Activating Circular Services in the Electric and Electronic Sector

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Deliverable 5.3.

Economic analysis: Life cycle costing (LCC)

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Executive summary

The C-SERVEES project aims to boost a resource-efficient circular economy in the electrical and electronic sector through the development, validation, and transfer of new circular economy business models. These models are based on systemic eco-innovative services that include: (1) eco-leasing of EEE, (2) product customization, (3) improved WEEE management, and (4) ICT services to support other eco-services.

The new circular economic business models were implemented and tested by means of demonstrations involving four target products: washing machines, laser printers and their toner cartridges, telecom equipment or Advanced Link Monitoring (ALM) and TV sets. The demonstrations involve the whole life cycle of the four target products, their associated value and supply chains, and the proposed eco-innovative services.

The techno-economic, environmental, and social feasibility of the target products and related eco-services were determined by means of life cycle sustainability assessment tools (LCSA), including environmental life cycle assessment (LCA), life cycle costing (LCC) and social life cycle assessment (S-LCA). Two different types of scenarios were assessed and compared for each target product:

- A conventional scenario, in which the products are produced and consumed under linear economy models.
- The C-SERVEES scenario, in which the products are produced and consumed under the new circular economy models relying on the systemic eco-innovative services demonstrated in the project.

This Deliverable 5.3 shows the life cycle costs of each target product under the conventional scenario, called Reference product, and under the C-SERVEES scenario, called C-SERVEES product, and their comparison.

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

Below are shown the main LCC indicators calculated for the four target products with their two scenarios and the relative reduction of costs, referred to their functional unit, including:

1) One washing cycle with an **ARÇELIK 7150370100 washing machine as Reference product and ARÇELIK 7150341600 as C-SERVEES product.**

Main life cycle cost indicators for one washing cycle of the washing machine.

Washing machine	Indicator	Unit	Reference	C-SERVEES	Relative reduction
	Internal	€	0.8126	0.8126	0.00%
	External	€	2.0454	2.0451	0.02%
	Total	**€**	**2.8581**	**2.8577**	**0.01%**

2) 1,000 printed pages with a **LEXMARK CX860dte professional multifunctional laser printer**

Main life cycle cost indicators for 1000 printed pages of the multifunctional laser printer.

Multifunctional laser printer	Indicator	Unit	Reference	C-SERVEES	Relative reduction
	Internal costs	€	65.48	65.48	0.0%

	External costs	€	4.57	4.46	2.4%
	Total	**€**	**70.05**	**69.94**	**0.2%**

3) One hour of the **telecommunications equipment** monitoring composed by **an active ALM unit (ADVA 16ALM/#1650D/AC) and 50 passive sensors**

Main life cycle cost indicators for one hour of the ALM product monitoring.

ALM product	Indicator	Unit	Reference	C-SERVEES	Relative reduction
	Internal costs	€	0.3596	0.2001	44.34%
	External costs	€	0.0221	0.0212	4.07%
	Total	**€**	**0.3816**	**0.2213**	**42.01%**

4) One watched hour of the **GRUNDIG G43C 891 5A 43” smart-TV set**

Main life cycle cost indicators for one watched hour of the TV set.

TV set	Indicator	Unit	Reference	C-SERVEES	Relative reduction
	Internal	€	0.042	0.042	0.0%
	External	€	0.121	0.115	5.0%
	TOTAL	**€**	**0.162**	**0.156**	**3.7%**

It should be noted that these results cannot be used to compare the products with each other, since each product has its own functions and functional unit, intensity of use, number of users per product unit and lifetime, resulting in products completely different in terms of composition, weight, life-cycle management and derived impacts; e.g., the washing machine is a consumer product used at home by a family, while the professional multifunctional laser printer is a large business product used by several office workers (over 30 users per product unit).

The main conclusion of this Deliverable 5.3 is that the four target products under the new circular economy models relying on the systemic eco-innovative services demonstrated in the project have reduced life cycle costs by an average of 11.5%.

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List of acronyms and abbreviations

Acronym	Full form
3D	Three dimensions
ABS	Acrylonitrile Butadiene Styrene
ALM	Advanced link monitoring
B2B	Business-to-business
B2C	Business-to-customer
CD	Compact disc
CE	Conformité Européenne
CSS	Country-specific sector
DVD	Digital versatile disc
EEE	Electric and electronic equipment
EI	Environmental impacts
EoL	End-of-life
E2N	Equal to new
FU	Functional unit
GB	Gigabyte
HEVC	High efficiency video coding
Hz	Herzio
ICT	Information and communication technologies
L	Lifetime
LCA	Life cycle assessment
LCC	Life cycle cost
LCCP	Lexmark Cartridge Collection Program
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LCSA	Life cycle sustainability assessment
LED	light-emitting diode
LECP	Lexmark equipment and collection program
MLP	Multifunction laser printer
PET	Polyethylene terephthalate
PSS	Product service systems
QALY	Quality-Adjusted Life Year
QR	Quick response code
RC	Recycled content
rPC	Recycled paper and cardboard
R&D	Research and development
S-LCA	Social life cycle assessment
TE	Telecom equipment
TR	Percentage of time replaced
TV	Television
U	Functional unit
USD	United States d
VAT	Value added tax
WEEE	Waste of electric and electronic equipment
WM	Washing machine
WP	Work package

1 Introduction

C-SERVEES is a European H2020 project that aims to boost a resource-efficient circular economy in the electrical and electronic sector through the development, testing, validation and transfer of new circular economic business models. The new circular business models, developed in WP2, are based on systemic eco-innovative services that include: (1) eco-leasing of EEE, (2) product customization, (3) improved WEEE management, and (4) ICT services to support the other eco-services. ICT tools were developed in WP3 as a driver of the proposed eco-innovative services. Figure 1 shows a schematic overview of the C-SERVEES project and its main innovative solutions.

The new circular economic business models were implemented and tested in WP4 by means of demonstrations involving four target products: washing machines, multifunctional laser printers and their toner cartridges, telecom equipment and TV sets. These products belong to different EEE categories that jointly account for 77% of the WEEE collected in the EU. The demonstrations involve the whole life cycle of the four target products, their associated value and supply chains, and the proposed eco-innovative services.

