate.
- The reflector also improves accuracy of the measurement since its reflection peak can be used to calibrate the measurement.
- The reflectors can be replaced by other, modified sensors that can detect various events and parameters. Then, the ALM system can be used for detecting intrusion, fire, water and other parameters.

The active ALM units (which contain the opto-electronics for the OTDR, the signal analysis and the management access) is available in two different versions, with 16 access-fibre ports and with 64 access-fibre ports, respectively. These have half ETSI width (~27.5 cm) and full ETSI width (~55 cm), respectively. They are shown in Figure 30 and Figure 31.

Figure 30. Active 16ALM/PTP/-48VDC unit

Figure 31. Active 64ALM/#1650D/-48VDC unit

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 the dedicated per-fibre components are fully passive. In addition, each fibre can contain several sensors (or partial reflectors), which further reduces cost and power consumption. Compared to electrical alternatives, this makes the ALM system advantageous in terms of cost and environmental footprint.

The active ALM units are available with AC and DC power supplies, respectively.

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 in Figure 32. The device is mainly made of plastic and has a total length of ~25 mm. The reflector does not have any mechanically moving parts.

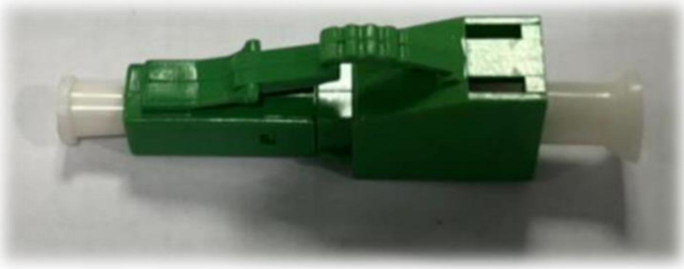


Figure 32. ALM reflector integrated into fibre-optic connector, ca. 25 mm length

Two further sensor types were available at the beginning of the project, a sensor that detects open doors and a water sensor. An open water sensor is shown in Figure 33. It is mainly made of black ABS. In addition, it contains a small metal spring that changes optical reflection when connected to a monitoring fibre and water enters the sensor. The sensor is revertive, that is, it can be reused after it dried.

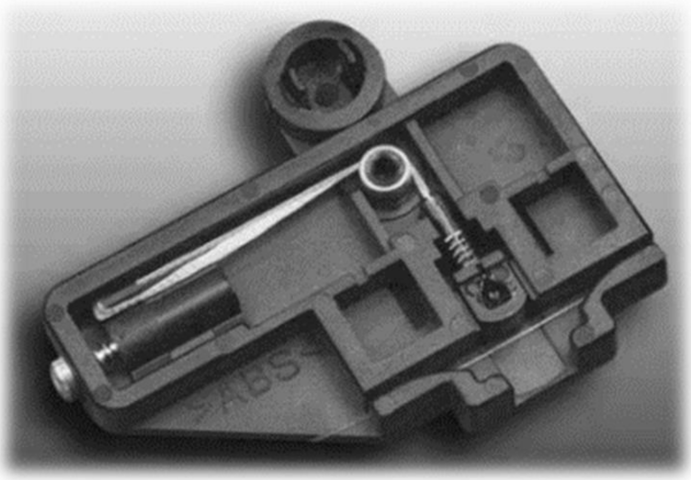


Figure 33. Open ALM water sensor mainly made of black plastic (ABS), ca. 40 mm width, 2g.

The sensor that detects door opening is shown in Figure 34. Variants of this sensor can be used to detect site access (entrance control) or to detect that, e.g., doors of active-equipment racks have been opened. The figure shows the switch that detects door opening in the upper right part. The lower left part shows the fibre connector.

All fibre sensors shown here (and the ones that are developed in the project) have the additional advantage of being immune against EMI (electromagnetic interference). They can thus be used, e.g., in high-voltage or nuclear environment.

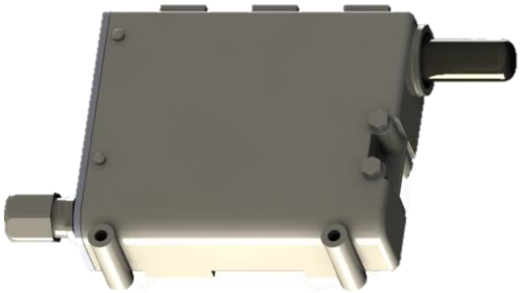


Figure 34. ALM door-opening sensor. Lower left part shows fibre connector, upper right part is the switch.

The new sensors for fire detection are described in Ch. 6.1.3.2.

According to Figure 28, a complete ALM system consists of an active unit, a certain number of passive sensors or reflectors, and the same number of passive wavelength couplers (fibre-optic filters) that couple the monitoring signal onto the fibre. This is required when the fibre is also used for carrying ICT traffic. In the case of the C-SERVEES ALM demonstrator, these couplers are *not required* since the monitoring fibres can be connected to the active ALM units directly.

The couplers, if required, consist of fused-fibre, wavelength-selective three-port couplers [42]. An example is shown in Figure 35. Material-wise, the coupler mainly consists of the three fibres that are cladded with Kevlar and a thin plastic sleeve.

Figure 35. Example of a fused-fibre wavelength-selective coupler.

In case an active ALM monitors several fibres, the respective couplers, if required, can be accommodated in a small passive metal shelf, see Figure 36.

Figure 36. 16ALM/PTP/-48VDC (left) with passive shelf for eight wavelength couplers (right). This additional passive shelf and the couplers are not required for the C-SERVEES ALM demonstrator.

Several lifecycle assessments (LCA) have been conducted for the active ALM units. Similar to other equipment with long lifetime and 24/7 always-on use mode, LCA is dominated by the use phase, see Figure 37. The figure shows the environmental impact in several categories (global warming, toxicity, acidification etc.) and across the entire lifecycle. Here, Support activities includes the ADVA contributions of purchased electricity, commuting and business travel.

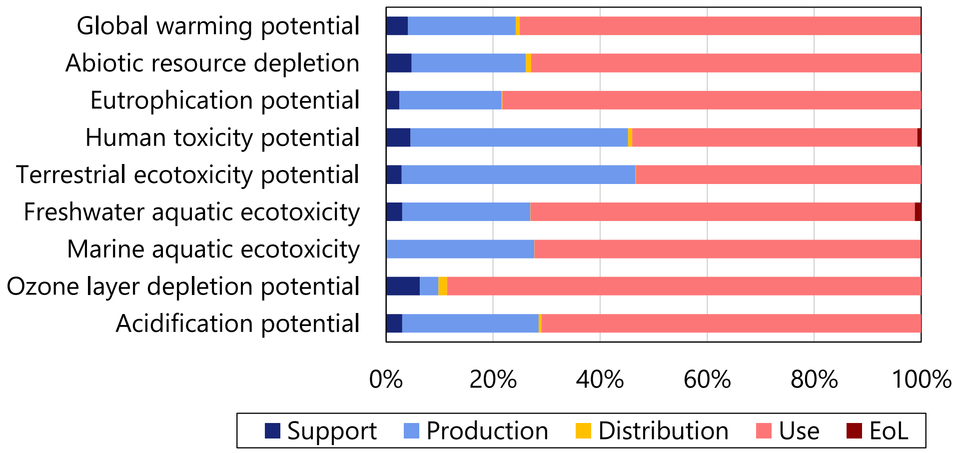


Figure 37. LCA of 16ALM/#1650D/AC

It can clearly be seen that all environmental-impact categories are dominated by the use phase. This results from the use mode and the long average lifetime. For the calculations, 8 years of permanent usage were considered. For the ALM, this is clearly a lower bound. In many cases, lifetime of 10-15 years will be seen. (No exact data exists since the ALM system is still too young.)

The use-phase dominance requires persistent focus on best-possible energy efficiency.

The active ALM units can be equipped with AC or DC power supply units (PSU). Typically, DC PSUs have better efficiency, leading to lower energy consumption. This can be seen in the LCA comparison of AC and DC ALMs in Figure 38.

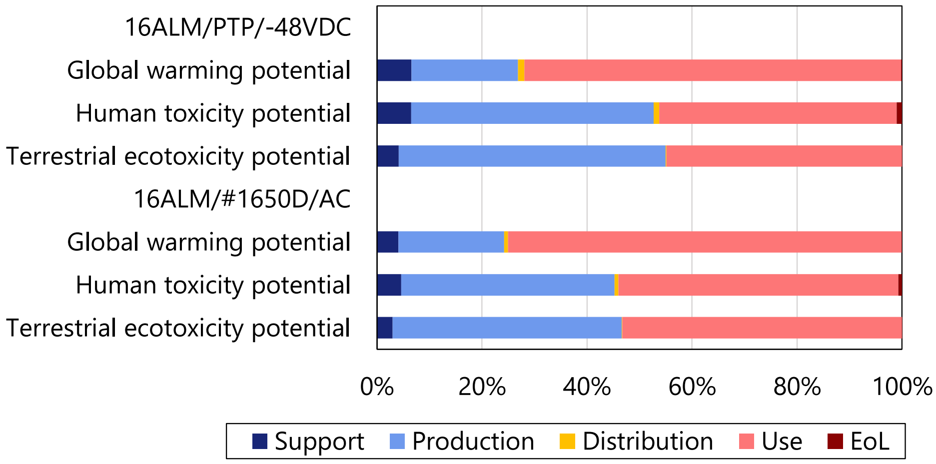


Figure 38. LCA comparison between 16ALM/PTP/-48VDC and 16ALM/#1650D/AC for selected impact

In summary, the active 16-port ALM units have the typical (maximum) power consumption and total lifecycle GWP listed in Table 5.

Table 5. ALM LCA parameters

ALM system	16ALM/PTP/-48VDC	16ALM/#1650D/AC
Power consumption (typ. / max.)	6.3 / 7.2 W	10 / 13 W
Lifecycle GWP	235 kgCO_2e	362 kgCO_2e

LCA can also be done for a more detailed analysis of the contribution of different groups of (opto-electronic) components in production. This is shown in Figure 39.

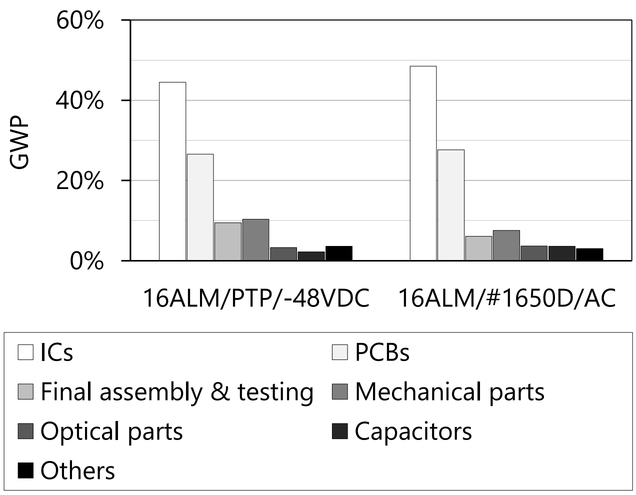


Figure 39. Production LCA comparison between 16ALM/PTP/-48VDC and 16ALM/#1650D/AC

It can be seen that integrated circuits (IC) and printed circuit boards (PCB) have the largest contribution, in this case, to the GWP. Consequently, these areas require attention after the focus on energy efficiency.

6.1.1.3. The ALM demonstrator

The ALM system and its characteristics regarding circular economy will be demonstrated in a large, refurbished industry site in Berlin, Germany. In particular, this is an old factory that is under monument conservation and is to be converted to an innovation campus centre. The building originates from 1938 and has a floor space of about 10.500 m^2.

Figure 40. Innovation campus: (left) current status, (right) render of refurbished building

During the refurbishment, the ALM system will be installed, including the newly developed fire and admission-control sensors. The sensors, together with the passive optical-fibre plant that connects them, will become part of the building infrastructure. They will stay there as long as no physical damage occurs. This means that the sensors have potential lifetime that scales in decades, and they will not be disassembled during the project.

Due to the size of the refurbished site, up to 500 passive sensors and up to 10 active ALM units will be installed. Details were not fully clear yet when this deliverable was written. A schematic diagram of the demonstrator is shown in Figure 41.

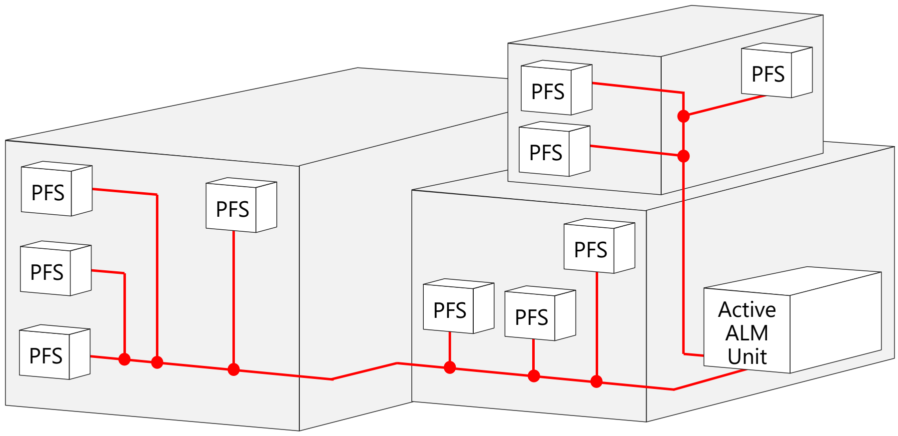


Figure 41. ALM demonstrator installation in refurbished factory sits. PFS: passive fibre sensors.

The exact number of active and passive units is still unclear and may change within certain limits, but the size of the former factory requires hundreds of sensors and a double-digit number of active units. Assuming no failures during the project runtime, even active units will not be disassembled and sent back. This underlines the claim that within the project, the ALM will define the upper bound of the considered EEE lifetime. This will have particular consequence on the respective business models that are to be investigated.

6.1.2. Ecodesign of the product and its business model

6.1.2.1. Ecodesign aspects of ALM active units

During the project runtime, no new eco-designed releases of active ALM units will be developed. The reason is that it is not possible to develop a new release, with external input, in such a period. ADVA's product lifecycle process and the quality-management requirements (telecommunications equipment has to comply with ISO 9001 and TL 9000 requirements) do not allow such an approach within such a short period. Nonetheless, 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 ecodesign guide that is integrated in the product lifecycle process. It is planned to release a new version of the DfE Guide toward the end of the C-SERVEES project. This new release will contain new recommendations derived from the project, as per the agreed actions 'ALM_A1.1.1 Design for longevity', 'ALM_A1.1.2 Design for recycling', 'ALM_A1.2.2 Eco-design approach in production and Design for Recycling' and 'ALM_A9.2.1 Reduce costs by design for recycling'. The focus of the next ALM releases most likely will remain on energy efficiency, as can be derived from LCA, compare Ch. 6.1.1.2.

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 plastic parts are shown in Figure 42.

Figure 42. 16ALM plastic parts after disassembly.

The disassembly also revealed small rubber and metal parts, see Figure 43.

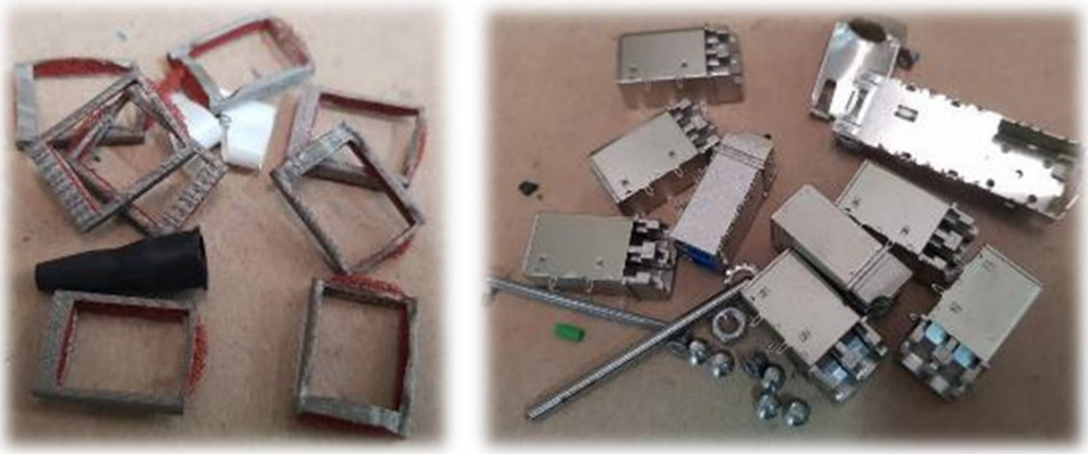


Figure 43. 16ALM rubber (left) and metal (right) parts after disassembly.

The remaining components fractions after manual disassembly were fibre-optic and copper cables, and large metal parts (chassis, heat sink), respectively. The cables are shown in Figure 44.

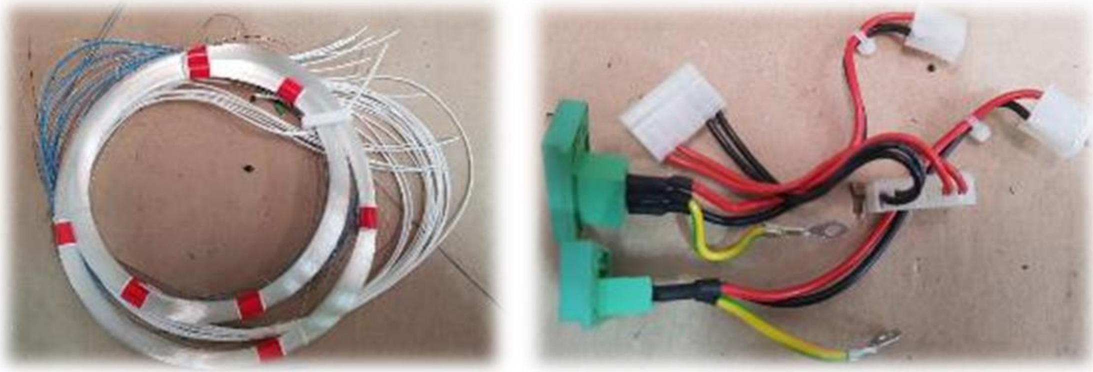


Figure 44. 16ALM fibre (left) and copper (right) cables after disassembly.

The empty metal chassis of an active 16ALM unit is shown in Figure 45.

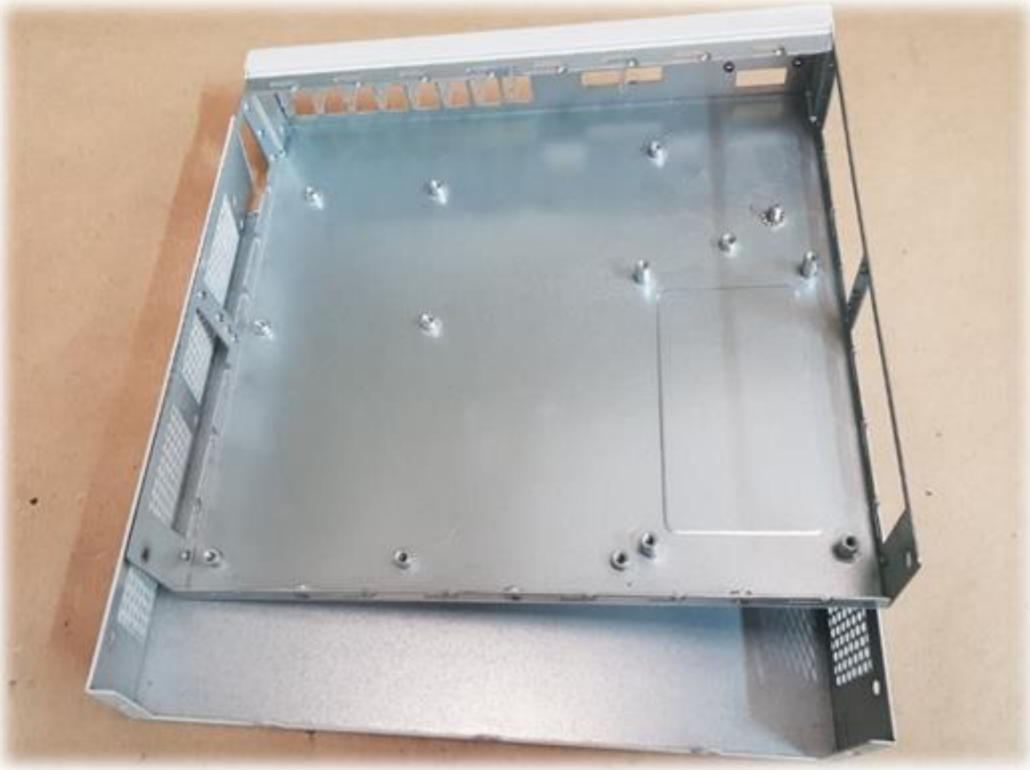


Figure 45. 16ALM metal chassis after disassembly.