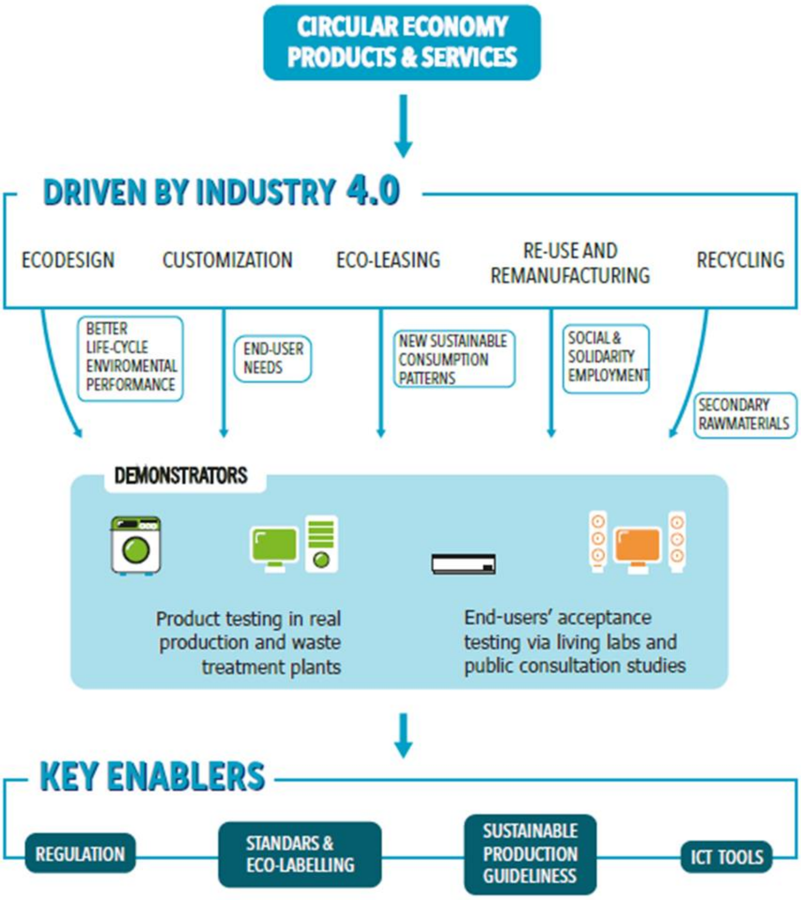

Figure 1. Schematic overview of the C-SERVEES project.

The environmental, economic and social viability of the target products and related eco-services were determined in WP5 by means of life cycle sustainability assessment tools, including: environmental life cycle assessment (LCA), life cycle costing (LCC) and social life cycle assessment (S-LCA). Two different types of scenarios were assessed and compared for each target product:

- A conventional scenario, in which the products are produced and consumed under linear economy models.

- The C-SERVEES scenario, in which the products are produced and consumed under the new circular economy models relying on the systemic eco-innovative services demonstrated in the project.

This Deliverable 5.3 shows the life cycle costs of each target product under the conventional scenario, called Reference product, and under the C-SERVEES scenario, called C-SERVEES product, and their comparison.

1.1 Context and relationship with other WPs

C-SERVEES project is structured into 9 work packages (WPs). Figure 2 shows the overall structure of the project work plan as well as the interlinkages between the different WPs.

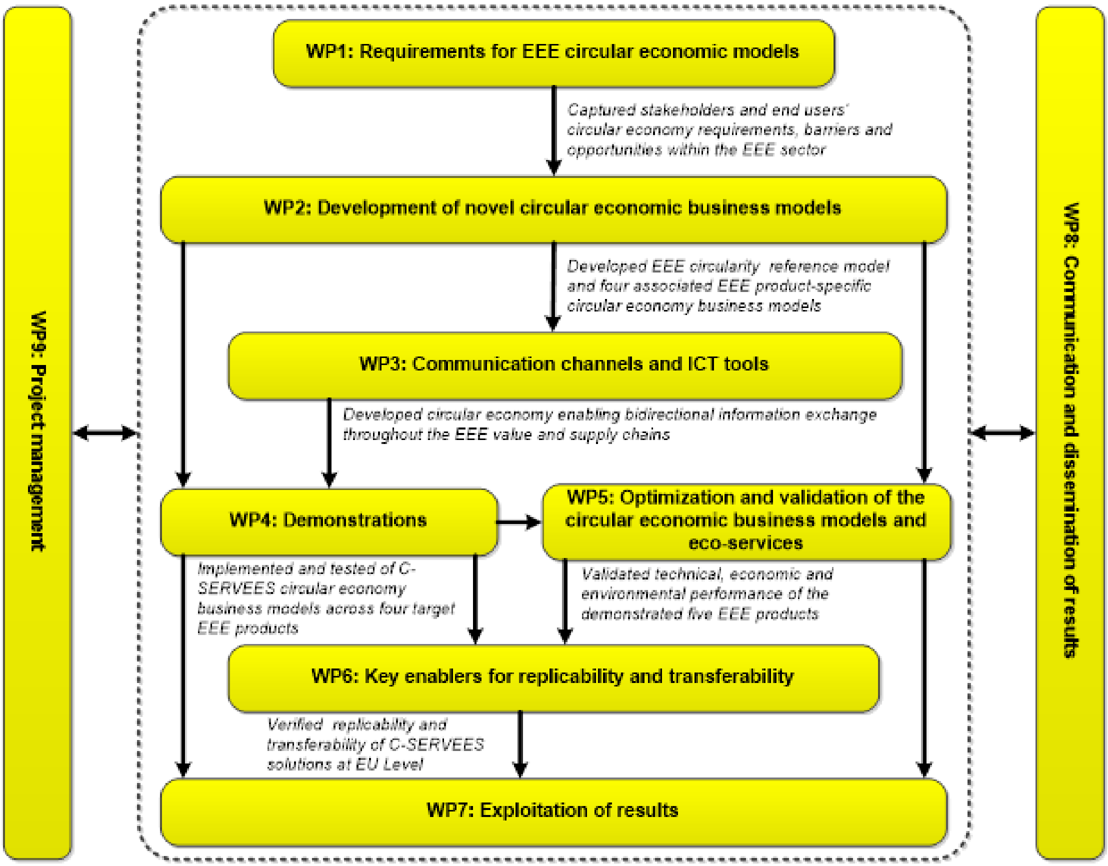

Figure 2. WP structure of the C-SERVEES project.

This Deliverable 5.3 is part of WP5, whose main objective is to validate the new circular business models by verifying their total costs (internal and external cots). The relationship of WP5 (and Deliverable 5.3 in particular) with the other previous WPs is explained below.

WP1. Requirements for the new circular economic models

Stakeholder consultation was initially conducted to identify the awareness, opportunities, challenges and enablers to implement the circular economy business models in the electrical and electronic sector. These comprised technical, business & management, legislative, economic, social, supply chain and implementation aspects (discussed in Deliverable 1.2).

WP2. Definition of new circular economic business models

A circular business reference model for the electrical and electronic sector (REF-CIRCMODE) was developed based on a comprehensive literature review, the findings of the stakeholder consultation (conducted in WP1) and requirements from industry partners in the EEE value chains. The reference model comprises five interlinked layers (presented in Deliverable 2.1): (1) Business Strategy, (2) Circular Economic Business Model Canvas, (3) Challenges and Opportunities, (4) EU Policies relevant to the electrical & electronic sector, and (5) Circularity Indicators.

The REF-CIRCMODE was designed to be relevant to all EEE products and its layered structure provides a framework encompassing all possible circular economy options at a strategic level as well as each stage of a product's life cycle (design, production, use and EoL). This ensures that all options are initially available when implementing the REF-CIRCMODE to meet the requirements of any specific EEE product, providing the most appropriate actions that leaded to the optimum product-specific circular economic business model.

The REF-CIRCMODE was further customised and tailored to the four specific products targeted in the project, resulting in four oriented product-specific circularity models:

- WASH-CIRCMODE for washing machines produced by ARÇELIK (presented in Deliverable 2.2).
- PRINT-CIRCMODE for printer products produced by LEXMARK, including laser printers and toner cartridges (presented in Deliverable 2.3).
- ALM-CIRCMODE for telecom equipment (TE) produced by ADVA (presented in Deliverable 2.4).
- TV-CIRCMODE for TV sets and displays produced by ARÇELIK (presented in Deliverable 2.5).

The four product-specific circular economic business models are therefore equally based on the characteristics of the REF-CIRCMODE. Each business model, however, relates to the specificities of the specific product, since each one was developed using the information provided by the corresponding producer and other actors in its associated value chain.

WP3. Communication channels and ICT tools

C-SERVEES is also dealing with the development of ICT tools for bi-directional communication and secure information exchange throughout the EEE value chains to support the new circular economic business models. These tools are based on blockchain and zero-knowledge technology, enabling the communication about individual products without the need for full disclosure of information, but with trust and accountability.

New ICT services were thus be provided and supported by information transfer through the EEE value chains, including EEE producers and their supply chains, end users and WEEE managers. These services were relied on QR codes (requiring product labelling), providing access to end users via their smartphones, while WEEE managers can use QR code scanners. Functionalities included product life-cycle tracking and feedback to producers, as well as interactive user manuals, repair manuals, warranty tracking or consumables management.

The ICT tools were developed in sprints with industry partners that tested them to validate and optimise their features and functionalities. They were structured in such a way that any type of EEE can be added to the ICT platform.

WP4. Demonstrations of the circular economic business models and eco-services

The practical utility of the product-specific circular economic business models (developed in WP2) lies in the possibility of posing and reviewing a series of circular economy options and evaluating them according to their viability and timeframes for implementation (short, medium or long term). This exercise was carried out by each EEE producer in C-SERVEES (ARÇELIK, LEXMARK and ADVA), leading to the selection of a set of circular economy actions that can be reasonably applied to their demo products within the timescale of the project (i.e., in the short term).

The actions initially selected for each target product (as for the WP2 and related deliverables D2.2, D2.3, D2.4 and D2.5) were implemented through the demonstrations for the 'Design and Production' phase (presented in Deliverable 4.1). These potential actions for increasing circularity from WP2 are summarized in Table 1, including some actions supported by the ICT tools developed in the project (in WP3). In addition, other circular economy actions considered feasible over a longer timescale (i.e., medium and long term) were explored by EEE producers for possible progression outside the confines of the project.

Table 1. Demonstration circular economy actions to be conducted along the C-SERVEES project for Washing Machines.

Demo product (producer)	Life-cycle stage	Circular economy action	Action description
Washing machines (ARÇELIK) 	Design & production	Eco-design of the washing machine	• Increase recycled plastic content in washing machines' components • Use novel formula to increase recycled PET content in the washing machines' tub to make it more durable • Use QR codes to provide information about materials and company's circularity to all the value chain
		Increase circularity in production process	• Perform LCA to detect improvement areas in production
	Use	Develop a renting model for B2B market	• Demonstration with focus on corporate customers • Obtain feedback from washing machines' B2B customers via questionnaires • Develop new corporate B2B sales channels in Europe for renting washing machines • Develop a washing machine rental business model • Assess the feasibility of washing machines' leasing/renting options • Target low income customers for the sale or rent of refurbished washing machines' (students, pensioners, house shares, etc.)
	End of life	Expand and improve repair & refurbishment operations	• Collect end of life products from B2B customers, refurbish them and provide refurbished products to B2B customers as a new business line • Enable collection of end-of use-washing machines' back from customers with a partner in Europe • Explore the use of 3D printing for spare parts and/or customisation • Reuse motors and electrical cards from returned washing machines as spare parts in Turkey • Develop dismantling and repair training programmes • Create awareness in relation to washing machines' circularity among B2B consumers via the help of QR codes inserted in products, which include examples of Arçelik's best practices in terms of circularity • Expand partnerships with Arçelik dealers and retailers to sell remanufactured B2C washing machines'
		Improve recycling process/recovering of the washing machine	• Use a QR code on washing machines' components to track their service call rate • Initiate a take back collection system for end of use washing machines in Europe with a partner • Develop circular end-of-life recovery strategies for collected washing machines outside Turkey

Table 2. Demonstration circular economy actions to be conducted along the C-SERVEES project for Laser Printers.

Demo product (producer)	Life-cycle stage	Circular economy action	Action description
Printer products, incl. laser printers and toner cartridges (LEXMARK) 	Design & production	Eco-design of the printer	• Identify levers to reduce dismantling and refurbishing cost by setting various operating models • Provide information about printers to LEXMARK recycling partners • Use materials that recyclers can easily and profitably recycle • Use ICT to support information sharing across the supply chain related to recycled content • Devise an eco-design strategy for printers during dismantling activities
		Increase circularity in the printer's life cycle	• Expand LCCP and/merge with LECP program (collecting and refurbishing whole printers and key components) • Assess options to reuse material from EoL/WEEE printers • 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
	Use	Improve data collection and management	• Reduce the number of unnecessary and incorrect shipments • Salvage working and repairable parts from collected/return printers and use on E2N (Equal to New) printers • Increase the flow of returned end-of-life printers by reducing the associated time and cost • Explore the competitiveness of 3D printing for spare plastic parts • Engage with key customer to understand their needs and requirements as it relates to refurbished products • Active lobbying at EU and/or national level for wider acceptance and promotion of circular business models • Active media/PR campaign on refurbished printers • Promote refurbished printers • Use QR code to inform customers about options to return their unused products to the manufacturer • Investigate economics of more CE suitable materials coming from end-of-life cartridges or printers
	End of life	Improve the LCCP	• Expand LCCP and/merge with LECP program (collecting and refurbishing whole printers and key components) • Implement ICT tools for improvement in logistics
		Improve the recycling of printers and cartridges	• Maintain highest levels of data security by ensuring that customers' documents are erased from refurbished (E2N) printers

Table 3. Demonstration circular economy actions to be conducted along the C-SERVEES project for ALM product.