Finally, the Aluminium heat sink of a 16ALM unit is shown in Figure 46.

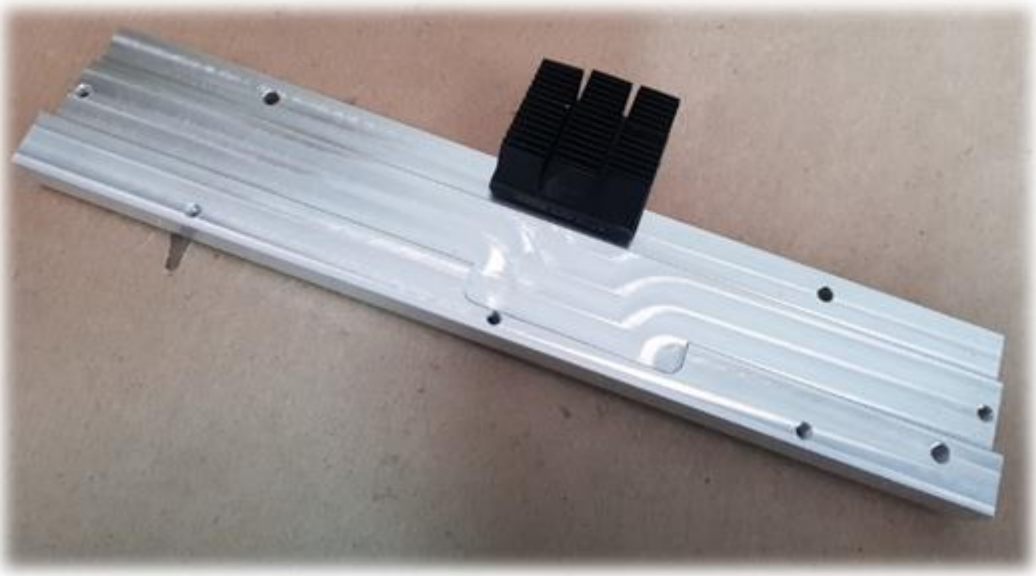


Figure 46. 16ALM Aluminium heat sink after disassembly.

The disassembly further revealed the relative portions of each material fraction of the active ALM units. Results for the 16ALM are summarised in Table 6. Results for the 64ALM are similar (with the obvious exception of total weight).

Table 6. 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 7.

Table 7. 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 placement of the battery is shown in Figure 47.

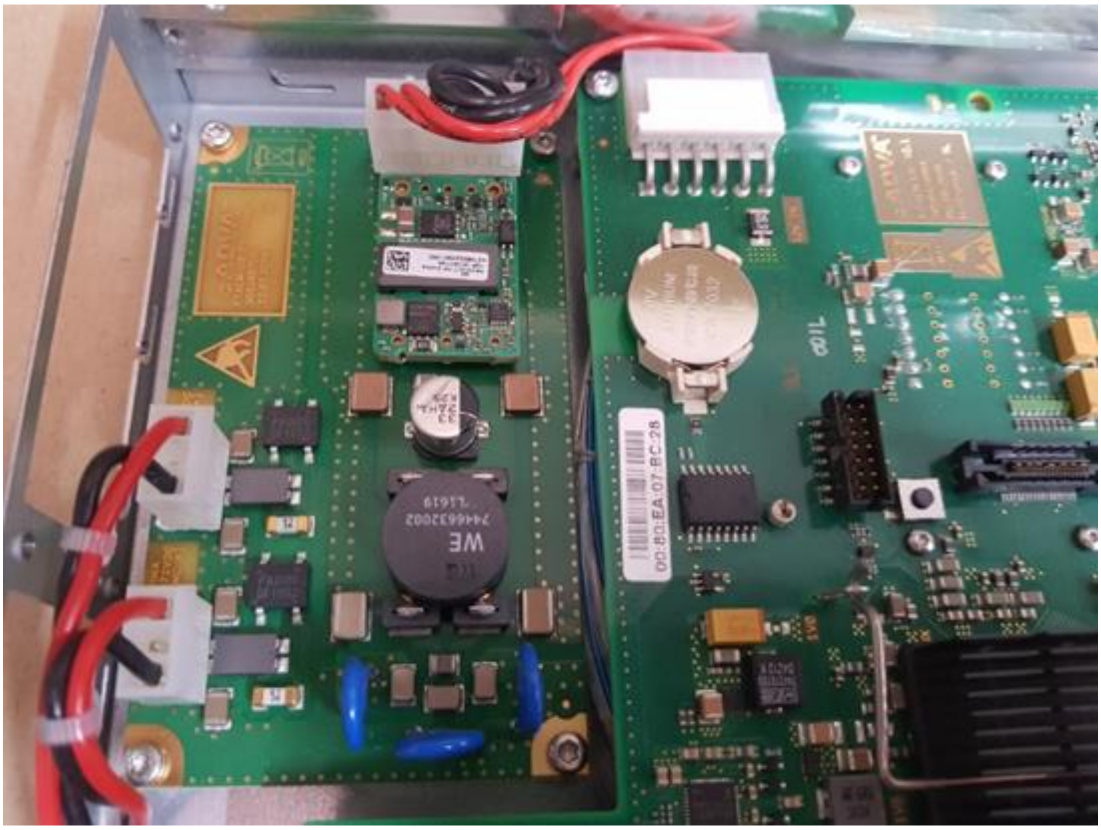


Figure 47. Battery from the 16ALM motherboard.

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. For some parts, the analysis was repeated since in the first analysis, some parts seemed to have high Bromine content. This result was corrected in the second analysis.

6.1.2.2. Ecodesign aspects of ALM passive sensors

The 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. Some sensors may not even have moving parts. 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.

Some ALM sensors, like water-detection sensors, even work revertive. After a triggering event and after drying, they return into their original state and can be further used. The same holds for the door-opening detectors. The fire sensors that are integrated into sprinkler heads must be replaced after a triggering event. However, in case of a large fire, this will be by far the smallest part that has to be replaced.

The passive ALM sensors have significant advantages over respective electrical sensors. To investigate some of these advantages LCA's has been performed for the passive sensors. At the time of the handover an electrical fire sensor is not at hand and therefore only the preliminary work and assumption has been made.

LCA Assumptions

For the LCA various life cycle phases has been considered: Production, Use and End of Life. The passive sensors do of course not have an energy consumption during use and therefore has a fixed emission during the entire lifetime. In order to compare the CO_2-emissions of the electrical sensors with the passive sensors, we need to consider its lifetime. The general life expectancy for a commercial fire detector is 10 years[45] and will be used for this purpose.

Furthermore, it is expected that the sensors will be able to last for the entire lifetime of the building and the end of life likely will be a part of demolition of the building, but End of Life is still considered.

As mentioned earlier, the exact number of passive units used for the demonstration is still unclear and will therefore be an estimate of 500 units.

The function of the passive sensors is described in chapter 6.1.4.2.

Fire-door sensor

In Figure 48 the results of the LCA for the fire-door sensor is presented. The overall CO2-emission is 285.8 kg CO2e. Production accounting for 276.1 kg CO2e and the End of life being 9.7 kg CO2e.

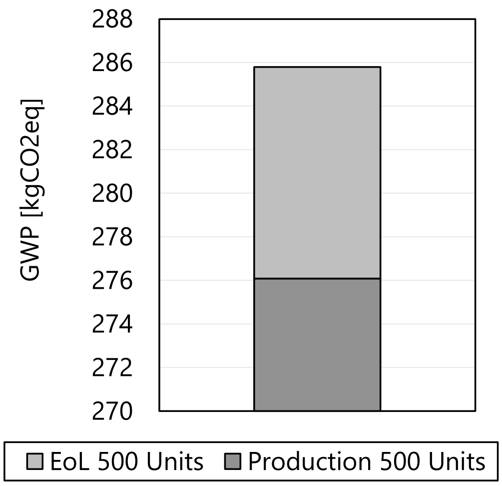


Figure 48. LCA of Production and End of Life for 500 fire-door sensors.

Sprinkler sensor

Figure 49 shows various pictures showing the different parts of the sensor and how it is attached to the sprinklerhead.

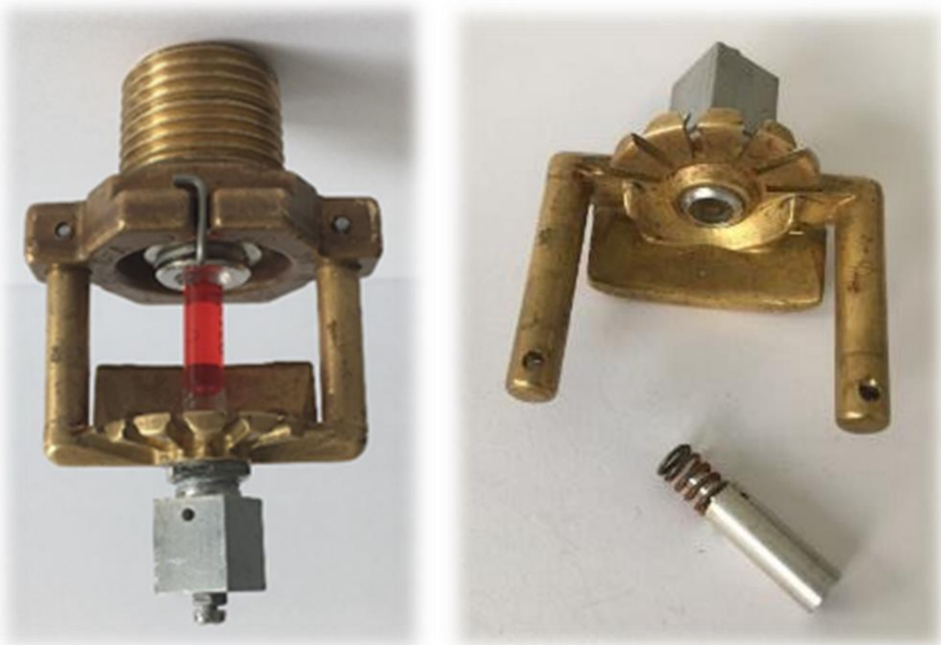


Figure 49. Sprinkler sensor and sprinkler head.

In Figure 50 the results of the LCA for the sprinkler sensor is presented. The overall CO2-emission is 13.1 kg CO2e. Production accounting for 13.7 kg CO2e and the End of life having a positive impact due to the recycling of aluminium.

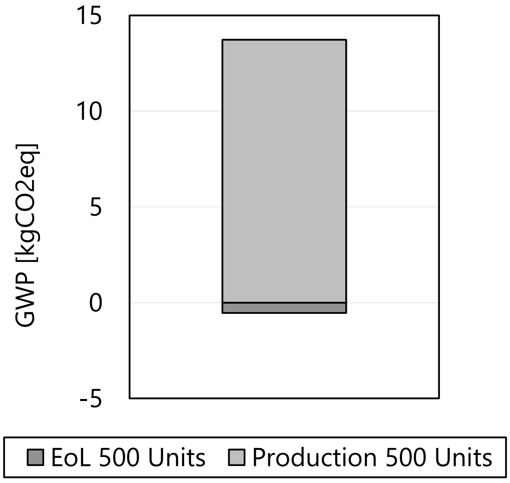


Figure 50. LCA of Production and End of Life for 500 sprinkler sensors.

Electrical fire sensor

As mentioned previously in this chapter we are not in possession of an electrical fire sensor. One aim of this chapter was to compare passive with electrical sensor. The comparison will, if possible, be presented in a future work package delivery.

One eco-design consideration regarding the new sensors was the respective material selection. The optical parts are determined in material choice by the required functionality. They require some silica glass, which is an uncritical material. They may also require some very small mechanical parts like metal springs, or optical reflector filters, which can be produced from dielectric thin films. This leaves a small housing where there is a certain degree of freedom for the material choice. An obvious recommendation is black plastic (e.g., ABS), as has been shown for the sensor in Figure 33 already.

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 have clear LCA advantages over electrical sensors. Their infrastructure (the cables) also has certain advantages over the infrastructure required for electrical sensors.

6.1.2.3. Ecological aspects of the business models

In general, product-service systems (PSS) are regarded most beneficial for supporting circular economy and the related environmental aspects [31], [32]. However, we already identified several hurdles that prevent some of the PSS to be successfully implemented for products with long lifetime and a high innovation pace in Annex 1, CE Challenges.

Here, we give a short overview on the advantages that can be expected from the various PSS, and preliminary results of the analyses we have conducted on PSS in WP4. An overview on the different PSS according to [31] is given in Figure 51. Here, the PSS that have already been identified as critical in Annex 1, CE Challenges are marked in red.

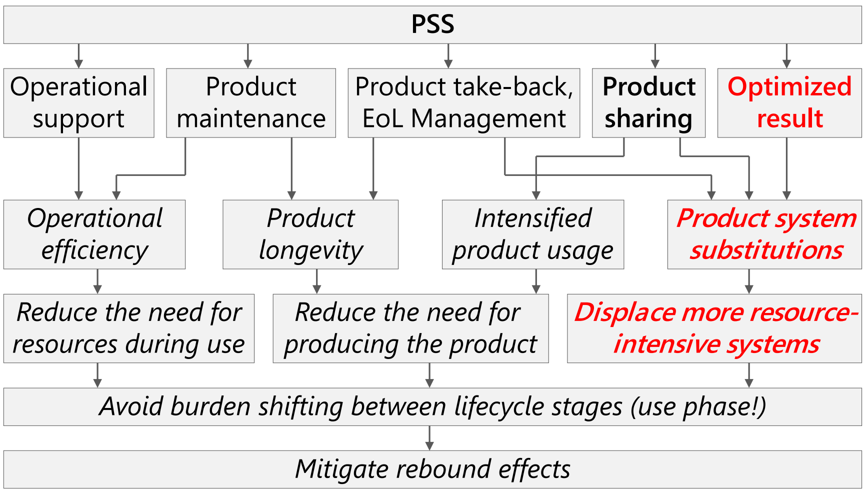


Figure 51. PSS analysis (also see Figure 103)

PSS are a key enabler of circular economy. The main ecological benefit comes from potentially decoupling economic growth from resource consumption [31]. Table 8 summarises the enablers for resource reduction for the different PSS types.

Table 8. PSS strategies supporting four different PSS enablers of resource reduction [31].

PSS strategy [type of PSS]	*Enabler of resource reduction*
Operational support (e.g., performance monitoring, training of customer personnel) [Product-oriented, use-oriented, result-oriented]	(1) Operational efficiency
Product maintenance (including repair, upgrades, etc.) [Product-oriented, use-oriented, result-oriented]	(1) Operational efficiency
	(2) Product longevity
Product sharing [Use-oriented, result-oriented]	(3) Intensified product usage
	(4) Product system substitutions
Take-back/EoL management (for reuse, remanufacturing, refurbishing, recycling, etc.) [Product-oriented, use-oriented, result-oriented]	(2) Product longevity
	(4) Product system substitutions
Optimised result (e.g., substitute physical transport with videoconference services) [Result-oriented]	(4) Product system substitutions

The order of the enablers mentioned in Table 8 states increasing resource-reduction potential. Operational efficiency has some limited capability for resource reduction, e.g., through reducing all maintenance efforts. The maximum reduction is estimated to be in the range of a factor of 2. Product longevity, if not restricted by aspects like energy efficiency, can massively shift the production (i.e., resource consumption) of a successor product into the future. Maximum resource reduction in this case is estimated to be in the range of a factor of 10. Intensified product usage has even higher potential, e.g., in cases where a product has low utilisation by a single user (e.g., <10% of total time) and can be shared in a meaningful way by several or even many users. Here, maximum reduction factor is approximated as a factor of up to 100. Note that ICT core-network systems already make use of maximised utilisation through sharing between many users! Product system substitutions potentially have the highest reduction factor, which can be as high as a factor of 1000 (or even higher in certain cases). An example is a virtualised conference (typical in Covid-19 times!). A single user may be online, say two days and download several presentations and videos. This may cause a total of several 10 kWh energy consumed, which translates to several 10 kg CO2e and consequently, less fossil energy consumed. When flying to the conference, including hotel and all other aspects to be considered, the global warming potential (and the related saving in fossil energy) can easily be in the range of several tons of CO2e.

6.1.2.4. Ecological end-to-end logistics aspects

ADVA has developed an efficient logistics concept for inbound and outbound logistics, together with its logistics supplier UPS, for a large customer (British Telecom, BT) in the UK [38]. Instead of shipping the products from ADVA's logistics hub in the UK (York) to the centralised BT logistic hub, the concept makes use of UPS's decentralised access points (UAP, UPS Access Point). From here, the equipment can be picked up by local BT service engineers. The concept is shown in Figure 52. The concept makes use of the sharing capabilities of a large logistics provider with a substantial network of geographically dispersed access points.

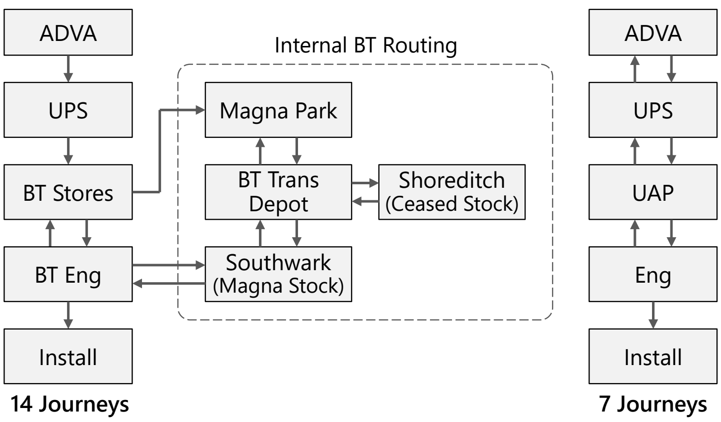


Figure 52. Logistics optimised for a large customer in the UK, together with UPS. UAP represents the nearest geographically dispersed logistics point of the logistics provider (UPS Access Point).

Compared to the old logistics scheme, the number of journeys for the installation of a single piece of equipment has been reduced by a factor of two. This saves truck-roll mileage and hence, carbon emissions. It also saves cost and (installation) time. Annual GWP savings of the logistics scheme are in the range of 500 t CO_2e related to British Telecom in the UK. Scaled across the globe, the saving would be at least ten times higher.

As a secondary effect, the logistics scheme significantly increased the number of units that are sent back for maintenance and refurbishment. As such, the scheme was an enabler for a certain amount of CE business with BT. The number of equipment units that are sent back and repaired/refurbished exceeds 1000 per year. The total installed base exceeds 100,000.

The main transport mode – air freight vs. sea freight vs. land freight – has the highest impact of all logistics contributions. This follows from straightforward carbon-emissions capture as done, e.g., in LCA. Thus, reduction of air freight is key to reducing logistics emissions. Since air freight also is the most expensive freight mode, its reduction is automatically followed in a cost-driven approach. However, there are certain limitations to reducing air freight beyond certain thresholds. Required customer lead times may not allow sea freight, which may take some six weeks or so when equipment is sent from China (which it often is). Then, aspects like the US-China trade war or the Covid-19 pandemic may require urgent, short-term shifts in the supply chain, which can only be compensated in terms of secured delivery by air freight. Only after these supply-chain changes have settled, a slow migration to sea freight or land freight may take place. As an alternative, a higher degree of production in the EU is considered meanwhile. This also follows from requirements (in the ADVA case) regarding higher degrees of business continuity, which in turn partly result from ADVA now being rated system-relevant in the Covid-19 context. This (partial shift of production back to Germany) will be done in 2020/2021. However, it leaves the unsolved problem that this will cause incrementally higher cost and that customers are not willing to pay for this.