Demo product (producer)	Life-cycle stage	Circular economy action	Action description
Telecom equipment (ADVA) 	Design & production	Eco-design of ALM system	• Design for longevity, in particular better maintainability • Design for better recycling, related to plastics • Improve energy efficiency in the use phase by at least 20% • Devise an eco-design approach in production and Design for Recycling • Reduce costs of manual disassembly for recycling
		Improve circularity in ALM production	• Perform LCA to detect improvement areas in production
	Use	Improvements in performance	• Implement eco-design strategies across the life cycle of ALM products and the subsequent reduction of energy use
		Explore feasibility of renting/shared use/PSS	• In-depth PSS analysis considering lifetime and other ICT product • Introduce options for leasing, renting or sharing products • Expand the scope of PSS (moving toward vendor ownership) • Move towards a rental model for B2B customers • Demonstration of leasing/renting with selected stakeholder
	End of life	Improve repair and refurbishment operations	• Carry out a feasibility analysis of AI for predictive maintenance • Assess components' reuse • Provide an analysis of part-exchange options as part of repair and maintenance
		Improve recycling of the ALM system	• Assign components to most efficient recycling pathways • Provide an analysis of how recycling needs to be changed to become more efficient • Define which level of material data is suitable for recyclers • Improve the proportion of components, parts and/or materials recovered • Reduce volume of packaging and develop plastic-free packaging

Table 4. Demonstration circular economy actions to be conducted along the C-SERVEES project for ALM product.

Demo product (producer)	Life-cycle stage	Circular economy action	Action description
TV sets (ARÇELIK) 	Design & production	Eco-design of the TV set	• Increase recycled plastic content in TV components • Increase the durability of LED panel and mainboard • Use QR codes to provide information about materials and company's circularity to all the value chain
		Increase circularity in production process	• Perform LCA to detect improvement areas in production
	Use	Develop a renting model for B2B market	• Demonstration with focus on corporate customers • Use 3D printing for TV components • Obtain feedback from TV B2B customers via questionnaires and living labs • Develop new corporate B2B sales channels in Europe for renting TVs • Develop a TV rent business model for Smart Boards and Digital Signage products • Assess the feasibility of TV renting options
	End of life	Expand and improve repair and refurbishment operations	• Collecting and remanufacturing end of use TV sets • Enable traceability of remanufactured TV parts • Develop dismantling and repair training programmes • Create awareness among TV B2B consumers via the help of QR codes inserted in products • Expand partnerships with ARÇELIK TV dealers and retailers to sell remanufactured B2C TVs • Target low-income customers for the sale or rent of refurbished TVs (students, pensioners, house shares, etc.) • Initiate a take back collection system in Europe with a partner
		Improve recycling process of the TV set	• Decrease packaging waste • Increase circularity of TV waste plastics • Develop circular end-of-life recovery strategies for end of use TVs outside Turkey

WP5. Optimization and validation of the circular economic business models and eco-services

The main objective of this WP was to validate the new circular economic business models by verifying their sustainability in the demonstrations of the four EEE products. The evaluation of the proposed solutions was conducted by applying life cycle sustainability assessment tools (LCSA) over the demonstrations to measure their performance in relation to the three pillars of sustainability (Figure 3):

- Environmental viability, measured with life cycle assessment (LCA, performed in Task 5.1).
- Economic viability, measured with life cycle costing (LCC, performed in Task 5.2).
- Social viability, measured with social life cycle assessment (S-LCA, performed in Task 5.3).

Figure 3. Life cycle sustainability assessment approach applied in the C-SERVEES project.

Two different types of scenarios were assessed and compared for each target product to validate the sustainability of the new circular business models:

- A conventional scenario, in which the products are produced and consumed under linear economy models.
- The C-SERVEES scenario, in which the products are produced and consumed under the new circular economy models relying on the eco-innovative services demonstrated in the project (in WP4).

A preliminary LCSA was included in D5.1. However, during the development of the C-SERVEES project and in accordance with the definition of the circular models, some changes were introduced in some parts of the linear product to achieve a more representative comparison.

This Deliverable 5.3 shows the life cycle costs of each target product under the conventional scenario, called Reference product, and under the C-SERVEES scenario, called C-SERVEES product. The impacts of the C-SERVEES scenario are also compared to those for the conventional scenario, also compiled here and replacing Deliverable 5.1, to calculate the sustainability benefits that can be achieved with the solutions developed in the project.

1.2 Structure of the Deliverable

Deliverable 5.3 contains the following sections:

- Introduction to C-SERVEES project with the overview of WP5 and its relationship with previous WPs.
- Definition of the Goal and Scope of the Deliverable.
- Methodology of the life cycle cost.

- One chapter for each target product containing the full LCC of the reference product, the C-SERVEES product and the comparative assessment.
- Conclusions.

2 Goal and scope

The present study aimed to calculate the environmental, economic and social impacts of four different EEE products used for demonstrations in the C-SERVEES project. The target products investigated include:

- Washing machine
- Multifunctional laser printer (including its toner cartridges)
- Telecom equipment
- TV set

The sustainability analysis is performed on the Telecommunication equipment (TE) which central device is called Advanced link monitoring (ALM).

These products and their main characteristics are described below.

Different Product Category Rules[1] aimed for stablishing different Environmental Product Declarations for similar EEE products showed that the functional unit is defined by two approaches:

1. A unit of the product, or/and
2. Dedicated function of the product

The first approach was justified in the way that each product is "marketed and sold in such units". This is intended to cover the end-user acceptance. On the other hand, comparison among the different products seems not straightforward when functionalities change. For that reason, each product was evaluated also against the functional unit defined for them.

This means that the assessment of each product was conducted for a unit of the product/system. Results are presented then both as per unit of the product but also as per the functional unit the product is intended for.

This Deliverable 5.3 shows the life cycle costs of each target product under the conventional scenario, called Reference product, and under the C-SERVEES scenario, called C-SERVEES product, and their comparison.

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

[1] Several references like UL, Environdec or Environment and Development Foundation were consulted. Main PCRs are not longer in force.

3 Life cycle costing

In parallel to the LCA, an economic evaluation of the four target products was carried out. The LCC methodology also follows a life cycle approach, but it assesses the economic costs of the products instead of the environmental impacts as in LCA. Thus, LCC was used to assess all economic costs associated with the whole life cycle of the products, including both internal and external costs (Figure 4).

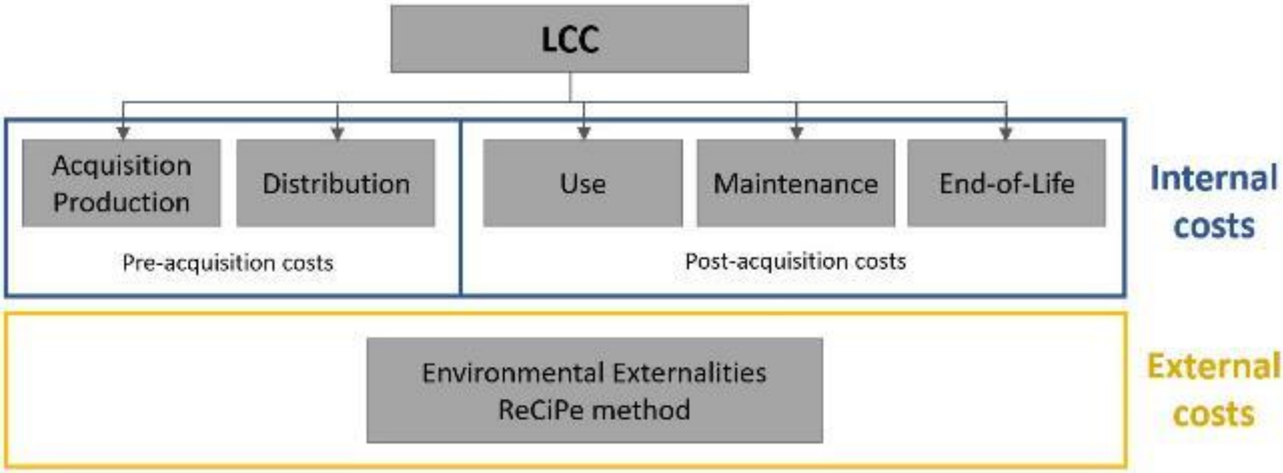

Figure 4. Scope of the LCC in the C-SERVEES project.

Calculation of internal costs was mainly based on operational and economic data collected from the industry partners producing the EEE products (ARÇELIK, LEXMARK and ADVA). Additionally, the external costs related to environmental externalities were calculated by applying monetisation factors to the environmental impacts obtained from the LCA studies. Below are described the main methodological aspects considered for the development of the LCC studies in the project.

3.1 Internal costs

The economic assessment of the target products includes the internal costs for: (i) acquisition of raw materials and components, including their transport to the product manufacturing plant; (ii) manufacturing of the product; (iii) product distribution to retailers or final customers; (iv) use, (v) maintenance (if required) and (vi) end of life. Most of the data required for the calculation of these internal costs were provided by industry partners. However, some data were gathered from literature, such as the market prices for the electricity, water and other consumables consumed by the products during their use.

According to the cost structure proposed, the internal costs were grouped into three categories:

- Manufacturing, which includes (i) costs for acquisition and transport of raw materials and components, (ii) costs for all manufacturing processes required to produce the finished product and (iii) costs for product distribution.
- Use, which includes (iv) costs for product operation (incl. electricity, water and other consumables) and (v) maintenance costs.
- End of life, which includes (vi) costs related to WEEE management.

3.1.1 Manufacturing

The sales price for each target product was assumed herein to include all the internal costs for manufacturing (including all investment and operating costs related to raw materials/components, product manufacturing and distribution, as well as additional costs related to product development like R&D costs). Sales price also includes the net revenues for the EEE producers and it represents the acquisition or purchase cost for the final customer. The sales price used in the LCC studies for each target product was taken from the website of the product manufacturers or retailers.

3.1.2 Use

This cost category includes the costs for operating the products and the costs for their maintenance. All the target products demand electricity for operation during their lifetime. In addition, some products need other additional consumables and spare parts for their operation and maintenance. The washing machine consumes water and detergent, while the printer needs paper, laser cartridges, photoconductors, colour developer units and fuser kits. Detailed information on the amounts of electricity and other consumables demanded by the target products and their linked costs are available in the Annexes, together with the complete cost breakdown for each product.

Electricity

According to other LCC studies,[1,2] the cost of the electricity consumed was calculated as the electricity price paid by the customers to operate the EEE products during their entire lifetime. Industry partners provided primary data on the product lifetime, power and/or electricity consumption (per unit of time or operation). The European average price for electricity for the year 2019 was used herein to estimate the cost of electricity consumption during product use. The European average electricity price was taken from Eurostat, distinguishing between price for household customers (0.216 €/kWh, including taxes and VAT, applied for washing machine and TV set) and prices for non-household customers (0.117 €/kWh, excluding VAT, applied for professional multifunctional laser printer and ALM product). The costs for electricity consumption for the following years (after 2019) were estimated assuming a 30% increase in the electricity price for the period 2018-2030, according to estimates by the European Commission.[3]

Water

Similarly, the water price paid by the customers to operate the washing machines during their lifetime was calculated herein. According to Eurostat, the average European price for water for the year 2018 was 0.0016 €/litre, considering an expense of 290 €/inhabitant/year and a water consumption ratio of 180,000 litres/inhabitant/year. The same cost for water consumption was assumed for the following years, given that price variations in the last 5 years have been negligible. ARÇELIK provided primary data on the lifetime and water consumption of the washing machine used for demonstration in the project.

Other consumables

The costs of the specific consumables for the multifunctional laser printer (cartridges, photoconductors, etc.) were directly obtained from the LEXMARK website, while the costs of other consumables like paper (used by laser printer) or detergent (consumed by washing machine) were based on their current average market prices.

3.1.3 End of life

The costs for WEEE management were assumed herein to correspond to the EEE fees paid by producers for EoL management of the products they put on the market. Table 5 shows the EEE fees used as reference costs for the EoL of the target EEE products. These were taken from the database of the SEWA, member of the European Recycling Platform.

Table 5. Costs for WEEE management for target products in the C-SERVEES project.