Packaging is a relevant area regarding total environmental impact of products. In the recent years, ADVA optimized almost all aspects of packaging:

- Weight, size (absolute)
- Size adaptation to Euro pallets (makes transport more efficient)
- Reusability (which is not always applicable)
- Recyclability
- Plastic reduction/elimination, which was not always possible

Reuse is not always feasible, although all packaging in general can be used more than once. Reason is that reuse requires respective logistics relationships between sites. If for example single products are delivered (outbound) to geographically dispersed locations, which is a scenario typical in telecommunications, it would require dedicated truck rolls to re-send the packaging to the vendor. In that case, there is the trade-off between the added truck roll and the reuse of the packaging. In certain instances, it may be environmentally better to have the packaging recycled near the products' final destinations. On the other hand, if regular transport between a logistics hub of a vendor and a logistics hub of a customer takes place, packaging reuse can easily be implemented since no added truck rolls are required. During the project, ADVA started implementing such a scheme, together with one of the resellers. Implementation is still ongoing, therefore, details regarding its efficiency cannot yet be presented.

Plastic elimination so far was the remaining hurdle for complete packaging optimisation. It was limited by two aspects:

- Up to 2020, there was an upper limit of the weight of the respective product, above which plastic was required to confirm the drop tests that are required for the packaging to comply with applicable quality standards like Telcordia GR 63 Core. The upper limit was slightly less than 1 kg weight of the product. Below this weight, packaging was already available that did not require plastics. Above this weight, plastic was required because other materials like cardboard could not withstand the *g* forces in the drop tests.
- The second limitation to plastic elimination in packaging is that ADVA's products are *opto-electronic* products. These products, at least partially, must be protected against electro-static discharge (ESD), and optical components must be fully protected from dust. ESD protection is typically done with ESD bags, which are plastic bags that are coated with a very thin conductive layer. These bags also protect the electronics from humidity. In certain cases, these bags may be replaced by paper bags with a similar conductive layer. However, both humidity and dust may then remain as problems. Optics must be protected from duct. Therefore, direct packaging in cardboard is not an option for opto-electronic devices. Again, certain alternatives may exist, but in general, a plastic bag remains the preferred option. It also needs to be noted that such a plastic bag is only a very small fraction of the total packaging. Moreover, certain customers require the elimination of single-use plastics. In these cases, the plastic bags may be taken back, be produced of recycled material, or go into related plastic recycling.

The first limiting aspect, weight of the product, has partially been solved during the project, with support of the project. The related new, plastic-free packaging design is described in more detail in Ch. 6.1.3.3.

Adhesive tapes used to wrap packaging in most cases consists of plastic as well. During the project, ADVA also selected new adhesive tape for its packaging. The new tape is paper-based. It was selected for replacing plastic tape after respective tests. More details can again be found in Ch. 6.1.3.3.

6.1.3. Development of the product

6.1.3.1. Development of new ALM active units

As explained in Ch. 6.1.2.1, no new active ALM releases will be or can be developed during the project. The development cycles take too long, and quality requirements (according, e.g., to ISO 9001) are too strict to allow quick input from external projects. However, any (ecodesign) findings that are derived during the project will be considered in a new release of ADVA's DfE ecodesign guide. There, they will influence new releases of any products in ADVA's portfolio in the future.

6.1.3.2. Development of new ALM passive sensors

Within the project, two new sensors are developed, a sprinkler and a firedoor sensor, in line with the agreed actions 'ALM_A1.1.1 Design for longevity' and 'ALM_A1.1.2 Design for recycling', as well as 'ALM_A1.2.1 Reduce energy consumption in the use phase' and 'ALM_A7.3.1 Implement eco-design strategies across the life cycle of ALM products and the subsequent reduction of energy use'.

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. Please see below for a simple illustration of the configuration. 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. For each sensor, a portion of the light is coupled out with a passive coupler after which a sensor is connected.

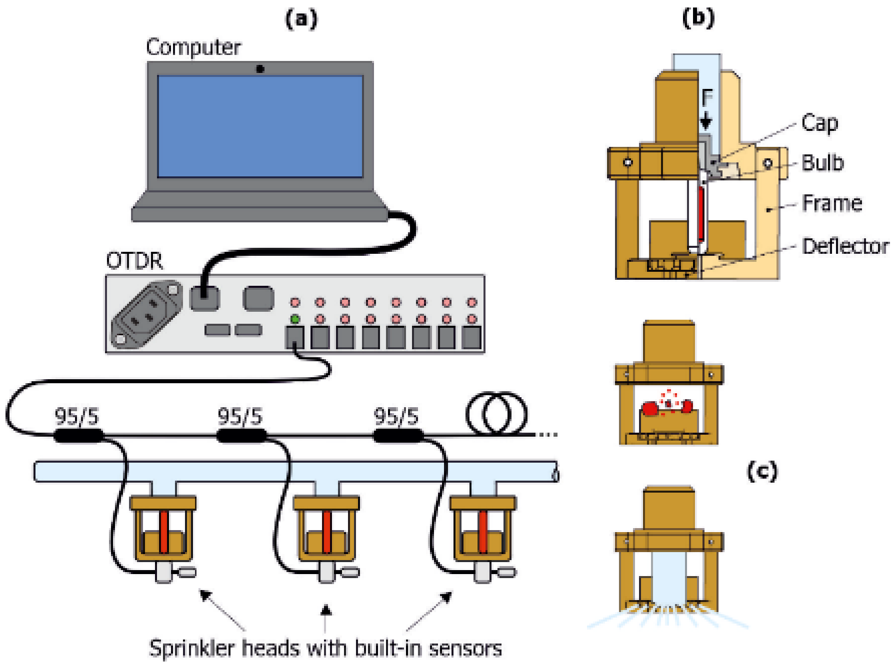


Figure 53. Sprinkler sensor architecture

The sensors are located on the bottom of the sprinkler heads as illustrated below in (a). (b) shows how the fiber is mounted in the sensor and (c) shows the operation principle. When the sensor is initially installed, the glass bulb is in place and as such light can pass through the fiber (yellow line in (b)). The light reflects at the End-reflector and thus a reflection peak can be seen by the ALM. When the sprinkler is activated, the glass bulb explodes to activate the water flow. With that, the spring pushes the fiber up and cases a bend as illustrated on the bottom figure of (c). This causes the light to be attenuated and as such, the reflection peak disappears (or at least is strongly attenuated).

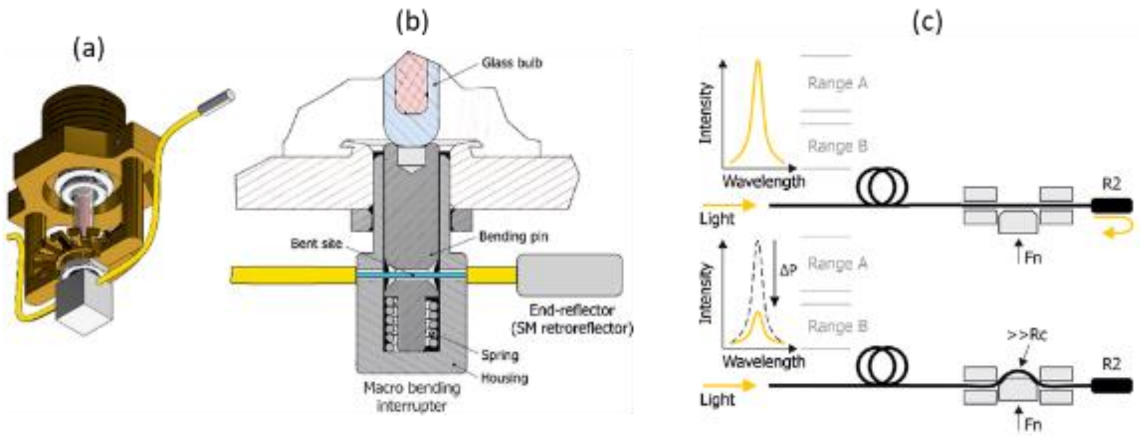


Figure 54. Sprinkler sensor operation principle

To test the performance of the design, 10 sensors were realised with 3D printing technology. Please see the pictures from the lab below, where (a) shows the test setup and (b) shows pictures from the actual evaluation process.

Figure 55. Sprinkler sensor evaluation setup

The OTDR trace results are shown below. In the upper plot, the bulb of the water sprinkler was in-tact and thus a clear reflection peak could be detected. After activation of the sprinkler, the complete reflection disappeared (bottom trace).

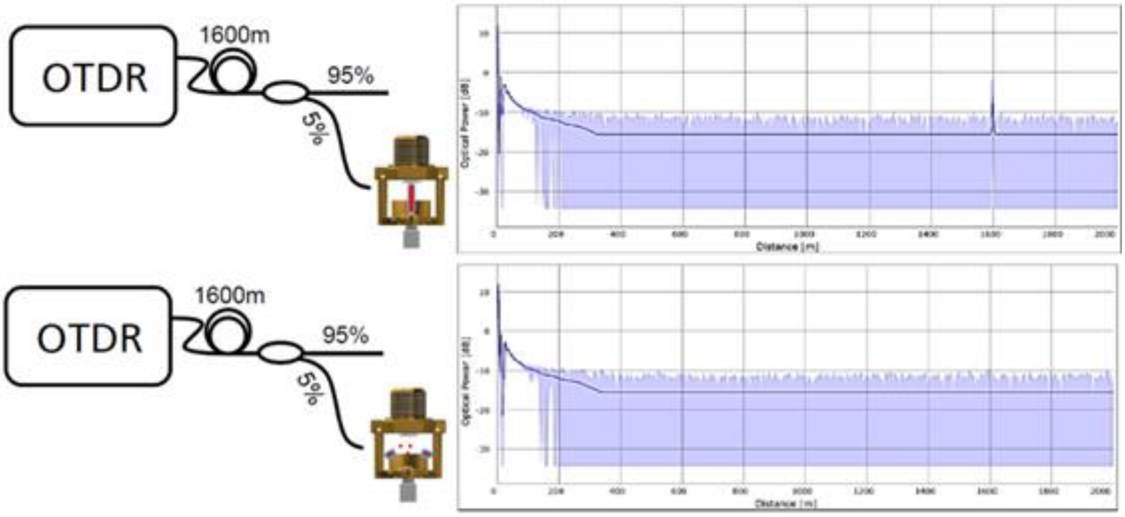


Figure 56. Sprinkler sensor measurements

Fire door 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.

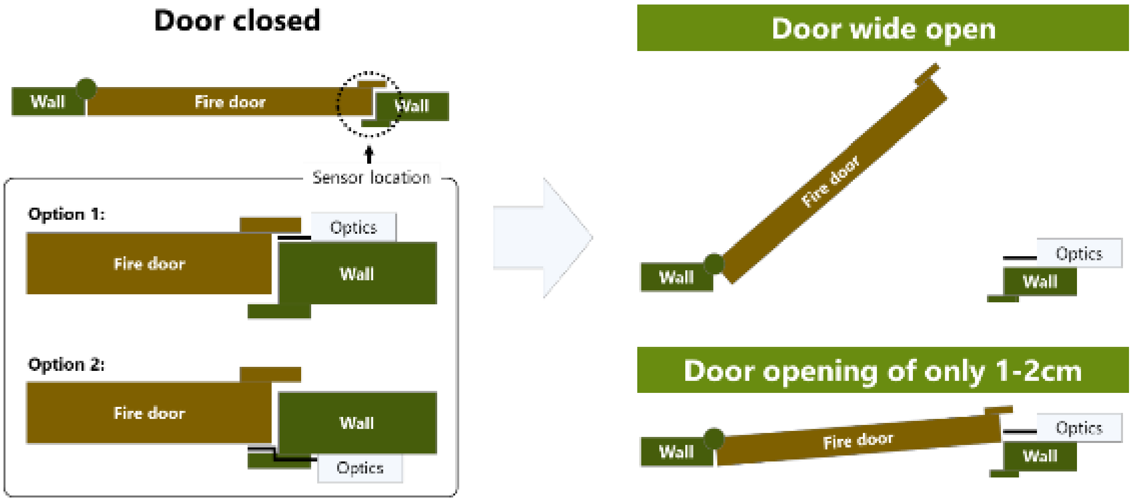


Figure 57. Fire door sensor operation principle

The operational concept of the door is identical to the sprinkler sensors described in the previous section. 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.

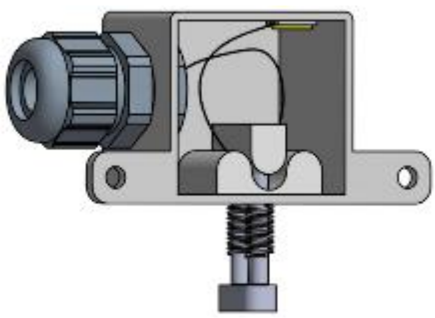


Figure 58. New fire-door sensor

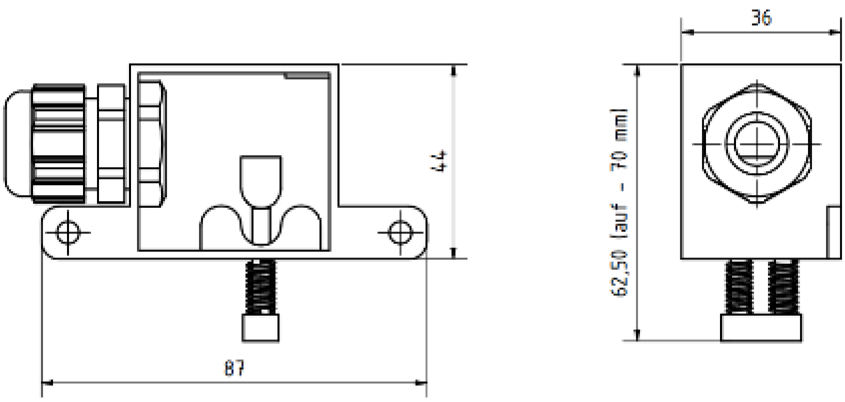


Figure 59. New fire-door sensor. All dimensions in mm.

The figure below shows the operation of the fire-door sensor. When the door is closed, the sensor does not attenuate the probing OTDR light in the fibre and as such, the demarcation reflection can clearly in the OTDR trace. When the door is opened, the fibre is bent and thereby the reflection peak attenuated.

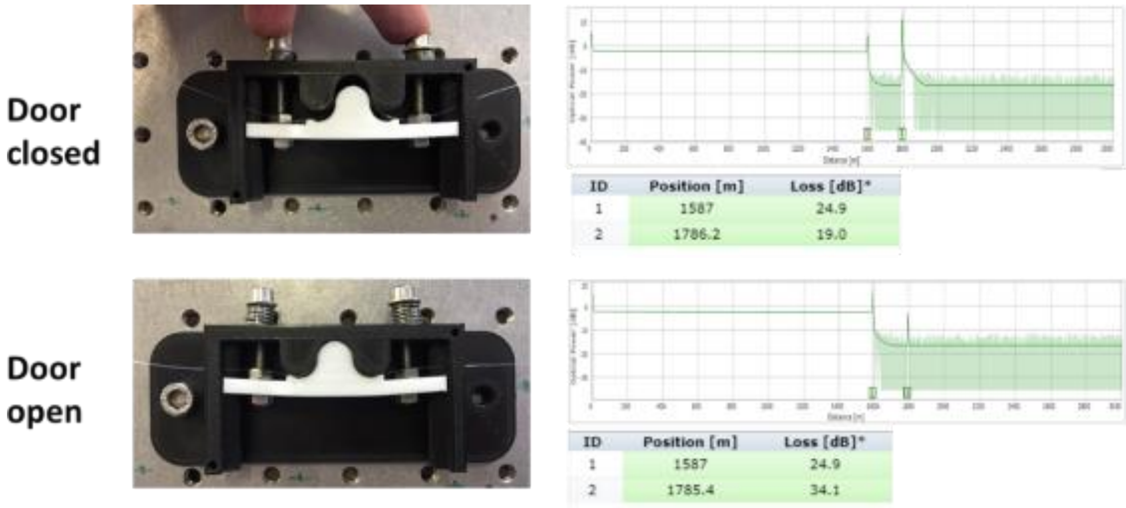


Figure 60. Fire-door sensor evaluation.

Sensor analysis

As explained in Ch. 6.1.2.2, 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 [39]. This advantage for the ALM system is primarily driven by lower energy consumption *per sensor*, with a secondary smaller contribution from lower material consumption.

For the project and the newly developed sensors, this leaves the question of the environmentally friendliest material recommendation. This only holds for the final mass production of the sensors (with hundreds to thousands per year). The prototypes are individually assembled lab samples, and the pre-series will be produced with 3D printing. 3D printing in general can make use of several plastics (e.g., ABS, PET, HDPE, PP, PVC, TPU, and Nylon). It can also directly use metal (DMLS, direct metal laser sintering). However, a dedicated recommendation for a small pre-series is not meaningful due to its limited impact. Therefore, the material choice for the pre-series is done upon material availability or other practical parameters.

Mass production of the sensors should use a (plastic) material that has minimum environmental impact during raw-material extraction and production. The material must also comply with the mechanical requirements of fibre-optic sensors and with the requirement of a very long sensor lifetime of up to several decades. Apart from this, no aspects need to be considered since the sensors only consume very little material. Therefore, they are negligible, e.g., in recycling, compared to plastics coming from other WEEE.

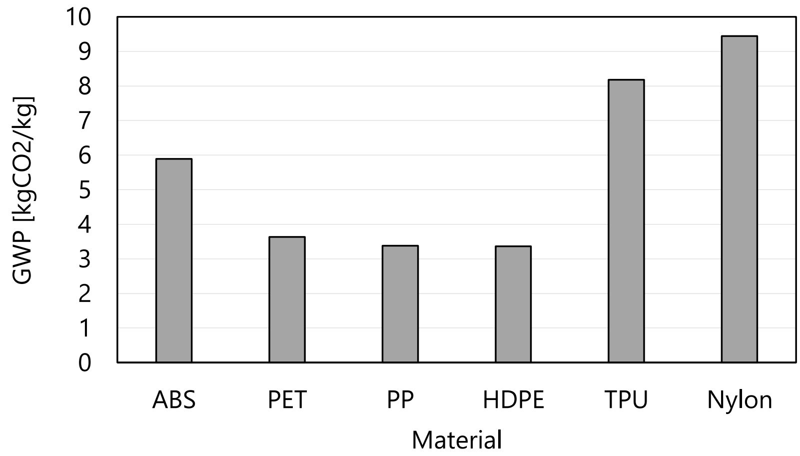


Figure 61. LCA comparison between various plastic types.

ABS has excellent mechanical properties e.g. it is easily mouldable and can be recycled [44]. However, ABS has a higher environmental impact than e.g. PET, PP and HDPE and the recycling of ABS shows a significant degradation of properties. The various plastics has not been tested, but the LCA result in Figure 61 leaves room for further discussion and investigation. It appears that ABS is often chosen due to the excellent properties. However, in some cases, the mechanical requirements might be lower and therefore it is possible to give the environmental impact higher importance.

6.1.3.3. Development of new ALM packaging

The aim of the revision of the existing packaging concept is to develop packaging without plastics. In addition to the main goal, the goal is to also reduce the size/volume and weight and having the packaging at simple as possible to handle and easy to construct. The Telcordia GR 63 core remains the criterion for compliance of product protection. These goals are in line with action 'ALM_A9.1 Reduce cost of packaging disposal'.

Various packaging concepts where tested and evaluated for a number of modules in ADVA's product portfolio.