Product	WEEE category	RECYCLING FEE (€/piece)
ARÇELIK 9123 WF	4.4.2 "Washing machines except portable mini washing machines, dryers, dishwashers, cookers, owns for baking" from the Household appliances section	3.86
LEXMARK CX860dte	4.11.1 "Large multifunctional printers" from the Large IT and telecommunications equipment section	15.00
ADVA 16ALM/#1650D/AC	6.3.2 "Unclassified IT&C equipment up to max. 3 Kg" from the IT and telecommunications equipment section	0.19
GRUNDIG G43C 891 5A	2.5.1 "Television sets from 37" to 49" diagonal" from the Consumer electronics section	1.20

3.2 External costs

Monetary valuation of environmental impacts was applied to assess the costs of environmental externalities. Different approaches for monetizing environmental damages exist, however, their application to LCA still shows some limitations.[4] For example, the observed-preferences approach, which is based on the willingness to pay in an existing market, is not extensively applied in LCA. Although partial applications of the market-price method in LCA are found in ReCiPe, the availability of appropriate market-price data that can be linked directly to the environmental impacts in LCA is a major limitation of this method. In general, hedonic-pricing and travel-cost approaches, both based on the willingness to pay in surrogate markets, appear to be excessively geographically- and temporarily-specific for most LCA applications, and their results are difficult to generalize consistently. Additionally, the application of the contingent-valuation approach, based on the willingness to pay in hypothetical markets or trade-off situations, has been scattered and no work exists that applies contingent valuation consistently to all areas of protection in LCA. Finally, the experiment method and the budget constraint method are proposed as the best options for monetary valuation in LCA.[4] The experiment method is very appropriate for use in LCA because it focuses the monetary valuation on the trade-off between different impacts and matches the objective of impacts' weighting. The budget constraint method is based on the willingness to pay for an additional Quality-Adjusted Life Year (QALY) in a hypothetical situation without externalities. It represents a relatively new contribution that finds its application in LCA to reduce the uncertainty in determining the budget constraint, which is a key parameter and source of uncertainty in other monetary valuation approaches.

Based on the critical review of existing approaches and methods, the monetary valuation was carried out taking as a reference the budget constraint method used by Weidema[5] in combination with the impact assessment method ReCiPe to obtain monetary values for environmental impacts as made in other previous study.[6] Table 6 shows the monetisation factors used herein to convert the environmental impacts calculated by means of LCA (both endpoint impacts and global warming) into external costs. It should be highlighted that monetisation factor for global warming can show a considerable uncertainty regardless of the estimation method and application contexts. The factor used herein for global warming is 130 €/tonne CO_2 eq, which is similar to that estimated in other studies, such as 97.12 €/tonne CO_2,[7] 94.79 €/tonne CO_2,[8] 101.06 €/tonne CO_2[9] or 134.74 €/tonne CO_2.[10] Other studies consider, however, very different magnitudes, such as 24.28 €/tonne CO_2[11–13] or 303.96 €/tonne CO_2.[14]

Table 6. Monetisation factors considered in the C-SERVEES project.[6] Values in €2017.

Impact category	Monetization factor
Human health (HH)	101,311 €/DALY
Ecosystem quality (ED)	1.23E+07 €/species.yr
Resource availability (RA)	0.9295 €/USD2013
Global warming	130 €/tonne CO_2 eq

As the results provided by ReCiPe method are expressed in $\$_{2013}$, they had to be adapted to $€_{2017}$ values, considering that 1 $\$_{2013}$ is worth 1.05 $\$_{2017}$ and 1 $\$_{2017}$ is worth 0.885 $€_{2017}$ (ECB and IMF official data).

The costs of environmental externalities were therefore obtained for each life cycle phase applying the monetisation factors to the LCA results for the global warming impact and the three endpoint impacts (human health, ecosystems and resources). The costs for externalities used in the LCC studies, which are added to internal costs, are those obtained through monetary valuation of endpoint impacts. However, the external costs obtained considering global warming impact are also included herein as additional results.

4 Washing machine

The washing machine selected for demonstration as the Reference product is GRUNDING C-SERVEES (7150370100), which has 9 kg capacity, energy efficiency class A^{+++} and connectivity features. It is manufactured in Çayırova (Turkey) and currently sold in Europe (especially Spain) and Turkey. ARÇELIK selected this model for its smart home technology, which allows the users to access the HomeWhiz app from their smartphones or tablets and control the smart features of the product (switch on/off, program selection, user instructions, etc.). By using connected products, ARÇELIK had a chance to collect data and learn customer usage habits to improve customers' experience and offer maintenance and repair services to extend product life. More details on the current washing machine selected for demonstration are shown in Table 7.

Table 7. Technical specifications of the demo washing machine.

MODEL	ARÇELIK 9123 WF
Image	
Product number	7150370100
Colour	White
Size	840 mm × 600 mm × 610 mm
Weight	75 (±4) kg
Capacity	9.0 kg
Max. spin speed	1,200 rpm
Fascia	Grundig
Dynamic group	Large
Number of programs	16
Features	HomeWhiz, ProSmart (Brushless Motor with 10-year guarantee), Wi-Fi and BLE, Steam Function, Anticrease+
Energy class	A^{+++} (-30%)
Electricity consumption per year	148 kWh
Water consumption per year	10,318 L
Country of origin	Turkey

The activities conducted in the LCSA were derived from the WASH-CIRCMODE short-term actions validated in WP2. The table below presents the WASH-CIRCMODE canvas sub-components and their validated short-term CE actions, as presented in Table 24 in D2.2, and the selected strategies implemented in WP5 as C-SERVEES product (Product number 7150341600).

Table 8. Validated short-term WASH-CIRCMODE Canvas Key Circular sub-components and their associated Circular Economy Actions relevant for the LCSA.

WASH-CIRCMODE Canvas Sub-Component	WASH-CIRCMODE validated short-term Circular Economy Actions	LCSA implemented
WASH_C1.1 Diversify circular activities	WASH_A1.1.1 Increase recycled plastic content in washing machine's components	Eco-PP inner cover and detergent box group
WASH_C1.2 Embrace eco design to ensure products circularity across life-cycle ages	WASH_A1.2.1 Use novel formula to increase recycled PET content in the washing machine's tub to make it more durable	Recycled PET TUB
WASH_C2.3 Introduce and/or expand the use of ICT to foster circular economy	WASH_A2.3.2 Use QR codes to provide information about washing machine's materials and company's circularity	
WASH_A1.3.1 Enhance the integration of circular strategies into the production process	Blowing agent inner cover and detergent box group	Mass reduction in tub, inner cover and detergent box group

4.1 Functional unit and system boundaries

The product function for the washing machine is washing clothes, which has 9 kg capacity and it results in 24,750 kg of clothes washed during its 12.5-year lifetime (assuming 220 washing cycles/year). The assessment was initially performed for one product and at the end converted to the functional unit. Table 9 shows the system boundaries considered for the washing machine, identifying the life cycle phases, processes and other elementary flows included and excluded in the study.

Table 9. System boundaries considered for the washing machine.

Life cycle phase	Included	Excluded
Raw material extraction and processing	Extraction of natural resources Refining and raw material production Intermediate product manufacturing Waste treatment and transport	Infrastructure
Product manufacturing	Energy for product manufacturing/assembly Transport	Infrastructure Production losses
Product distribution	Transport	
Product use	Electricity consumption Water consumption Detergent consumption	Maintenance
End of life	Transport EoL treatments Landfilling of waste fraction not recycled	
Benefits and burdens beyond system boundaries	Recycling benefits (included as credits)	

4.2 WM Reference life cycle costing

4.2.1 Internal costs

The internal costs assessed for the washing machine includes the costs for:

(i) Acquisition of raw materials and components, including related transport operations.
(ii) Manufacturing of the product.
(iii) Distribution of the product to retailers or final customers.
(iv) Use, including product operation and required consumables.
(v) End of life, including WEEE management.