Unfortunately, the preliminary designs for the 16ALM showed a significant increase in packaging material and volume. Based on the result it was decided not to progress with a plastic free design. However, in the process, the packaging of other modules was evaluated, e.g. of the 24CSM filter modules. This showed a positive initial result and it was decided to progress with testing of the packaging. The plan is now to finish developing the packaging for the 24CSM in order to then see whether the model for the 24CSM can also be adapted for the 16 ALM.

Moreover, an alternative to small plastic bags for packing loose part was suggested. This is a bag made of 50 g/m^2 Glassine, which is a thin translucent paper product. The bags are illustrated in Figure 62.

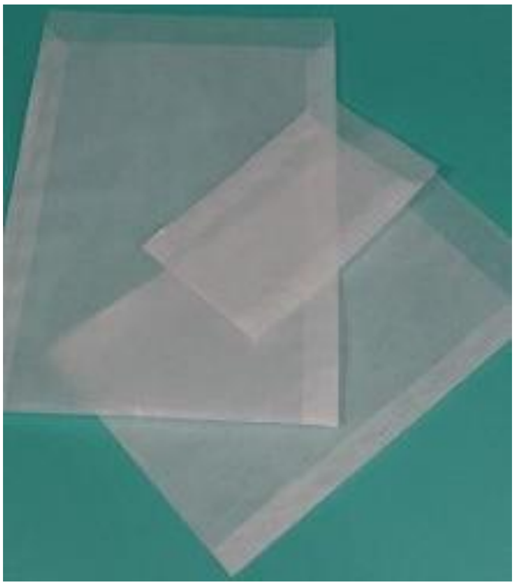


Figure 62. Glassine packing bags.

A LCA shown in Figure 63 that was conducted to compare the new plastic-free packaging and the existing packaging with plastic shows clearly the environmental advantage of the new design for the 24CSM. The total saving is 1.21 kg CO_2eq./unit. As can be seen in the figures the emission from the production in the plastic-free packaging is higher than the original with plastic. This is due to that the new packaging is slightly heavier. The reason that a saving despite heavier packaging occurs is due to the volume of the packaging, which is smaller for the plastic-free packaging. This means it will take up less space when being transported.

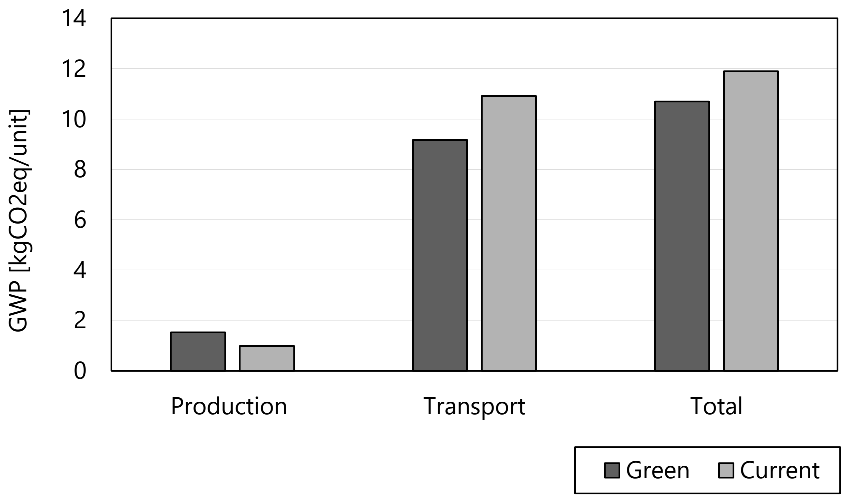


Figure 63. LCA comparison between new plastic-free packaging (Green) and existing packaging with plastic parts (Current) for the 24CSM.

Due to the positive results, it is planned to re-designing packaging for more of the ADVA portfolio. A first preliminary re-design has been made for the 4CSM filter module.

Given that a new plastic-free packaging is implemented for the 24CSM and 4CSM, it would give savings of around 1.2 t CO_2eq over a period of three years for about 1,000 units. Given the plastic-free packaging is successfully implemented for one of the most sold modules like the GE102 Ethernet NID, we could have a saving of about 1,200 t CO_2eq for about 100,000 units.

Paper tape

In order to reduce the amount of plastic usage a suggestion of replacing plastic tape with paper tape was made. A performance test to evaluate the paper tape was performed and showed only advantages in comparison to the plastic tape. Based on the results the paper tape has been implemented in four of ADVA's facilities.

Figure 64. New plastic-free (paper) packaging tape.

A simple LCA to investigate environmental benefits was created. Assuming the only difference is the paper and plastic and all other elements such as the roll and glue are the same. The paper tape is slightly heavier per meter than plastic tape. This means for a roll with the same weight that it contains 50 m of paper tape or 66 m of plastic tape.

Figure 65 shows a LCA comparison between plastic and paper tape. Paper has a worse performance in many categories. However, looking at the main category GWP, paper has a significant better performance. On a yearly basis, it will lead to a reduction from 676.7 kg CO_2e to 88.9 kg CO_2e. On a yearly basis, with ~450 km of tape required, this leads to a reduction from ~680 kg CO_2e (plastic) to 90 kg CO_2e (paper).

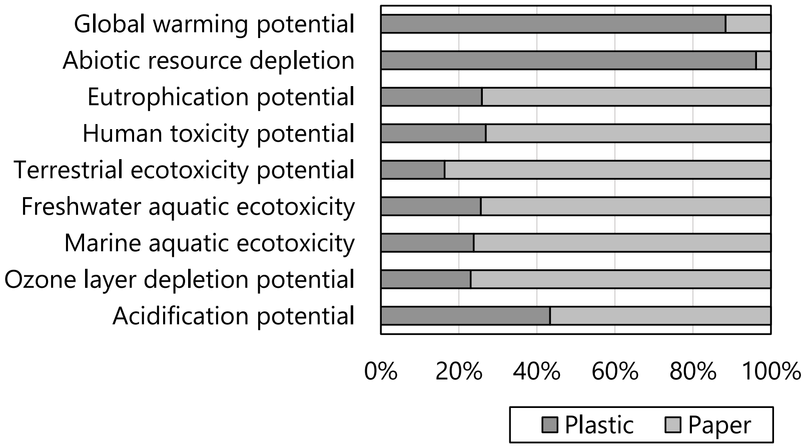


Figure 65. Simplified LCA comparison between plastic and paper tape for different impact categories.

Green packaging has a potential of further savings if implemented across the product portfolio. The subject will continue to be developed and improved after this deliverable.

6.2. ICT functionalities

6.2.1. What is not included and why

New ICT (tool, database) functions are not directly integrated into ADVA's demonstrator. The reason behind is that with the development cycles and quality requirements that are typical for telecommunications products, it is impossible to integrate any third-party functions into B2B products within the timeframe of the C-SERVEES project.

In addition, certain attempts to ICT tools and their data content in particular from early phases of the project seemed at least debatable. This specifically referred to the data content and complexity, which has been subject of discussions within the work group of ADVA's demo. Even though potential contents were repeatedly discussed, a consensus has not yet been reached concerning this point, thus no implementation has been realised for any specific software or ICT-tool-related aspects.

The question of data content and complexity refers to two areas. First, there was discussion about the data to be compiled and provided in order to support recycling and possibly other CE aspects like parts reuse, content of recycled material and some others. Some proposals discussed were after *maximum* information content, which included high complexity. This included, for example, material declarations, as used for REACH, for supporting recycling. At the same time, we collected first feedback from recyclers (that do not participate in the project) that such level of detail would be completely useless in their recycling business. This is particularly obvious when considering the standard recycling method used today on broad scale, which is shredding without detailed prior disassembly and sorting of material fractions into respective recycling streams. Obviously, without massively changing broad-scale recycling modes, no data would help. This aspect should be further discussed. ADVA brought this aspect forward in a paper for Electronics Goes Green 2020+ [40]. This aspect – *what needs to change in recycling itself to make use of ICT data?* – must be further investigated beyond this project.

The second area referred to data in support of logistics aspects. Again, discussions did not (yet) lead to results acceptable from the large-industry perspective. It is not feasible to provide data on all sellable items (more than 5000) and all suppliers (more than 500). In particular, it is absolutely impossible to quickly change such a supply chain without disrupting the supply. This is particularly true since during the project, certain changes had to be done with regard to the supply chain to counter-act both, effects of Covid-19 and effects of the US-China trade war. Therefore, only a few sample data sets were provided to the project partners.

Consequently, the question remains as to which data is required in order to support recycling and logistics. In both cases, the tool and software technology itself (e.g., Blockchain) is regarded *irrelevant* compared to the content question. Moreover, in both cases, the next relevant questions are how to migrate and what else needs to change (e.g., in recycling itself). The discussion results also led to the application of a German funded research project (under the *Digital GreenTech frame program*) that is dedicated to the data content of the future Digital Twin or *Asset Administration Shell*. Given acceptance, this project can be regarded as triggered by the C-SERVEES project.

As mentioned, ADVA does regard the software itself and its features as of secondary importance. The content is far more important, and still completely unclear. In particular, we believe that Blockchain is an overrated technology that possibly will not sustain. In particular, if implemented and used in less efficient modes, Blockchain has unacceptable energy consumption that further fuels the problems stated in Annex 1, Ch. 1. According to [41], Bitcoin alone (which is based on a public Blockchain) was responsible for 0.2% of world electricity consumption, which is unacceptably high. In addition, Blockchain may address the wrong IT security requirement in the given context. If at all, Blockchain secures data integrity (and even here, breaches have been shown in the past) [41]. However, data integrity is possibly not the primary concern in sharing CE data along value chains. Authentication, similar to databases, depends on implementation, and confidentiality is low. This is summarised in

Table 9.

Table 9. Comparison of relevant aspects of Blockchains and databases [41].

	Blockchain (public / private)	Client-server database
Integrity	++	++
Authenticity	Implementation-dependent	
Availability	++	+
Confidentiality	-- / 0	+
Resource consumption	High / low	Very low

Therefore, ADVA regards Blockchain as irrelevant in the context of ICT tools that aim at supporting CE aspects.

6.2.2. ALM ICT functionality and development

The ALM system is part of product portfolio of B2B, *carrier-class*, i.e., professional telecommunications systems. Within the telecommunications networks, these systems in almost all cases connect to the so-called data communication network (DCN). Within the telecommunications network, the DCN is a dedicated network that is solely used for monitoring and managing the network elements. This is shown in Figure 66.

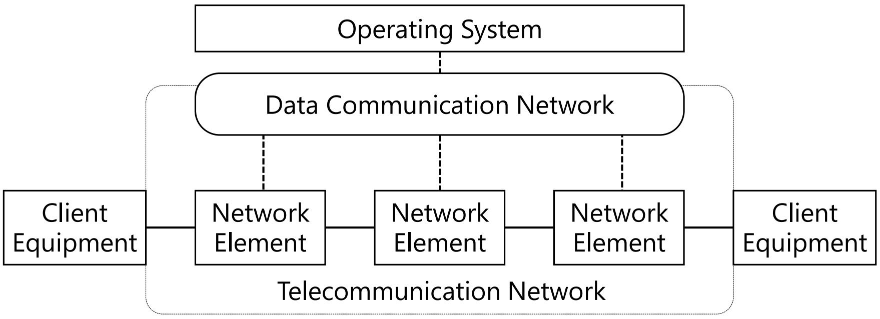


Figure 66. DCN concept as implemented for all carrier-class telecommunications equipment [42]. In the demonstrator context, the active ALM units constitute network elements.

The monitoring and management tasks and functions are quasi-standardised under the term FCAPS, which stands for fault, configuration, accounting, performance and security management. The FCAPS functions are summarised in Table 10.

Table 10. FCAPS functions in telecommunications networks [42]. NE: network element.

Fault	Configuration	Accounting	Performance	Security
Alarm handling	System turn-up	Invoicing	Data collection	Control NE access
Fault detection	Network and service provisioning	Asset management	Report generation	Enable NE functions
Fault correction	Auto discovery	Work order	Data analysis	Access logs

Relevant functions in the context of ICT tools that support aspects of circular economy fall into columns one and four of Table 10.

Fault management allows the supervision of all installed network elements, including fault detection, correlation and even prediction. The latter is based on monitoring various physical parameters of the network elements and analysing them for any signs of system degradation. Fault prediction can be used to initiate preventive maintenance, which in turn can include aspects such as scheduled maintenance. The latter has the potential to minimise truck rolls in the necessary reverse logistics. This also partially falls under asset management (accounting).

Performance management supports fault management in that it collects general data (in this case, about the network elements, not the services they provide). Together with fault and asset management, it allows scheduled maintenance. The latter can then be optimised together with logistics providers, as described in Ch. 6.1.2.4. Therefore, telecommunications systems, including the ALM, have certain inbuilt ICT functions that support CE aspects like maintenance and logistics. This is enabled because the respective network elements are connected to a dedicated management network, the DCN.

In 2016, ADVA developed a proposal for extending the DCN-enabled management capabilities by local tagging of telecommunications products, e.g., with RFID (radio-frequency identification) tags. This aimed at becoming more independent from connection to the DCN, e.g., in cases where the respective equipment had been disconnected from the network. Another aim was to get quick and simple access to product data on circular-economy and health-and-safety aspects via a hand-held device (the RFID interrogator). The concept is shown in Figure 67.

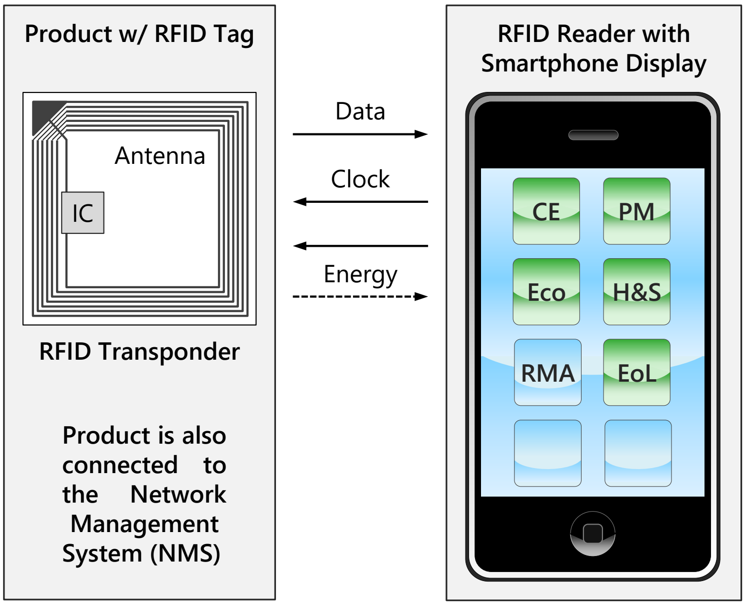


Figure 67. RFID / NMS concept proposed for US010700917B2 [43]. CE: circular economy. PM: preventive maintenance. H&S: health & safety. Eco: Eco settings and Ecodesign aspects. EoL: end of life treatment. RMA: return material authorisation.

The idea behind using additional RFID tags was to provide data, e.g., on CE options or health & safety characteristics in a local tag that was attached to the product. Depending on the RFID type, the tag could have contained the data directly, or it could have contained a link to a web-based database.

In total, the RFID tags, together with the network-based management functions, can help providing information in order to support all CE mechanisms and lifecycle phases. This is indicated in Figure 67.

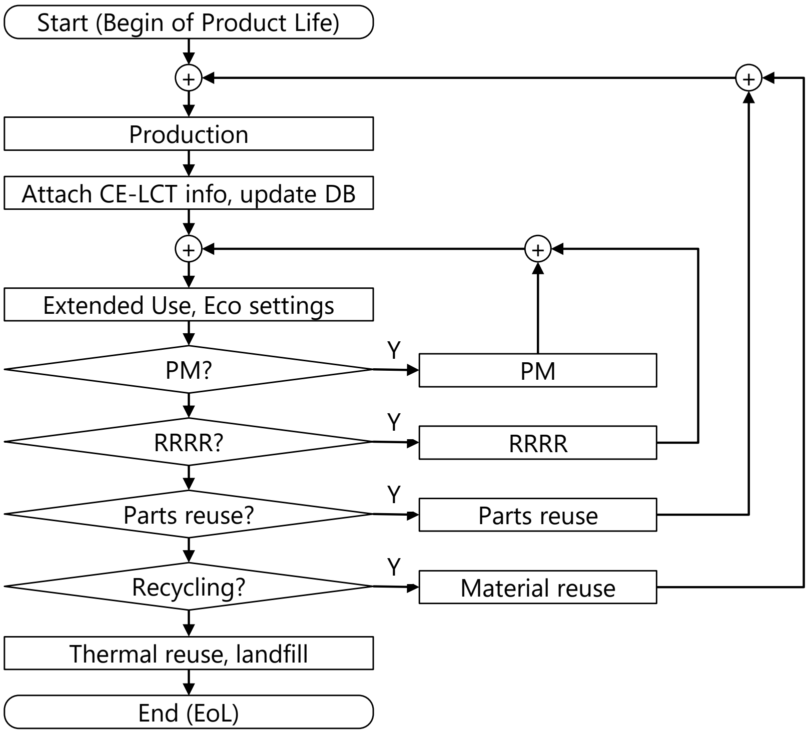


Figure 68. Flow chart proposed for US010700917B2 [43]. CE-LCT: CE lifecycle tag. DB: database. EoL: end of life. PM: preventive maintenance. RRRR: repair, repurpose, reuse, or recycle.

The data either on the tag or in the network-management database can help following the respective loops indicated in Figure 68. This may contain relatively simple tasks like triggering preventive maintenance actions, including the necessary return-material authorisation. It may contain information on parts or components that are suited to further reuse (compare Annex 1, CE Challenges). It may also contain information that supports more efficient recycling. However, this information has not been specified any further.

This leaves the question still open which data is required to best support recycling.

7. TV sets and displays demonstrator

The activities conducted in the design and production phase were derived from the TV-CIRCMODE short-term actions validated in WP2. The short-term actions were developed into demostration actions to be implementated in WP4. The table below presents the TV-CIRCMODE canvas sub-components integrating short-term CE actions corresponding to the design and production phase, as presented in D2.5.

Table 11. Validated short-term TV-CIRCMODE Canvas Key Circular sub-components and their associated Circular Economy Actions relevant for the design and production phase.

TV-CIRCMODE Canvas Sub-Component	TV-CIRCMODE validated short-term Circular Economy Actions
TV_C1.1 Diversify circular activities	TV_A1.1.1 Increase recycled plastic content in TV parts
	TV_A1.1.2 Decrease packaging waste
TV_C1.2 Embrace eco-design to ensure products circularity across life-cycle stages	TV_A1.2.1 Improve durability and reparability
TV_C1.3 Adopt circular strategies in the production process	TV_A1.3.1 Enhance the integration of circular strategies into the production process
TV_C2.3 Introduce and/or expand the use of ICT to foster circular economy	TV_A2.3.1: Use ICT to enhance TV circularity during the production and end-of-life phases

The following sections provide an overview of the TV demonstrator, the product description and related design and production activities. It also provides a description of the ICT functionalities developed to be implemented and tested in the design and production phase of the TV demonstration, as well as the description of validation tests performed for the demonstrator products.

Information and features of the demo product are given below. Product demos will be held in Spain and Turkey in the next phase of the project to demonstrate new CEBM (renting/leasing for home appliances).

7.1. Demonstrator description

Demo TV set enables to receive and watch digital stations (via DVB-S, DVB-T and DVB-C), including the High Definition (HD) ones. At present, reception for these digital television stations in High Definition is only possible in some countries in Europe.

This television can receive and process all analogue and all unencrypted digital stations. This television set has an integrated digital and analogue receiver. The digital receiver unit converts the signals from digital stations to provide outstanding audio and picture quality.

The TV guide (only for digital stations, if provided by the broadcaster) tells of any schedule changes at short notice and provides an overview of all the stations' schedules for the next few days.

The TV set can be connected to various data media, for example an external hard drive, a USB memory stick or a digital camera to the USB socket. Using the file browser, the user can then select and play the file formats desired (for example, MP4, MP3 or JPEG data).