Table 10 shows the breakdown of the internal costs of the washing machine by life cycle phase, namely manufacturing (including i, ii and iii), use (iv) and end of life (v).

Retail price provided by ARÇELIK was assumed herein to consider manufacturing costs. The retail price covers all the costs related to raw materials and components, product manufacturing and distribution, as well as other any other costs for product development (like R&D costs) and net revenues from sales.

The use phase includes the costs for electricity, water and detergent consumed by the washing machine for operation during its whole lifetime. Total consumption values were therefore estimated at 1,847.5 kWh of electricity, 128,975 litres of water and 206.25 kg of detergent. The average market prices for these consumables were assumed as follows (see Section 3.1.2): 0.216 €/kWh of electricity for year 2019, with a sustained annual growth factor of 1.022 for the following years; 0.0016 €/litre of water (constant value assumed for the whole lifetime) and 5.6 €/kg of detergent.

The costs for WEEE management were estimated at 3.86 € (for one washing machine), which corresponds to the fee paid by producers for the EoL management of each washing machine they put on the market.

Table 10. Internal costs for the whole life cycle of one Reference washing machine (cradle-to-grave).

Life cycle phase	Concept	Cost (€)	Total cost (€)
Manufacturing	Retail price (incl. costs for materials/components, manufacturing, distribution, other product development costs and net revenues)	414.01	414.01
Use	Electricity consumption	453.93	1,816.89
	Water consumption	207.79	
	Detergent consumption	1,155.17	
End of life	WEEE management fee	3.86	3.86
TOTAL		-	**2,234.75**

Figure 5 graphically shows the contribution of each life cycle phase to the total internal cost of the washing machine. It can be found that the use phase is the most expensive by far, while the contribution of end-of-life phase is negligible.

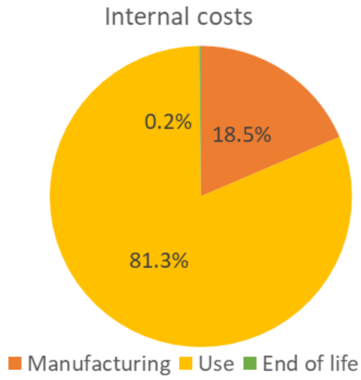

Figure 5. Contribution of each life cycle phase to the total internal costs for the Reference washing machine.

4.2.2 External costs

Monetary valuation of environmental impacts was applied to assess the costs of environmental externalities. To this end, LCA results obtained for the washing machine (see Deliverable 5.2) were combined with monetisation factors given for different environmental impact categories (see Section 3.2). External costs were estimated using two different approaches for monetary valuation: (1) monetisation of global warming impact and (2) monetisation of endpoint impacts. It should be noted that the economic costs obtained in each case cannot be added together since the global warming impact (as well as the other midpoint impacts) is included in the endpoint impacts.

The results from the monetary valuation of environmental impacts are collected in Table 11. These are broken down by life cycle phases and impact categories monetized.

Table 11. External costs for the whole life cycle of one Reference washing machine (cradle-to-grave).

Phase	Impact category	Total amount	Monetisation factor	Economic cost
Manufacturing	Human health	2.98E-03	101311 €/DALY	301.57 €
	Ecosystems	3.15E-06	1.23E+07 €/species.yr	38.84 €
	Resources	32.42	0.929 €/USD	30.13 €
	Sub-total endpoint impacts	-	-	370.54 €
	Global warming	359.55	130 €/tonne CO2 eq	46.79 €
Use	Human health	3.02E-02	101311 €/DALY	3062.76 €
	Ecosystems	1.72E-04	1.23E+07 €/species.yr	2123.66 €
	Resources	64.10	0.929 €/USD	59.58 €
	Sub-total endpoint impacts	-	-	5246.00 €
	Global warming	1969.10	130 €/tonne CO2 eq	256.23 €
End of life	Human health	5.64E-05	101311 €/DALY	5.71 €
	Ecosystems	1.15E-07	1.23E+07 €/species.yr	1.41 €
	Resources	1.39	0.929 €/USD	1.29 €
	Sub-total endpoint impacts	-	-	8.42 €
	Global warming	20.11	130 €/tonne CO2 eq	2.62 €
TOTAL	Human health	3.33E-02	101311 €/DALY	3370.05 €
	Ecosystems	1.76E-04	1.23E+07 €/species.yr	2163.91 €
	Resources	97.91	0.929 €/USD	91.01 €
	TOTAL COST	-	-	**5624.96 €**
	Total global warming	2348.76	130 €/tonne CO2 eq	305.63 €

Figure 6 graphically shows the contribution of each endpoint impact to the total external costs for the manufacturing and end of life since these are the life cycle phases in which the project is expected to achieve higher improvements. Most of the external costs are due to human health damages, while the costs of damages to ecosystem diversity and resource availability are lower and comparable with each other.

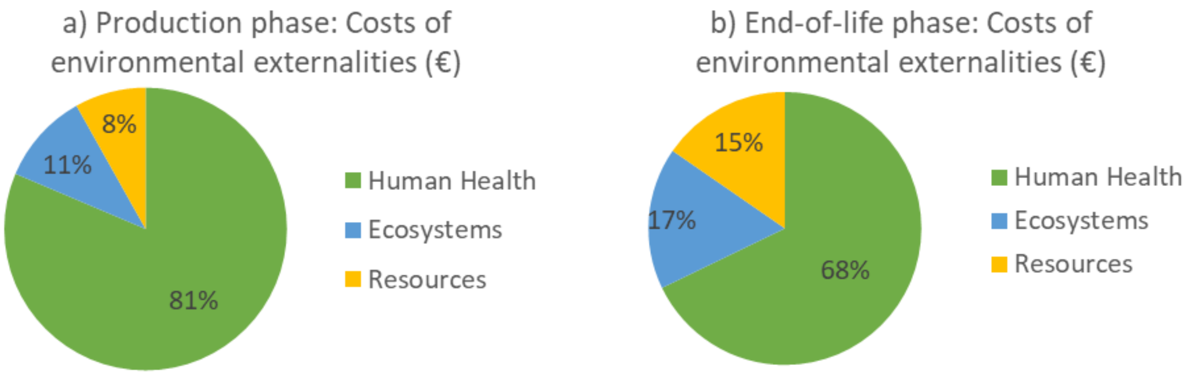

Figure 6. Contribution of each endpoint impact to total external costs of manufacturing and end-of-life phases for the Reference washing machine.