With the Time Shift function, the user can easily stop and resume a programme with the remote control in a fast and simple way. Programme is recorded to the external data medium.

The TV set can save any digital TV channel chosen, if no limitation has been imposed by the broadcaster. The TV channel is transformed by the TV and saved to a USB external data medium.

Interactive applications allow to use various Internet services easily.

HDR (High Dynamic Range)

The Grundig TV provides an optimised cinematic quality image performance with HDR support. High-dynamic-range imaging (HDRI) is a technique used in photographic imaging and films, and in ray-traced computer-generated imaging, to reproduce a greater range of luminosity than what is possible with standard digital imaging or photographic techniques. Standard techniques allow differentiation only within a certain range of brightness. Outside this range, no features are visible because in the brighter areas everything appears pure white, and pure black in the darker areas. The ratio between the maximum and the minimum of the tonal value in an image is known as the dynamic range.

HDR stands for High Dynamic Range and refers to a technique that reveals details in content in both very bright and very dark scenes. It offers a more natural and realistic image even in a wider contrast range. For example, in a very dark cave scene, HDR TVs show the look and color of cave walls as well as their texture. In a scene with a yacht on the ocean, one by one is clearly seen where the sun's rays shine regardless of the background where the sun shines.

Best Quality Sound

Thanks to the soundbox positioned according to the special acoustic design principle, the user can enjoy better quality sound with less loss compared to TVs using standard speakers.

4 core processor

TV's performs faster with powerful processors. By its interface designed for fast and practical use, favorite applications or television channels are easily selected.

Application Market

The product has a wide application market. It can easily access the content whenever the user wants. Netflix, YouTube, beIN CONNECT, Blu TV, Puhu TV, SS IPTV, open browser and more in one TV! Also, some of the applications are supported by country based.

HEVC

Grundig TV's provide best quality video performance with HEVC feature. High Efficiency Video Coding (HEVC), also known as H.265 and MPEG-H Part 2, is a video compression standard designed as part of the MPEG-H project as a successor to the widely used Advanced Video Coding (AVC, H.264, or MPEG-4 Part 10). In comparison to AVC, HEVC offers from 25% to 50% better data compression at the same level of video quality, or substantially improved video quality at the same bit rate.

Dimensions

Height: 62.5 (cm)

Depth: 23.1 (cm)

Width: 97.6 (cm)

Energy class

A+

Annual On-Mode Energy Consumption (EP): 80 kilowatt-hours

Stand-by Power Consumption(W) (EP): 0.45

Nominal Power Consumption (EP): 55.1 watts [joules/second]

Networked Stand-by Power Consump.: 1.95 W

Part/component	Numbers which are shown in the figure below
Plastic back cover	600
Plastic Front Cover	300
Plastic Midframe	57
Plastic stands	716
Plastic Stand Holder	717
Metal back cover	643
Lens Plastic	323
Main Board AV Braket Plastic	633
Speaker	428
Main Board	110
Power Board	190
Remote control	987

User Manual	901

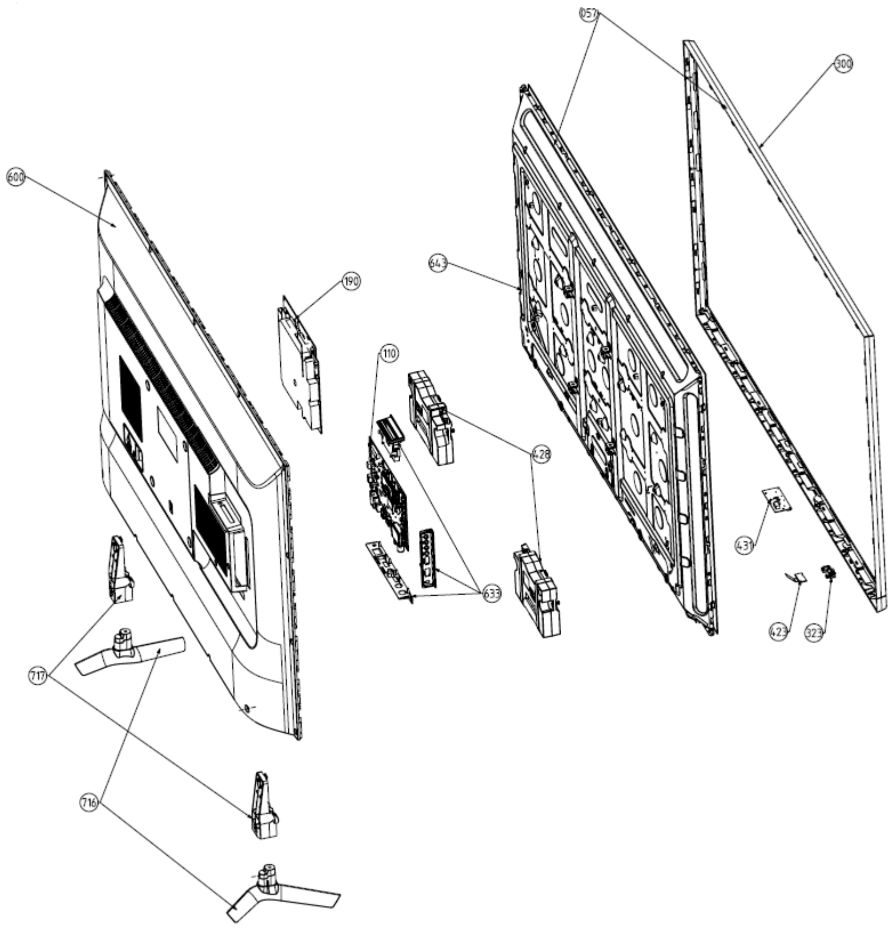


Figure 69. Exploded view of the TV showing the main components of the product, referenced in the table above.

Figure 70 below shows the card structure within the demo product. Mainboard and power unit board are the main materials used.

Figure 70. Card structure of the product.

A label containing a QR code has been added to the demo products. When the QR code is scanned, ICT tool communication will take place and access will be provided to the following information about the product.

- C-SERVEES project information
- Product user manual
- Parts made from recycled materials used in the product and their proportions
- Survey (can be added to get feedback on demo product usage)
- Hazardous substance information in product raw material content
- The product materials that can be recycled after EoL

Figure 71. QR Codes

Figure 72. C-SERVEES Demo Production in Arçelik TV Production Facilities

Demo products will be used in nursing homes (in Spain) and dormitories (in Turkey). Products used in such areas can be used in a special mode that we call the hotel TV mode. When these products work in this mode, the following table features are active. These features are provided by many people to use the product. For example, since the product is used in the common living area, it has a sound limitation feature. In this way, a person who is a guest in the next room is less affected by the sound level.

Table 12. Features included in the demo TV set

Feature	**Demo Product**
Channel Clonning	Yes
Power Mode (Stand-by or power on)	Yes
Volume limitation	Yes
Opening Volume level	Yes
Welcome Screen (Photo)	Yes
Hotspot	No
Menu limitation	Yes
Hotel Setting on Tv Menu	Yes
Extra warning pop-up to log-out from app.	Yes

The opening logo feature has been developed to explain that the product belongs to the C-SERVEES project. When the product is opened, it is shown that the product belongs to the C-SERVEES project. This photo will remain on the screen until you press a button on the remote control.

Figure 73. C-SERVEES Demo Product

Goals of the TV set Demonstrator

The main objective of this phase is to implement eco-design in the TV set by increasing the recycled plastic content in target components and decreasing the use of raw plastic materials, as per the agreed action 'TV_A1.1.1 Increase recycled plastic content in TV parts'. Covestro would be used as supplier for the recycled PC_ABS_V0 for the demo. The demonstration would require the redesign, production and testing of 100 units. These would be produced by ARCELIK at its electronics plant located in Çerkezköy, Tekirdağ, (Turkey).

Additionally, tracing of recycled content would be enabled via ICT (ICT-based certification), as agreed in action 'TV_A2.3.1 Use ICT to enhance TV circularity during the production and end-of-life phases'. The percentage of recycled plastic would be traced by means of digital twin and QR codes. Also, a QR code would be inserted on recycled and/or refurbished parts.

CIRCULARISE would create a digital twin of the TV set via blockchain technology. Supplier documentation of recycled plastic content/formula would be embedded in the digital twin. A QR code would be inserted on the product, for consumers to see information via app and for recyclers/reusers to test ICT functionalities.

- Target: TV back cover (30% PC_ABS_V0, halogen free)

The second objective for this phase of the demonstration is to implement measures to increase the sustainability of the packaging in the TV sets and displays, namely introducing reusable packaging for TVs, using recycled cardboard and eliminating Styrofoam in TV packaging, in accordance with the agreed action 'TV_A1.1.2 Decrease packaging waste'. The measures to be implemented would be supported by the results of the LCA carried out for the whole production process (WP5).

- Target: implement shipments with multi-use plastic boxes instead of individual cardboard packaging (for B2B clients) and reverse logistics (between service centre and factory in Turkey).
- Target: switch to 100% recycled cardboard in boxes

7.2. Eco-design of the TV set

TV product design changes will be planned to use resources in the most efficient way and to reduce our environmental footprint.

According to this, two planned actions were carried out:

- Increase recycled plastic content in TV back cover
- Increase recycled cardboard content in packaging

7.2.1. Eco-design of the back cover

TV has different plastic parts that consisted of different raw material and weight.

The plastic parts of the TV are shown in Table 13.

Table 13. 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

PC/ABS (Polycarbonate/Acrylonitrile Butadiene Styrene) is a blend of PC and ABS providing unique combination of the high processability of ABS with the excellent mechanical properties, impact and heat resistance of PC. The PC/ABS property balance is controlled by the ratio of PC and ABS in the blend, the polycarbonate molecular weight and the additive package. The ratio of polycarbonate and acrylonitrile-butadiene-styrene affects mainly the heat resistance of the final product. PC/ABS blends exhibit a synergic effect resulting in excellent impact resistance at low temperatures that is better than impact resistance of ABS or PC.

Main PC/ABS properties are:

- High impact strength even at low temperatures
- Heat resistance
- High stiffness
- Easy processing
- Low overall shrinkage and high dimensional accuracy
- Colourable & printable

Typical PC/ABS applications are:

- Automotive
    - Middle console
    - Glove box
    - Lower instrument panel
    - Pillars
    - Knee bolster
    - Overhead console
    - Blow moulded seatbacks
    - Structural components

- Electronics
    - TV frames
    - Laptop monitor enclosures
    - Portable hand-held devices
    - LCD panels
    - Keypads
    - Adapters and chargers
    - Mobile phone bodies

https://www.resinex.co.uk/polymer-types/pc-abs.html

In today's world, humanity's rapidly growing consumption of resources is causing severe damage. Therefore, alternative solutions were started to be searched for instead of using virgin raw materials and important steps were taken on recycling. However, due to the fact that plastics can not be collected separately and cleanly at their source, the desired rates in recycling have not been reached yet. Plastics that are contaminated with other wastes lose their economic value and they have to treated to be used as secondary raw materials. For this reason, waste plastics are imported from abroad in order to meet the secondary raw material need and it is very difficult to find raw material suppliers in Turkey.

Therefore, 30% recycled PC_ABS_V0_halogen free raw material supplied by Covestro was used in TVs' back cover within the project. This is the first time such innovation is applied in Arçelik'sTV products.

The reason for choosing TV' back cover as a potential part is that its weight is higher than all plastic parts and it is not a visual aesthetic part of the product.

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 to these analyses, parameters that cannot be measured in the factory are sent to the external laboratory. Within the project, new raw material was tested by accredited laboratory. Thus, it was seen that it complies with the relevant applicable regulations.

All tests required for the approval stage which are storage testings, vibration testings, drop testings, wall mount testing and stow testing have been also completed.

Figure 74. TV' back cover

7.2.2. Eco-design of packaging

Two actions were carried out for eco-design of packaging:

- Switch to 100% recycled paper instead of kraft paper for TV's box
- Multi-use plastic boxes instead of individual cardboard packaging in forward and reverse logistics

There is information about the product features on the product packaging box. As an example, connection information (HDMI, miracast etc.) or broadcast standards (DVB-C / T / S2 etc.). It is important for B2C users to see this information in their grocery store or at home. However, for a B2B customer such as a hotel, hospital or dormitory, this information on the packaging box is not necessary. For B2B customers, installations are carried out collectively, and product packaging is not requested by the customer. For this reason, the utilization of multi-use plastic boxes for B2B customer products is considered relevant. This box is shown in Figure 98 below. The use of this packaging can significantly raise logistics costs because of the need to control the return cycle. However, it should only be used for B2B customers in Turkey.

On the other hand, reusable packaging has cost advantages and uses less cardboard and styrofoam. The same plastic box and styrofoam can be used over and over again back and forth between factory and corporate client. The analyses of this implementation from the environmental point of view will be carried out as part of LCA (in WP5).

In addition to this reusable packaging being more durable and robust, it also tends to offer better protection of the products. By minimising transit damage, it also helps to reduce the resources required to refurbish of the returned products.

Therefore, it is planned to use multi-use plastic boxes for forward and reverse logistics in Turkey. Because of COVID-19 situation, multi-use plastic boxes have not been received yet. Therefore, 100% recycled carboard boxs were used for demo products in Turkey. Multi-use plastic box will be used in reverse logistic operations.

Figure 75. Multi-Use Plastic Boxes

TVs boxes were made by 100% recycled & recyclable material that will be used within the project. All tests required for the packaging approval stage, namely storage testings, vibration testings, drop testings, wall mount testing and stow testing have been completed. These tests ensure that the product is used with its packaging from the transportation stage to the installation process. The test details are explained in the validation test section. Presence of restricted substances with X-ray fluorescence (XRF) has also been analysed. In addition to these analyses, parameters that cannot be measured in the factory were performed in an external laboratory.

Figure 76. 100% recycled carboard TV' box

7.3. ICT functionalities

The first part of the demonstration process for TV and washing machine demonstration overlaps and can be found in Section 4.3. ICT functionalities.

The identification of component and recycled material supplier

Arcelik chose a product component most suitable for the addition of secondary raw material. Arcelik and Circularise then identified a material supplier 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. This required the certification based on an audited production batch of recycled material at Covestro and the identification of the specific amount of it purchased by Arcelik.

Onboarding of the supplier and Arcelik on the Circularise system

Arcelik and the material supplier were onboarded on the Circularise Web App. Arcelik was provided with a QR-Code (see Figure 71) for the back cover of the TV. Arcelik received a personalised dashboard in order to receive tokens from their supplier, certifying the material as recycled. Furthermore, Circularise created a personalized page on the mobile app showing the product properties upon scanning of the QR-Code.

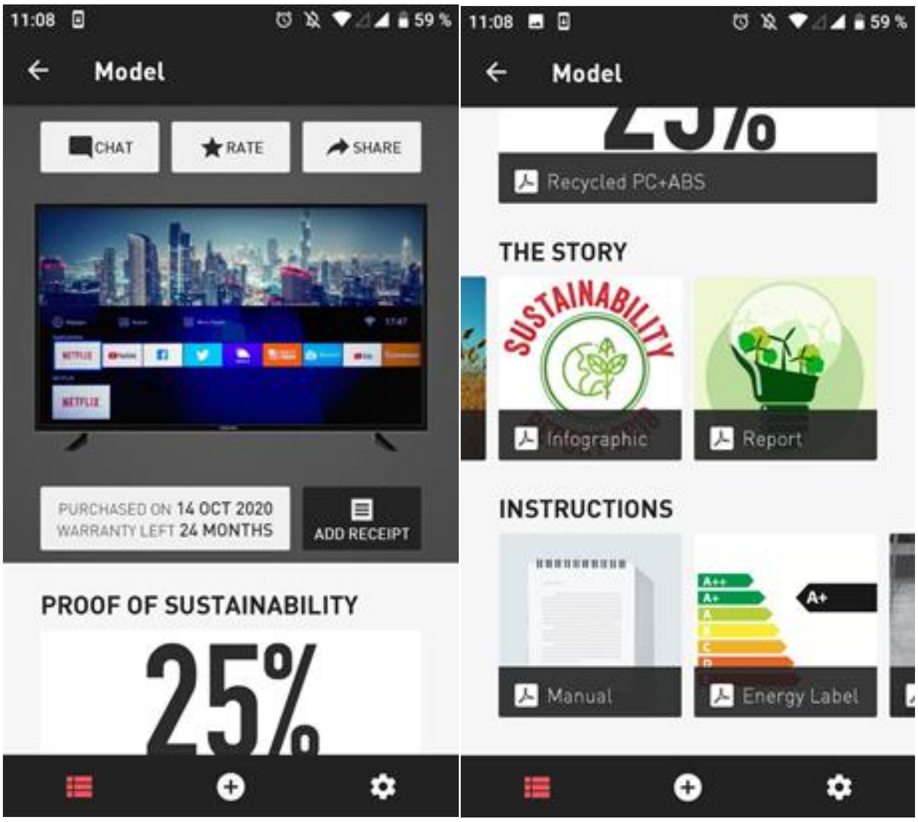


Figure 77. Product in the Mobile App (percentage or recycled content tbc)

Tokens creation

The recycled material was audited by a third-party LCA-expert and verified in its nature of secondary material. This certificate specifying the amount or recycled material. This document was going to be uploaded by the supplier and an equal amount of recycled content tokens was going to be created in order to be transfered to Arceliks account as proof of recycled content. Arcelik sent a purchase order to the recycled material supplier. The material was shipped and passed the quality and security test of Arcelik.

The supplier received the purchase order and gathered the documents of the third-party auditor certifying the total amount of the production batch of recycled material in order to then create tokens.

Next steps

Based on the documents certifying the production batch of recycled material, the supplier, Covestro, will create tokens on its Circularise-Dashboard and transfer them to the Arcelik Dashboard. The demonstration will, according to the current calculations be finalised within 4 weeks. There were no challenges encountered in this demonstration.

7.4. Validation tests

We can divide the tests performed on the demo product into two parts. The first corresponds to the tests performed during and after product design. The second corresponds to the tests applied to each product during product manufacturing.

First of all, we want to share the details of the design tests. These tests are applied during product design. The errors that occur are solved while the design continues, and it is expected that the pre-production product will be error-free. These studies are carried out by the T&V department under R&D.

Errors that occur are reported with the help of the Aquila system and are followed up with the help of this tool. Aquila is an error tracking and reporting tool developed by Arçelik. It provides communication between design and test departments.

Product design tests can be divided into two parts: software tests applied to the demo product and hardware-mechanical tests applied to the product. Both test types are carried out and reported by engineers and test technicians specialised in their fields. Most of the test are applied by test department of electronic plant, however to get some approvements products send to external labs, like HDMI approvment.

Product software tests includes broadcasting (dvb), network, audio, video, user interface, perfomance tests. Each test title contains a large number of test cases and is applied to products. For example, in network tests includes sub-components such as application tests (youtube etc.), miracast tests, IP broadcast tests, HBB TV tests. Details of the test parts applied in demo product design are given in the table below. It is mandatory to pass all these tests to start mass production.

Table 14. TV Test List

ID	SW Test Tasks	Explanation
1	Dolby Vision Tests	To get Dolby approvment
3	Dolby MS12 + Atmos Test	To get Dolby approvment
4	DTS Virtual:X Tests	To get DTS approvment
8	YouTube 2021 Tests	To get Youtube apps. approvment
10	HbbTV 2.0.2 Ligada Tests	To get HBBTV approvment
12	DTS-HD Onay Tests	To get DTS approvment
14	HDMI 2.1 Onay Tests	To get HDMI 2.1 approvment
16	Wi-Fi RF Tests	To test wi-fi performance
17	Frontend Tests (DVB-T,T2,C,S,S2 broadcasting tests)	To test broadcasting performance
18	Panel Performance Tests	To test picture/video quality
19	Bluetooth Performance Tests	To test bluetooth performance
20	Resonance Tests	To test sound performance
21	Audio Performance Tests	To test audio perfoamance
22	HDMI Tests	To get HDMI 2.1 approvment
23	Keypad Tests	To test keypad usage
24	Factory Automation Testi	To simulate production
25	On/Off Product Tests	To test on/off performance
26	Image Quality Tests (PQ)	To test picture/video quality
27	Picture and Video Performance Tests	To test picture/video quality
28	Acoustic-Audio Evaluation (AQ)	To test sound performance
29	Publication Standards and Picture Formats Tests	To test picture/video quality
30	Audio/Video On/Off Tests	To test sound performance
31	Welding Transitions Tests	To test source trans. performance
32	Source and Environment Connection Tests	To test all connection
33	USB (Full Test) Source Tests	To test USB source
34	Audio Performance and Audio Standart Tests	To test sound performance
36	CEC Test	To get HDMI-CEC approvment
37	Panel Adaptation Tests	To test picture/video quality
38	Bluetooth User Tests	To test bluetooth performance
39	ARC Tests	To get HDMI-ARC approvment
41	Menu OSD (user interface) Tests	To test user interface usage
43	Outsource Devices (audio) Control	To test all connection
45	Eco Design Check Tests	To be suitable eco design specs.
46	Broadcast Tests	To test broadcasting performance
47	Hotel TV Usage Tests	To check hotel tv usage
49	Application Tests	To check application store
51	OTA (online update, oad) Tests	To test update of SW
52	CI+ 1.4 Certificate Tests	To get CI+ approvment
54	CI/CI+ Modul User Test	To get CI+ approvment

Other tests applied during the demo product design phase are hardware and mechanical tests. These tests include EMC tests, LVD test, drop test, remote control performance, energy label power measurement, vibration, temperatura test (at different temperatures), humidity, life tests. In order to apply some of these tests, it is necessary to take measurements from the product main board or product power card.

In addition, as in heat tests, the products are exposed to different temperatures for a long time and their operating performance under these conditions is measured. EMC tests are applied by the accredited test laboratories in the enterprise. In this way, the EMC compatibility of the product is confirmed.

All of these tests were applied to the demo product. In addition, the rate of recycling material used in the back cover material in the demo product has been increased by 30%. For this reason, the drop test was especially followed. This test includes dropping the products at a certain height and angle. As a result of these tests, no negative finding that prevents production was found. Figure 78 below shows the drop test application mechanism.

Figure 78. Drop Test Application Mechanism

After product software and hardware tests, the products are approved and ready for production. As a result of the different tests applied, production is carried out with the software and hardware version (approved ones) in which the product can be produced.

Production tests are applied to each product during the production phase. These tests can be divided into tests performed on a piece-by-part basis before the product is finalised, and tests performed after assembly. Before the product assembly, separate tests are applied to the basic components of the product. These tests; panel BMS, main board and power unit tests. The tests for the electronic card are applied after each card is produced. And it is checked whether there is any malfunction in the cards by measuring the voltage value from the measurement points on the card.

After the assembly, tests are applied to determine the product performance and failure status at different stations. These tests include color adjustment, image quality, input controls, volume controls, resonance, cosmetic tests. All of these tests were applied during each demo product production. Figure 79 below shows the production test station structure.

Figure 79. TV Production Test Stations

As an example, Figure 80 shows colur adjusment of each demo TV sets.

Figure 80. C-SERVEES Demo Production in Arçelik TV Production Facilities

Figure 81 shows the tests applied to the products during demo product production. As a result of these tests, it has been confirmed that each product leaves the production without any problems.

Hat HAT3S
Şasi NX Sasi Plan

Sasi Tipi NX S1 0

Sasi	Sasi	Test No	Test Aciklama	Sure (sn)	Ts	Sira
HAT3S	NX	192	WB	0	T1	1
HAT3S	NX	33	BLUETOOTH_SEARCH	0	T1	2
HAT3S	NX	326	CONNECTWIFI	0	T1	3
HAT3S	NX	212	SWITCH_TO_HDMI1	0	T1	4
HAT3S	NX	60	HDMI1_REZONANS	0	T2	1
HAT3S	NX	214	SWITCH_TO_HDMI3	0	T2	2
HAT3S	NX	299	HDMI3_CHROMA_OPTIC_AUDIO_OUT	0	T3	1
HAT3S	NX	345	OPERATOR_VISUAL_CONTROL	0	T3	2
HAT3S	NX	194	USB_LINE_TEST	0	T3	3
HAT3S	NX	199	IR_CONTROL	0	T4	1
HAT3S	NX	34	BLUETOOTH_FIND	0	T4	2
HAT3S	NX	239	SWITCH_TO_DVBC	0	T4	3
HAT3S	NX	176	DVBC_OPERATOR_AUDIO_OUT	0	T6	1
HAT3S	NX	198	BACKLIGHT	0	T6	2
HAT3S	NX	204	SWITCH_TO_DVBT	0	T6	3
HAT3S	NX	175	DIGITAL_RF_MPEG4_OPERATOR_AUDIO_OU	0	T6	4
HAT3S	NX	283	SWITCH_TO_DVBS	0	T6	5
HAT3S	NX	208	DVBS_4K	0	T8	1
HAT3S	NX	200	LED_CONTROL	0	T8	2
HAT3S	NX	327	CHECKWIFI	0	T8	3
HAT3S	NX	224	SHIPPING	0	T9	1

Figure 81. TV Production Test Stations Detailed

It is ensured that each product is produced flawlessly with the tests applied both during the design phase and the production phase. In addition, after the production, the products are taken by the quality deparment with sampling method and checked. In this area, detailed tests (more than production tests) are applied to the products and after product shipment approval is given. Figure 82 shows some of tests which applied in this process.

Figure 82. Audit Test Rooms

8. Conclusions

The first stage of the C-SERVEES demonstration in WP4 has been focused on the implementation of specific short-term actions for the design and production phase included in each of the four product-specific CEBMs developed in WP2, which were presented as D2.2, D2.3, D2.4 and D2.5. This first phase of the demos also included the testing of the ICT tools developed by WP3, namely the ICT-enabled certification of recycled material content by Circularise.

The activities planned for this fist phase of the demonstrations have suffered varying degrees of delay due to the COVID-19 situation. This has translated into a general 6-month delay for the production of the first demonstrator, with some activities still not completed (e.g. the certification by ICT, which is still to be finalised for the washing machine, TV and printer demonstrators as described in the respective sections of the deliverable).

The results shown in this report were achieved in the period from February 2020 up to September 2020, and from the diversity of the activities carried out the different nature of the demonstrators in the C-SERVEES project becomes apparent.

For the washing machine and TV set demonstrations, led by Arçelik, 100 units of each device have been designed and produced in line with circular economy principles. These demo products contain increased recycled content, QR codes with access to product information and specifications, besides the additional connectivity features offered by the Arçelik products. These physical demonstrators are ready to be used in the second phase of the WP4 demonstration, the Distribution and Use Phase, where the washing machine and TV set CEBMs contemplate a change from conventional sales towards new renting or eco-leasing alternatives.

In the printer and toner cartridges demonstration, led by Lexmark, no new products are being developed or manufactured specifically for the project. The idea behind this demonstrator is to enhance the current PSS (MPS, or Managed Print Services) run by Lexmark to offer longer lasting devices and increase the percentage of printers which can be recovered and refurbished at their end of life, avoiding the generation of waste and improving the overall circularity of the company. Within the design and production phase, the focus was on the examination of a selected number of printer and toner cartridge models - in cooperation with the dismantling/refurbishment partner, Syncreon and recycler partners, Indumetal and Greentronics - in order to collect feedback that can be translated into future eco-design measures for the Lexmark devices. The outcome of the trials was successful so far, with opportunities for improved end-of-life management and a potential to establish new business agreements and generate revenues from the treatment of end-of-life printers and toner cartridges. Further exercises and analyses will be carried out for the next phase of the demonstration, including the finalisation of the recycled content certification by ICT.

For the ALM demonstration, led by ADVA, no new active ALM units are being developed within the project time frame, as this is not feasible due to time constraints, same as for the printer demo. The focus of this demonstrator is on new releases of ALM passive units or sensors, specifically designed as an alternative to the currently used electrical fire detection sensors. This eco-designed alternative was in development during the first stage of the demonstration and has materialised into two new fibre-optic based fire-detection sensors (sprinkler and firedoor models) ready to be used in the following stage, which involves testing a PSS for the ALM system (active and new passive units involved) with a selected client.

ADVA is specially interested in analysing how the several potential improvements to CE business proposed within the ALM-CIRCMODE can actually be implemented, and if the existing limits to CE in the ICT sector can be overcome. As a basis for this goal, within the current phase of the demonstration ADVA has already carried out an in-depth analysis of the environmental impact of the ICT sector, which is included as part of this demonstrator. The inclusion of new ICT functionalities beyond what ADVA has already implemented has not been realised for the ALM system yet, discussions on potential benefits and hurdles are still under way.

Since the beginning of the design and production phase of the demonstration, a common dialogue between the partners involved in the demos has taken place in order to understand and establish the necessary interactions and plan and execute the demo activities. With the ground provided by the results of this initial stage, interactions planned between demonstration leaders will help to achieve a higher degree of harmonisation and sharing of experiences.

Annex 1 (ADVA – ALM demonstration)

Environmental impact of ICT equipment

1. ICT Environmental Status

The main components of the ICT sector, or the Internet, are wired (access and backbone) and wireless (access only) networks, data centres, and end-user equipment. The networks interconnecting users and data centres account for ~25% of the total resulting energy consumption and associated emissions. They split into backbone or core and access (incl. wireless) parts. The core networks consist of aggregation switches, routers and fibre-optic WDM (wavelength-division multiplexing) long-distance transport. For these *infrastructure* equipment classes, some 80-90% of the environmental impact are determined by the use-phase energy consumption, which can be derived from lifecycle analyses [1]-[5], also refer to Ch. 1.2. This is particularly true for the global warming potential (GWP), that is, emissions of greenhouse gases (GHG, i.e., carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3)).

1.1. Traffic growth

Since the global ramp-up of the Internet, its throughput and the associated bitrates have been growing exponentially. This can be tracked in the standard reference for Internet throughput, the Cisco Visual Networking Index, VNI, [6]-[8]. It is shown in Figure 83 where the log scale of the Y-axis is to be noted. The traffic growth is driven predominantly by video traffic, as can also be derived from [8].

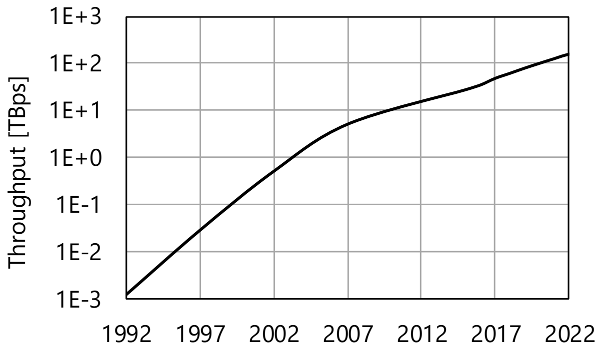


Figure 83. Global Internet traffic [6]-[8]

Because of the persistent traffic growth, the related negative ICT environmental impact grows as well. This holds for all environmental impact categories: GWP, resource depletion, ozone depletion, various toxicity parameters, acidification, eutrophication, etc.

The most important impact of the persistent traffic growth in ICT is on the GWP. This is primarily driven by the related use-phase energy consumption. The energy consumption, in turn, is driven by the increasing traffic, or bandwidths, which is analysed in more detail in Chapter 1.3.

The growth trends (increasing bandwidths, increasing wireless video usage) lead to increasing ICT energy consumption. This is also forecasted for the next couple of years, as is shown in Figure 84 [9]. Here, the ICT energy consumption for Germany has been forecasted. Total growth is comparatively moderate (in particular compared to older forecasts). This is driven by decreasing end-user-equipment consumption. Data centres and in particular networks, however, show relatively strong increase. The main reason is that these ICT parts have to cope with high accumulated and increasing bandwidths.

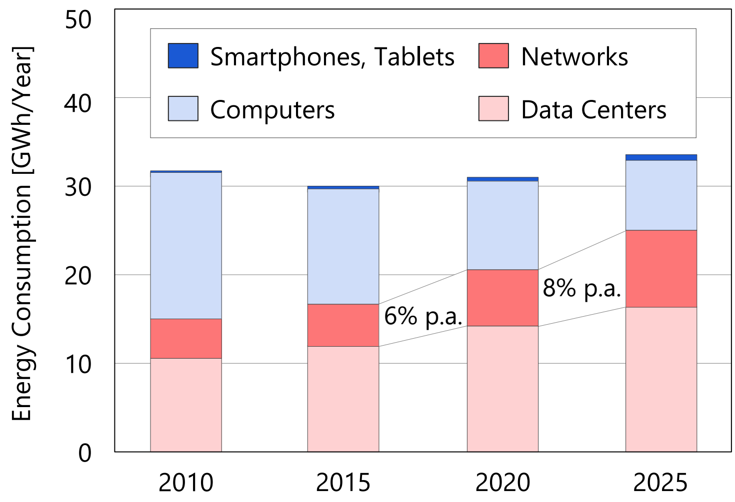


Figure 84. ICT energy consumption in Germany [9]

Regarding the ICT networks, a bit more than 50% are attributed to the wireless part, the rest to the fixed networks. The wireless part is also forecasted to grow faster [10]. In turn, this is driven by 5G rollouts.

Increasing ICT energy consumption leads to increasing ICT GHG emissions. As shown in Figure 85, this increase has been (and will be) somewhat slower than the energy-consumption increase. This is because over time, the related electricity emission factors (with dimension [kgCO_2e/kWh], that is, the amount of kilograms of carbon dioxide equivalents per kWh that is generated) decrease following climate actions toward a higher degree of renewable energy. Note that Figure 85 shows global ICT emissions.

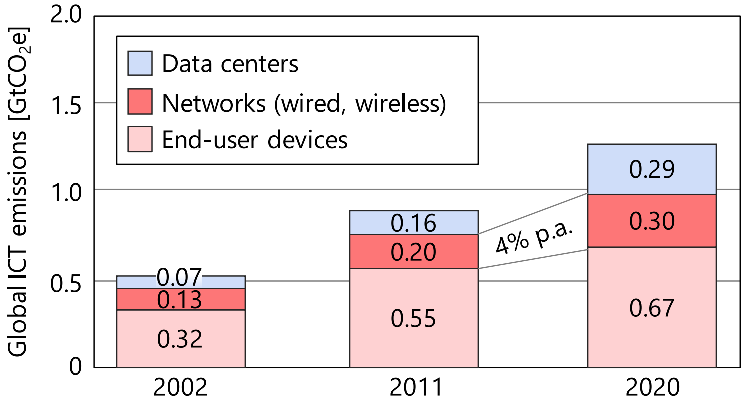
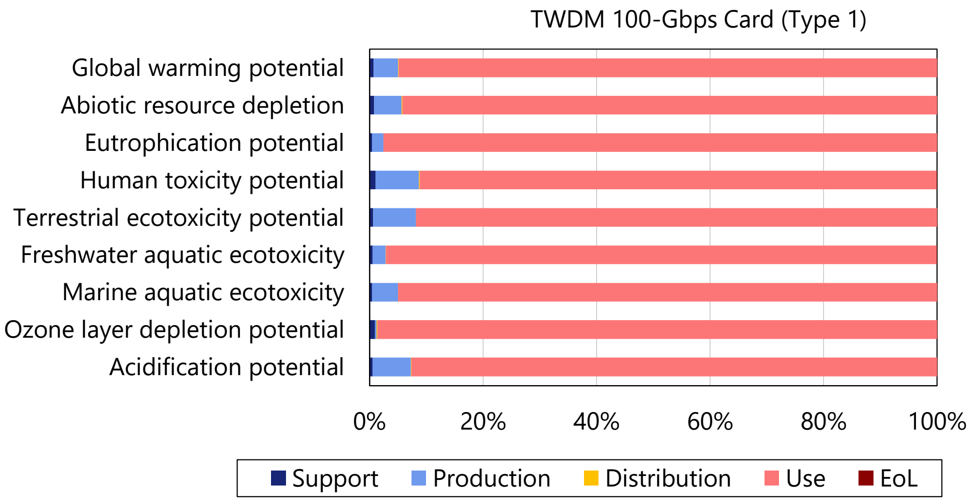


Figure 85. Global ICT emissions [10]

Given the threats of global warming and general resource depletion, the ICT environmental-impact growth is critical. In Chapter 1.5, we will show that this negative ICT effect is compensated by positive environmental effects. However, in the next chapter, we will also show that the ICT sector itself runs into certain problems within the next two decades or so.

1.2. LCA and Power Consumption

Lifecycle analyses (LCA) are important to derive the areas of maximum environmental impact of any (ICT) products. This is necessary in order to identify those areas that require most attention for further improvements. In Figure 86, examples for LCAs for ICT infrastructure equipment (wavelength-domain multiplex (WDM) transport equipment, Ethernet network interface devices (NIDs)) are shown.



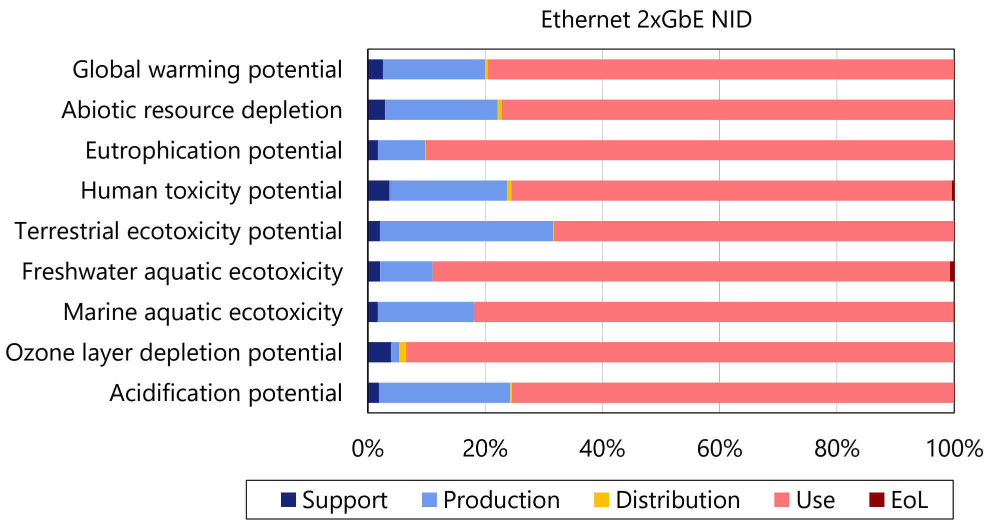


Figure 86. Lifecycle assessments for WDM 100-Gbps channel card (top) and Ethernet NID (below)

For both classes of infrastructure equipment, WDM transport and Ethernet NIDs, all impact categories shown are dominated by the use phase. The same can be shown for Ethernet switches and IP routers [4]-[5]. This necessitates continued work toward better energy efficiency since use-phase impact is driven by the related energy consumption. In turn, this may be *conflicting with design in support of CE*, at least in those cases where total development effort is limited.

LCA can further be used to demonstrate several effects that are related to the use-phase energy consumption and other impact parameters. Figure 87 shows a comparison of two generations of a WDM system.

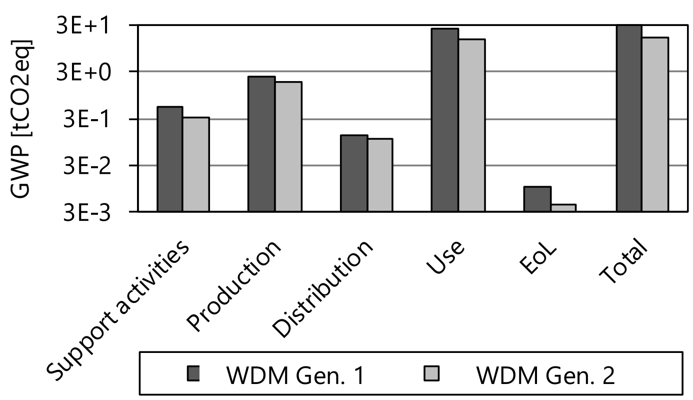


Figure 87. LCA comparison of two succeeding WDM system generations. Note ordinate-axis log scale.

It can be seen that in this particular case, the impact of all lifecycle phases on the resulting GWP improved. Nonetheless, the use phase maintained its dominance (note the log scale of the ordinate axis!). To decrease this dominance to certain extent, the emission factors of the electricity used for operating the equipment must improve since improvements in efficiency are limited [11]. The impact of different emission factors – resulting from 100% renewable energy vs. EU grid mix 2017 – is demonstrated in Figure 88.

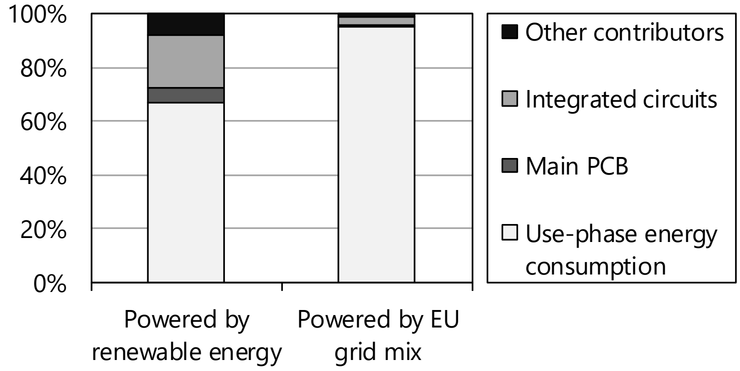


Figure 88. LCA comparison for WDM system operated with renewable energy vs. EU grid-mix energy (2017)

Figure 88 shows that even with 100% renewable energy, the use phase maintains its dominance, although now the next relevant phase, production, becomes more apparent. The figure also identifies the most relevant components in production, namely integrated circuits and printed circuit boards (PCB). Consequently, these are the components most relevant for further CE considerations.

1.3. Trends and Fundamental Limits

The exponentially growing bitrates of Internet applications lead to respectively growing throughput per ICT equipment. In the last one to two decades, this increase has been overcompensated *for end-user equipment* regarding energy consumption and related emissions due to strong gains in energy efficiency. This was mainly achieved by replacing desktop PCs and cathode-ray-tube monitors by laptops and flat screens, in particular the ones based on LCD or OLED (liquid-crystal display, organic light-emitting diodes).

ICT data-centre and network equipment also got more efficient. However, it also had to cope with the accumulated bandwidths of an increasing number of applications. For core-network equipment (switches, routers, and WDM transport equipment), it has not been possible to cope with this bandwidth growth by gains in energy efficiency: as a result, *core-network equipment, over time, consumes more energy*. This has been investigated by several authors, including own research in particular for WDM equipment [12]-[15]. Results of these studies are summarized in Figure 89.

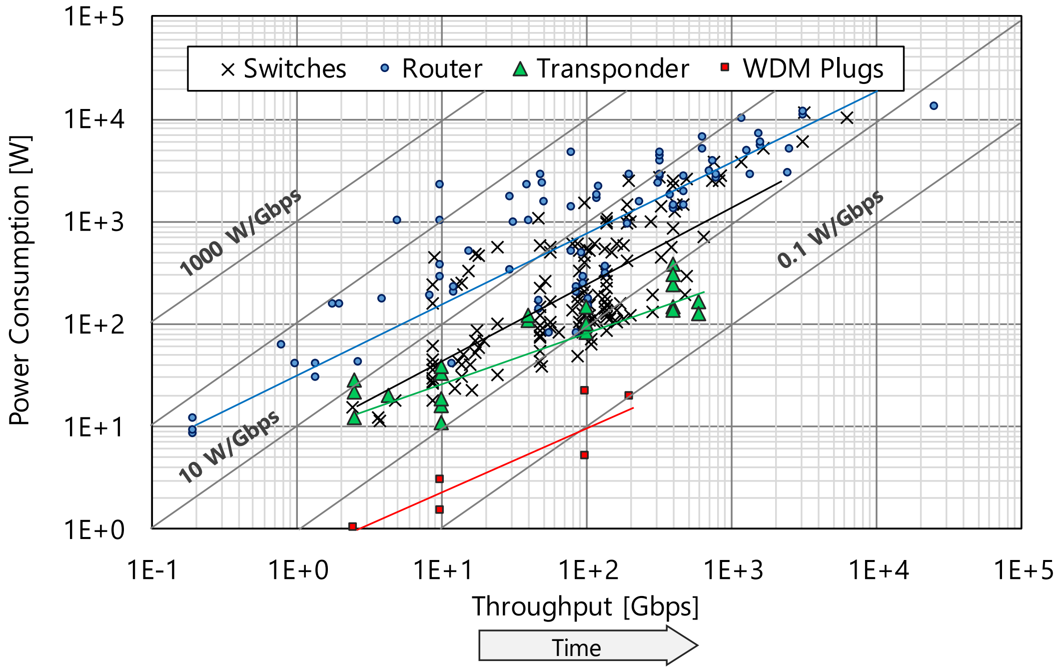


Figure 89. Power consumption of core-network ICT equipment [12]-[15]

Note the log-log scale of the diagram. The X-axis also pretty much reflects a time axis, albeit at almost linear scale.

For WDM equipment, two classes of equipment are shown, transponders and pluggables. The former provide higher performance, e.g., long-distance capability, and have less compact form factor and higher power consumption, compared to pluggables. They are used in long-haul core networks. Pluggables are used in the access networks and in data-centre interconnects over limited distances.

Over the last three decades or so, all equipment classes achieved substantially higher throughput. However, total power consumption per respective piece of equipment also grew. In Figure 89, the development toward higher power efficiency can be derived from the coloured trend lines that are crossing the isolines of constant power efficiencies (0.1…1000 W/Gbps).

As an example, the power efficiency for WDM transponders improved by a factor of ~50 from approximately 10 W/Gbps in the mid-90s to almost 0.2 W/Gbps for the latest generation in 2019. This could not cope with the bitrate increase. For fully-loaded systems, they developed from 40 Gbps to ~8 Tbps in the same period, i.e., a factor of ~200.

The power-efficiency development for (our) WDM transponders is shown in Figure 90 [14]. With the exception of the 40-Gbps class around 2006, it followed a straight trend in log-log scale.

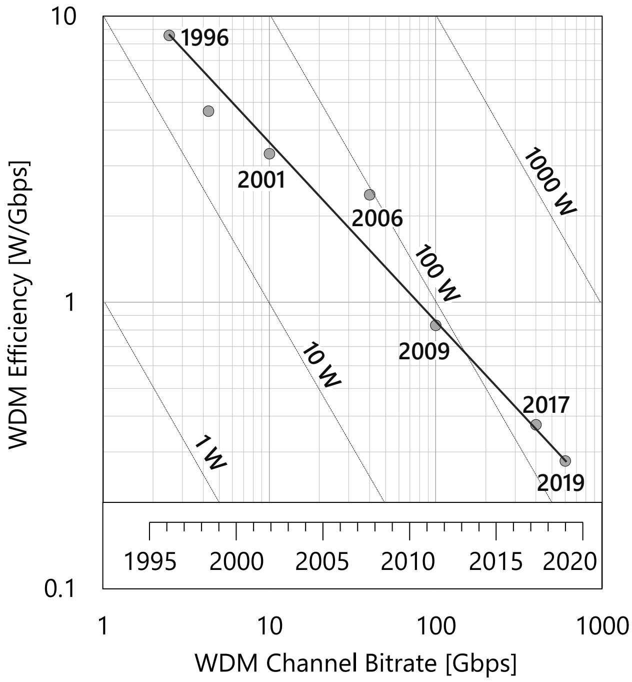


Figure 90. Power efficiency development for WDM [14]

The trend curves so far do not indicate that efficiency might over-compensate bandwidth or throughput growth in the near future. On the other hand, the VNI forecasts regarding bandwidth (or traffic) growth so far have been reliable, which can be derived when comparing current numbers with old forecasts.

Several applications fuel the bandwidth growth. This includes 5G (and in the future its successor, 6G), Industry 4.0, Internet of Things (IoT) / Machine-to-Machine (M2M) communications, HPC (high-performance computing) together with big-data applications like the LHC (large hadron collider) or the SKA (square-kilometre array), and 3D-high-resultion video streaming.

In addition to bandwidth growth, which is likely to be sustained over the next couple of years, we are approaching another problematic area. *The increase of energy efficiency in electronic switching and fibre-optic transport is approaching some fundamental limits in the next 20 years or so*. Ultimately, for both, switching and photonic transport, this will be the Shannon-von Neumann-Landauer (SNL) thermal limit [16]-[18].

In electronic switching/computing and signal transmission, the per-bit energy is lower-bound by the Shannon-von Neumann-Landauer limit:

$$E_{\mathrm{bit}} \geq E_{\mathrm{SNL}} = k_{\mathrm{B}} T \ln 2$$

Here, k_B is Boltzmann's constant, and T is absolute temperature in Kelvin. Minimum size and switching time of a machine at the SNL limit can be derived from Heisenberg's Uncertainty relation:

$$t_{\min} = \hbar/\Delta E = 0.04\ \mathrm{ps}\,,\ x_{\min} = \hbar/\Delta p = 1.5\ \mathrm{nm}$$

Here, ΔE and Δp are the energy and momentum uncertainties, and $\hbar$ is the reduced Planck constant, respectively. The power dissipation per unit area of such a machine is given by, with size-limited density of switches n_{max}:

$$P = \frac{n_{\max} E_{\text{bit}}}{t_{\min}} = 3.7 \cdot 10^6 \ \text{W/cm}^2$$

This switch has *only a factor of 6 less size than 22-nm node CMOS technology* (complementary metal-oxide semiconductors with physical gate length of 9 nm). Its power density is $4{\cdot}10^4$ larger than end-of-ITRS (International Technology Roadmap for Semiconductors) projections. It would thus require *forced* cooling. The minimum per-bit energy then becomes

$$E_{\text{bit}}^{\text{total}} = E_{\text{bit}} + \frac{T_{\text{a}} - T_{\text{dev}}}{T_{\text{dev}}} E_{\text{bit}}$$

T_{a} = 300 K and T_{dev} is the device temperature. The resulting total bit energy is shown in Figure 91 (*a* is the minimum switch size).

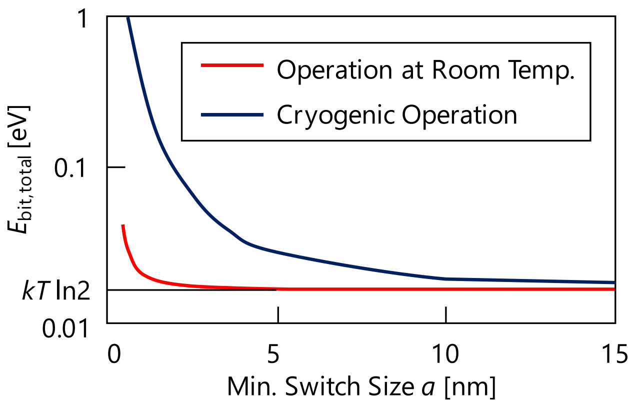


Figure 91. Bit energy as a function of switch size [17]

The practical consequence is *the end of combined density / switching-speed scaling.* Without disruptive developments, minimum switch size will stop somewhere below, but close to, 5 nm.

According to Figure 92, this is confirmed in [19]. Here, the gate-length decrease is predicted to stop around 4 nm, and it does so within the next 10 years or so. In addition, the corresponding energy asymptotically approaches a value that is more than a factor of 100 higher than the theoretical SNL limit.

Even if scaling development proceeded below 4 nm gate length, the fundamental SNL limit would be reached roughly 10 years later, as can be derived from Figure 93 [20].

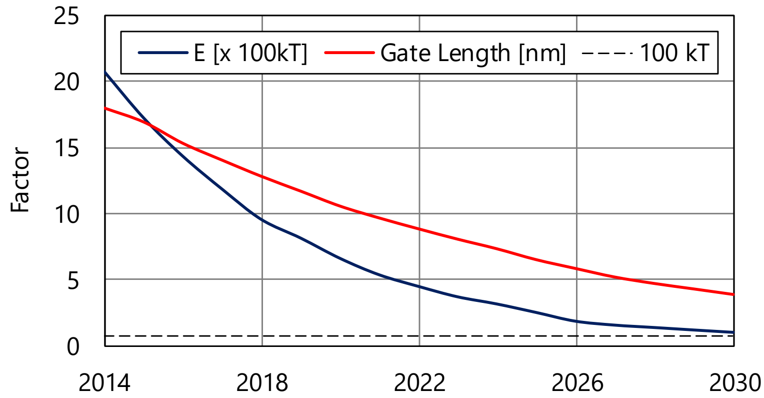


Figure 92. Energy vs. gate length, alternative limit [19]

Here, another interesting threshold is marked – the photon energy at the wavelength of 1550 nm, which is the center wavelength of almost all commercial WDM systems. So far, no commercial WDM systems have reached this sensitivity. This means that certain practical limits may be reached even earlier than the ultimate SNL quantum limit.

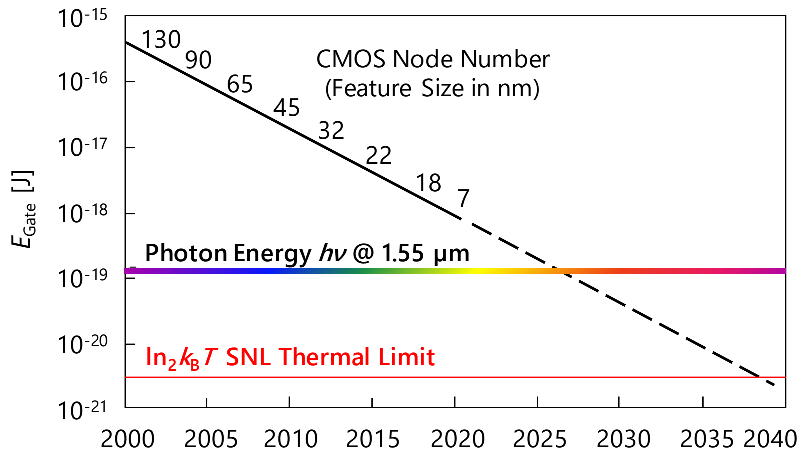


Figure 93. Development of semiconductor-gate energy and fundamental limits to energy efficiency [20]

The fundamental downscaling limit also lower-bounds further efficiency increase for the equipment classes considered so far. This will become apparent in the next 10 years or so.

In addition, and related to data-centre equipment, further saturation effects already became visible. As a consequence, there has been strong increase in energy consumption for the highest-ranking HPC machines over the last four decades (from ~150 kW around 1980 via ~700 kW in 2005 to 17 MW in 2014) [21].

Again, with increasing performance requirements, there does not seem to be a way out of this situation since CPU performance is almost saturating, as can be derived from Figure 94 [22], [23]. This may lead to simply scaling the number of CPUs, which will lead to energy-consumption increase since in addition, gain through parallelization saturates (Amdahl's Law).

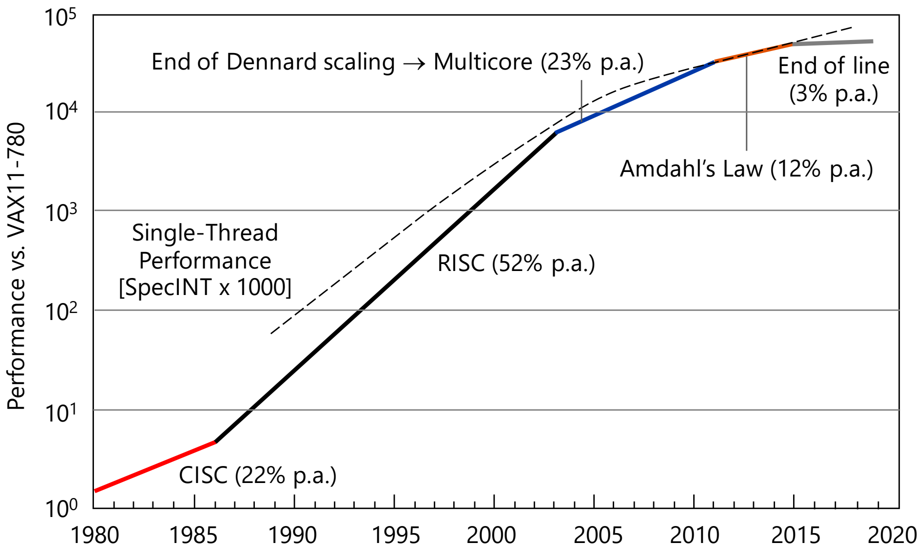


Figure 94. Development of CPU performance [22], [23]

With increasing bandwidth requirements, the saturation effects may lead to the necessity to use more of what is available. Ultimately, this will further fuel energy-consumption increase. In [24], [25], the global ICT energy consumption has been predicted beyond 2025, taking into account strong growth that is primarily mobile-driven. The result is shown as the black solid curve in Figure 95.

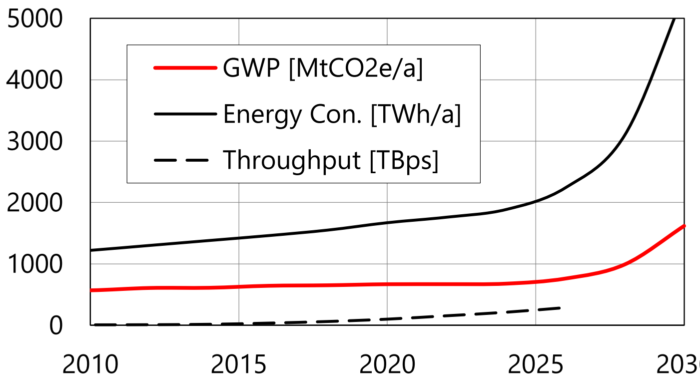


Figure 95. Forecast of global ICT throughput according to [6]-[8] (extrapolated to 2026), and yearly ICT energy consumption and GWP [24], [25]

The red curve in Figure 95 shows the resulting GWP. Here, electricity emission factors that are linearly decreasing from 0.4 in 2020 to 0.3 in 2030 have been used. Under these assumptions, significant increase in ICT energy consumption and GWP is to be expected beyond 2025.

The forecasted GWP increase is critical since it may achieve some 5% of total global emissions in 2030. This is demonstrated in Figure 96. Here, the global emissions according to [26] are shown up to 2020, where decarbonization must be started when global warming is to be limited. Strong growth of ICT emissions may interfere with such decarbonization. Figure 96 also shows the well-known Keeling Curve (smoothed, i.e., not showing the per-year behaviour) [27] that describes the global carbon concentration.

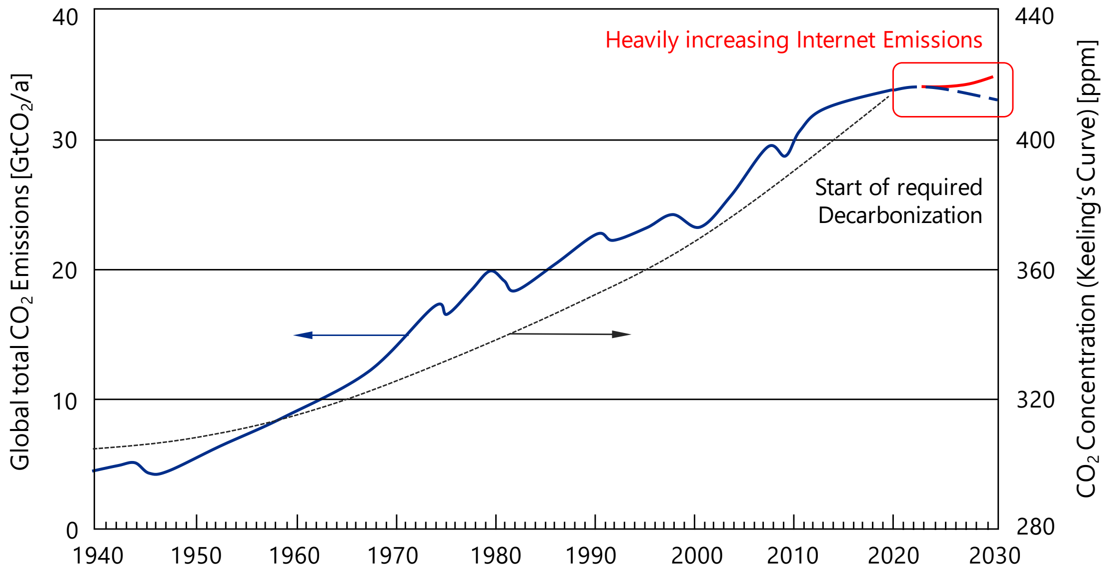


Figure 96. Global emissions and potential ICT contribution, and carbon concentration ("Keeling's Curve") [26], [27]

Unlike energy efficiency and related emissions, the development of equipment throughput (e.g., total WDM system transmission capacity) *did* cope with global ICT throughput, as shown in Figure 97.

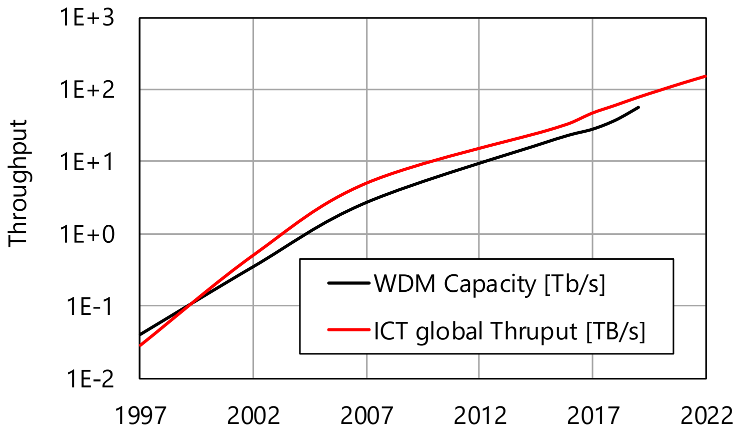


Figure 97. Internet throughput increase [6]-[8] and WDM system-capacity increase [14]

Here, WDM system capacity and ICT global throughput are displayed in ordinate log scale. Both curves have similar slope. Similar slope can also be derived for other infrastructure equipment (switches, routers) [12], [13], [15]. This means that the amount of equipment and waste electrical and electronic equipment (WEEE) is growing slower than its energy consumption. (It is growing somewhat due to other effects in network infrastructure rollout.) This can also be seen from Figure 98, where WEEE generation in the EU has moderate, almost linear, growth rate [28].

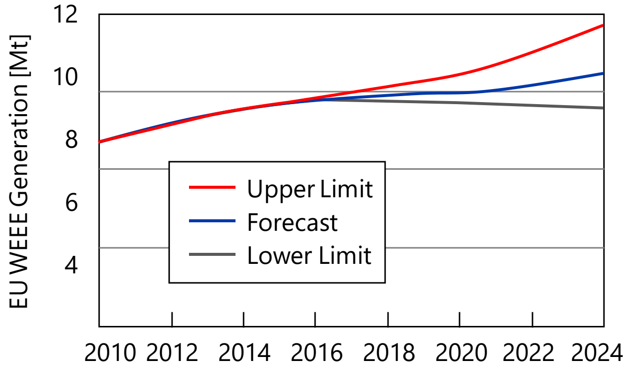


Figure 98. Development of WEEE generation in the EU [28]

WEEE generation is one of the main aspects to be improved by CE. CE also aims at minimizing raw-material intake. This is particularly relevant for the ICT sector. Figure 99 shows materials regarded critical by the EU in 2017 [29].

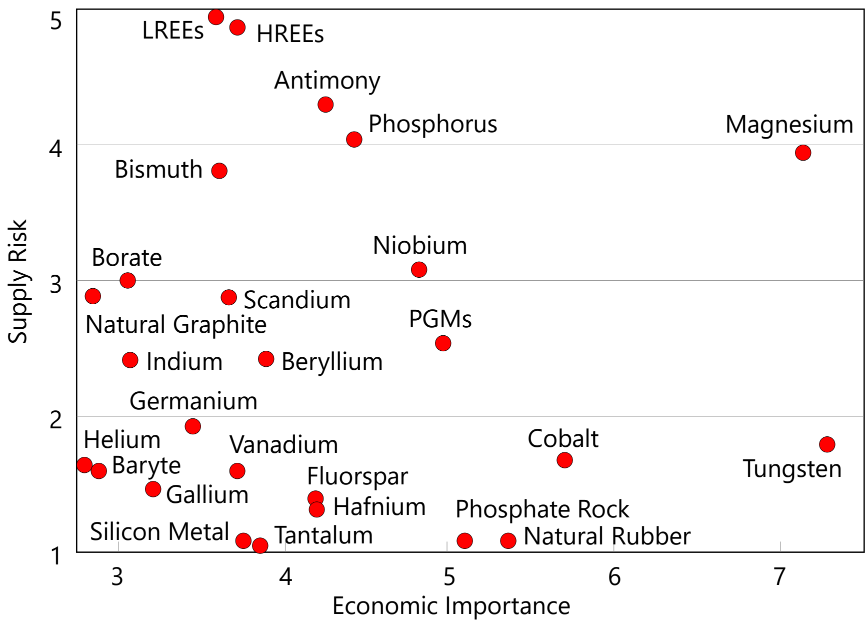


Figure 99. EU critical raw materials 2017 [29]. LREE/HREE are light and heavy rare-earth elements, and PGMs are Platinum-group metals, respectively.

At least one half of these elements are critical for the ICT sector. Therefore, maximum efficiency of the related CE mechanisms is important.

As a first conclusion, components and raw-material aspects of ICT infrastructure gear are important, but are still less important than energy-efficiency.

1.4. CE Challenges

Given the alarming result of Figure 99, effective CE measures are necessary. They must be complemented by energy-efficiency improvement for ICT infrastructure equipment. In general, CE is about longevity, that is, the approach to keep material in closed loops as long as possible, as indicated in Figure 100, which is based on the technical-material part of the well-known CE diagram [30].

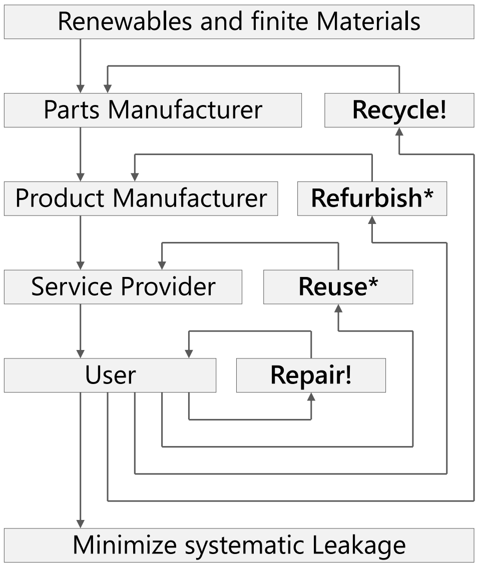


Figure 100. Circular-economy loops for ICT equipment, based on [30] for technical materials.

As indicated in Figure 100 by the asterisks, the CE concepts reuse and refurbishment / remanufacture are strictly limited for infrastructure ICT equipment and effectively, should not be followed.

Long lifetime – often in the range of 10-15 years, is given for this equipment. It is enabled by modular design (a key CE concept), supportive technical functions, and business models for maintenance. These include permanent, and even predictive, remote supervision and maintenance contracts, the latter being a first entry level to product-service systems (PSS). However, further lifetime extension (2^{nd} life, reuse, etc.) does not make sense for the equipment class under consideration. Ironically, this is due to the strong improvements in energy efficiency.

Due to the fast pace of ICT development, energy efficiency of successor product generations is also rapidly increasing, albeit at a lower rate than ICT throughput itself. *It therefore sets an upper limit to maximum lifetime*. Above this limit, further use of old equipment becomes net-negative, e.g., for the Global Warming Potential, according to LCA. This is a combined effect of strong efficiency increase and the always-on use mode. It leads to the fact that, after a certain lifetime, using a new product generation is more efficient even if its production is considered. This is shown in Figure 101, again for a WDM system, where both generations have similar functionality.

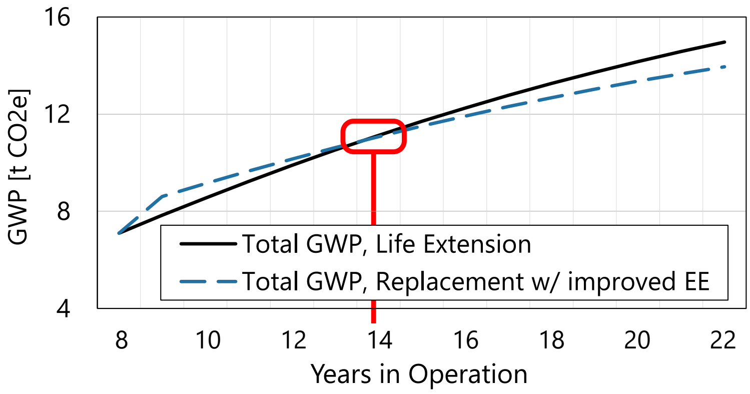


Figure 101. Lifetime optimization with LCA

Here, a lifetime of eight years has been considered for the first system generation. This is in the range that we see today for WDM equipment, and it is the reason why the time axis starts with 8. Further relevant and realistic assumptions include the decrease of emission factors for the considered period of 22 years by 50%, and a next-generation energy-efficiency improvement of 25%, where such next generations are available after some 10 years. It can be seen that the replacement generation performs better, including its production, after six years. The example shows that after a nominal lifetime (eight years here) plus a certain limited extension (six years here, for a shorter second life), the equipment must be taken out of service in order to prevent negative effects.

Components reuse is also limited by the fast ICT development toward ever-increasing bitrates. Combined with the long average system lifetime, this fast pace leads to components, systems and functionality obsolescence.

We conducted an analysis for the main components' groups of our WDM equipment with regard to their reusability:

- Electrical parts, PCBAs, etc.
  - Strong trend to functional obsolescence. Example: around 2010, electronics in ICT transmission had to support bitrates of 10 Gbps or 40 Gbps, respectively. 10 years later, this changed to 100…600 Gbps.
  - Successor parts become much more energy-efficient, see Figure 90 and Figure 101.
- Optical parts (~60% of product cost)
  - Passive optics do not age significantly (in the sense that they start failing)
  - They seem to be perfect for parts reuse, but
    - Complex and costly optical filters, interleavers, gratings etc. become obsolete. Example: in 2000, WDM filters provided 16×200 GHz channels, 10 years later, this changed to 40×100 GHz, and there was no use for the old filters anymore. Today, we are at 96×50 GHz, 128×37.5 GHz or at a fully flexible grid.

        - Simple, cheap 3-dB couplers etc. already pose a disassembly-cost hurdle

- Mechanical parts (~5% of cost)
    - This is the smallest components fraction regarding both, cost and LCA environmental contribution
    - Reuse of small plastic parts, screws etc. is regarded difficult / cost-prohibitive
    - Is shelf / chassis reuse possible? Regarding *weight*, this is the majority of a product, but not regarding LCA impact. So far, it was not possible to design chassis that support several system generations since this would require predicting needs of a system some 10-15 years in the future. Moreover, metal chassis are the only components area where a relatively high content of recycled material is in use already.

Together, this limits the CE loops shown in Figure 100 to lifetime extension up to the LCA optimum (but not beyond), and to optimization of recycling. The former is given today already for many ICT infrastructure products. The latter is an area of ongoing discussion and research.

One of the questions currently under consideration is to what extent recycling (and other lifecycle stages) can be improved using ICT tools, i.e., shared databases (DB). This is indicated in Figure 102.

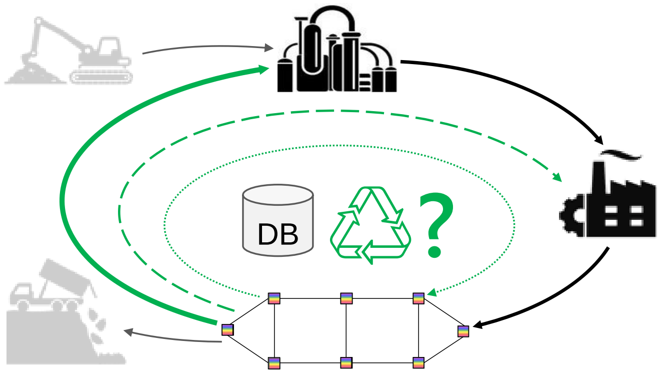


Figure 102. The open role of ICT in circular economy

Aspects of ongoing research include database access, security and integrity and how such DBs can improve value along the value chain (components manufacturers, product manufacturers, service partners, customers). Regarding improved recycling, this currently is not clear yet. One of the reasons is that there is dissent regarding the DB content, i.e., the type, complexity and structure of the data that is to be provided to the respective value-chain members.

One proposal that ranges toward the high end of data complexity suggests storing product material declarations in the DB. Material declarations are known from the REACH regulation. They declare, for all the components of a product, the weight percentages of all contained material (substances). For complex products, this poses several severe problems.

First, compiling complete declarations can lead to substantial effort, in particular in complex supply chains. Then, it is completely unclear how such a level of detail shall help recycling. Complex products can contain 4-digit numbers of components, which in turn leads to very complex declarations. First feedback that we collected from WEEE recyclers says that this data is completely useless in order to improve recycling.

This leaves two questions not answered yet. First, what data can help recycling? The second question is what changes are required in recycling in order to make use of any additionally available data. This may include aspects of reverse logistics that aim at aggregating WEEE with similar characteristics. This is also discussed in Chapter 0.

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 [31], [32]. An overview on PSS and their primary advantages is given in Figure 103.

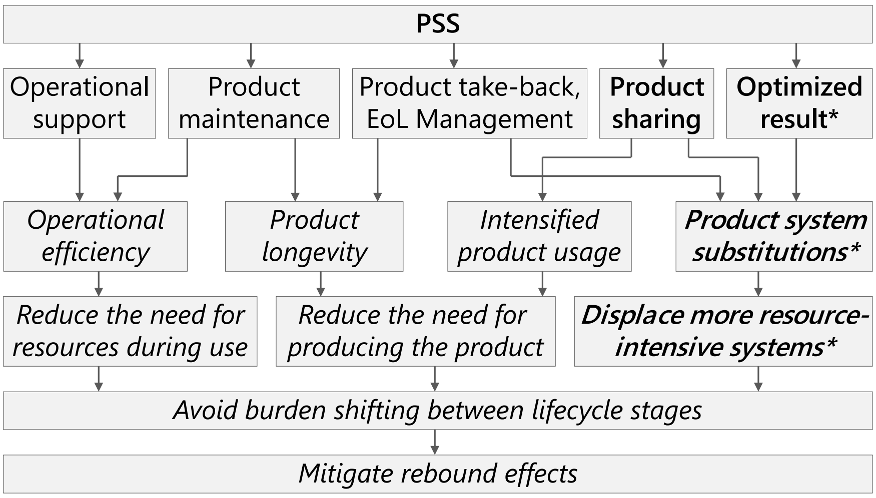


Figure 103. Overview on PSS, based on [31]

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 103 by the asterisks, those PSS paths regarded most efficient ("optimized result") are the ones that do not work for infrastructure ICT equipment.

Equipment sharing between lots of customers is done in 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 vendor, since no successful vendor-operators exist. This narrows PSS paths for the equipment vendor. 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, which is also discussed in the next chapter. Again, this complicates the PSS paths at the right edge of Figure 103.

1.5. A Way out?

It is unrealistic simply to request bandwidth-growth limitation. Some relevant applications may require this growth, and without the growth, an economic Internet crisis is likely to occur. Therefore, ways out of the switch-scaling dilemma are blurry at best. This affects all basic ICT functions including optical transport. Scaling energy efficiency will become more difficult. The same holds for gate size and related logic-gate performance and density, including storage densities. With increasing bandwidths, this will lead to the necessity to use more of what is available by that time.

Disruptive new developments are not clear right now. Theoretically, concepts like entropy-preserving switching (or thermodynamically reversible computing) can break the SNL limit, but they may not be acceptable in practice because the energy advantage comes at the cost of switching speed [16], [18].

Other technologies like carbon nanotubes [17] or biological-cell processors [18] may allow getting close to the SNL limit (i.e., closer than CMOS technology). However, they do not yet present mature technology.

Therefore, risk is that the Internet either consumes rapidly growing amounts of energy, or that its energy (and likewise resource) consumption in turn limits the bandwidth growth and the number and/or kind of the applications. The former can make the Internet the biggest energy/resource-consuming machine on Earth, the latter has the potential for a global economic crisis.

There is one important aspect that can relax the emissions situation, which results from the energy consumption. This aspect is sometimes referred to as *Green-by-ICT* [33]. It refers to emissions savings in sectors other than ICT that are *enabled* by ICT. The most relevant sectors that can be made significantly more efficient regarding energy consumption and emissions are manufacturing, energy (e.g., the power grids), buildings, mobility, and agriculture. According to [34], the carbon-saving effect on a global scale can be *almost a factor of 10 higher than the ICT emissions* themselves. It can thus help to achieve the climate targets of the UN [35].

The per-sector carbon savings that are predicted in [34] for the year 2030 are listed in Table 15. Green-by-ICT carbon **savings per sector in 2030** [34]

Table 15. Green-by-ICT carbon savings per sector in 2030 [34]

Global ICT-enabled CO_2 Reduction 2030	
Sector	$GtCO_2e$
Manufacturing	2.7
Energy	1.8
Buildings	2.0
Mobility	3.6
Agriculture	2.0
Total global	12.1
Global ICT Emissions 2030	1.25
Saving Factor	9.7

The effect of these carbon savings is indicated in Figure 104. It shows a zoom into the upper right part of Figure 96 where in addition to the ICT emissions, the potential Green-by-ICT carbon savings according to [34] are displayed.

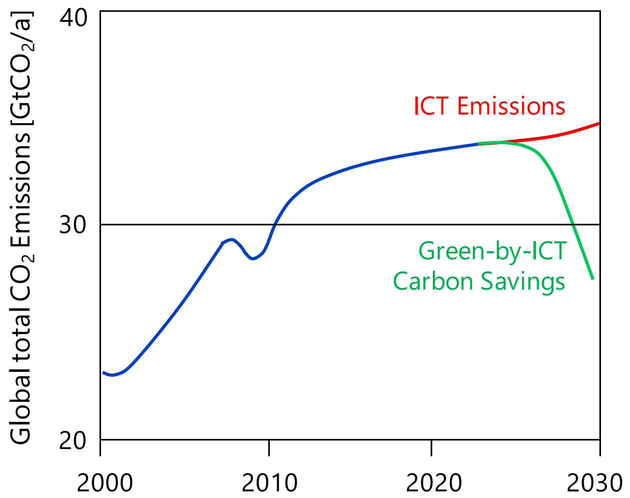


Figure 104. Detrimental ICT effects on global warming vs. Green-by-ICT carbon savings [26], [34]

A white paper from British Telecom [36] even stated a Green-by-ICT carbon-saving factor of almost 19, albeit with regard to the UK only.

Green-by-ICT will not solve the energy-efficiency problems of ICT that are to become apparent in one to two decades. Neither can it solve any of the resource-depletion problems that may result from using an increasing amount of ICT equipment. The latter is one of the *Green-of-ICT* aspects as described in [33].

These detrimental effects must be addressed by treating bandwidth as a precious resource rather than flat-rate abundance. This may include:

1. People get charged for internet use on an environmental-cost basis
2. Companies like social-media providers get charged per bandwidth
3. High-resolution content is subject to cost penalties

This has to be complemented by certain technical improvements like smart caching that help reducing in particular the video-download energy-consumption burden.

In addition, resource depletion must be tackled by a substantial increase in resource efficiency, i.e., by strictly following circular-economy principles within the limits that have been derived in this chapter.

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