4.2.3 Total life cycle costs

Concluding, Table 12 shows the total life cycle cost including internal and external costs. Clearly, the cost of environmental externalities, and especially the external cost for the use stage, is the highest cost element. In contrast, the product waste management in the end-of-life phase is the one with the lowest cost, both for internal and external costs.

Table 12. Total costs for the whole life cycle of one Reference washing machine (cradle-to-grave).

Life cycle phase	Internal cost (€)	External cost (€)	Total cost (€)
Manufacturing	414.01	370.54	784.55
Use	1,816.89	5,246.00	7,062.89
End of life	3.86	8.42	12.28
TOTAL	**2,234.75**	**5,624.96**	**7,859.72**

4.3 C-SERVEES WM life cycle costing

4.3.1 Redesign changes

Redesign changes implemented in the LCSA as described in Table 8 are detailed in Table 13. Recycled materials are included for the inner door (64%), the detergent box (64%) and the tub (10%), as well as mass reduction of the tub, 1.021 kg, and some less reductions in the inner cover and the detergent box.

Table 13 C-SERVEES WM changes.

	Reference	C-SERVEES
Product:	7150370100	7150341600
Lifetime	12.5 years	12.5 years
Functional units	2750	2750
		Inner door: 64% recycled
		Detergent box: 64% recycled
Recycled content	No recycled materials	Tub: 10% recycled
		Reduction of 1 .09 kg in tub
		Reduction of 17 g in inner cover

	Reference	C-SERVEES
Mass reduction	No	Reduction of 21 g in Detergent box

4.3.2 Internal costs

The internal costs assessed for the washing machine includes the costs for:

(i) Acquisition of raw materials and components, including related transport operations.
(ii) Manufacturing of the product.
(iii) Distribution of the product to retailers or final customers.
(iv) Use, including product operation and required consumables.
(v) End of life, including WEEE management.

Table 14 shows the breakdown of the internal costs of the washing machine by life cycle phase, namely manufacturing (including i, ii and iii), use (iv) and end of life (v).

Retail price provided by ARÇELIK was assumed herein to consider manufacturing costs. The retail price covers all the costs related to raw materials and components, product manufacturing and distribution, as well as other any other costs for product development (like R&D costs) and net revenues from sales.

The use phase includes the costs for electricity, water and detergent consumed by the washing machine for operation during its whole lifetime. Total consumption values were therefore estimated at 1,847.5 kWh of electricity, 128,975 litres of water and 206.25 kg of detergent. The average market prices for these consumables were assumed as follows (see Section 3.1.2): 0.216 €/kWh of electricity for year 2019, with a sustained annual growth factor of 1.022 for the following years; 0.0016 €/litre of water (constant value assumed for the whole lifetime) and 5.6 €/kg of detergent.

The costs for WEEE management were estimated at 3.86 € (for one washing machine), which corresponds to the fee paid by producers for the EoL management of each washing machine they put on the market.

Table 14 Internal costs for the whole life cycle of one C-SERVEES WM (cradle-to-grave).

Life cycle phase	Concept	Cost (€)	Total cost (€)
Manufacturing	Retail price (incl. costs for materials/components, manufacturing, distribution, other product development costs and net revenues)	414.01	414.01
Use	Electricity consumption	453.93	1,816.89
	Water consumption	207.79	
	Detergent consumption	1,155.17	
End of life	WEEE management fee	3.86	3.86
TOTAL		-	**2,234.75**

Figure 7 graphically shows the contribution of each life cycle phase to the total internal cost of the washing machine. It can be found that the use phase is the most expensive by far, while the contribution of end-of-life phase is negligible.

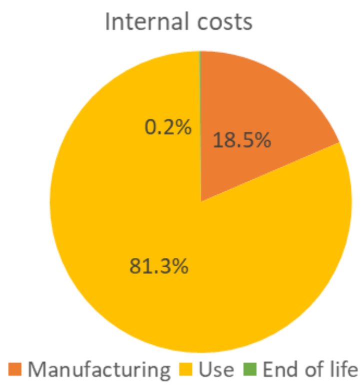

Figure 7 Contribution of each life cycle phase to the total internal costs for the washing machine.

4.3.3 External costs

Monetary valuation of environmental impacts was applied to assess the costs of environmental externalities. To this end, LCA results obtained for the washing machine (see Deliverable 5.2) were combined with monetisation factors given for different environmental impact categories (see Section External costs). External costs were estimated using two different approaches for monetary valuation: (1) monetisation of global warming impact and (2) monetisation of endpoint impacts. It should be noted that the economic costs obtained in each case cannot be added together since the global warming impact (as well as the other midpoint impacts) is included in the endpoint impacts.

The results from the monetary valuation of environmental impacts are collected in Table 15. These are broken down by life cycle phases and impact categories monetized.

Table 15 External costs for the whole life cycle of one washing machine (cradle-to-grave).

Phase	Impact category	Total amount	Monetisation factor	Economic cost
Raw materials, production & transport	Human Health	2,97E-03	101311 €/DALY	301,06 €
	Ecosystems	3,14E-06	1,23E+07 €/species.yr	38,74 €
	Resources	32,13	0,929 €/USD	29,86 €
	Sub-Total production phase	-	-	369,67 €
	Global warming	354,82	130 €/tonne CO2 eq	46,17 €
Use	Human Health	3,02E-02	101311 €/DALY	3062,76 €
	Ecosystems	1,72E-04	1,23E+07 €/species.yr	2123,66 €
	Resources	64,10	0,929 €/USD	59,58 €
	Sub-Total use phase	-	-	5246,00 €
	Global warming	1969,10	130 €/tonne CO2 eq	256,23 €
End of Life	Human Health	5,56E-05	101311 €/DALY	5,63 €
	Ecosystems	1,14E-07	1,23E+07 €/species.yr	1,40 €
	Resources	1,39	0,929 €/USD	1,29 €
	Sub-Total EoL phase	-	-	8,32 €
	Global warming	19,93	130 €/tonne CO2 eq	2,59 €
TOTAL	Human Health	3,33E-02	101311 €/DALY	3369,45 €
	Ecosystems	1,76E-04	1,23E+07 €/species.yr	2163,80 €
	Resources	97,62	0,929 €/USD	90,73 €
	TOTAL COST	**-**	**-**	**5623,99 €**
	Global warming	2343,85	130 €/tonne CO2 eq	304,99 €

Figure 8 graphically shows the contribution of each endpoint impact to the total external costs for the manufacturing and end of life since these are the life cycle phases in which the project is expected to achieve higher improvements. Most of the external costs are due to human health damages, while the costs of damages to ecosystem diversity and resource availability are lower and comparable with each other.

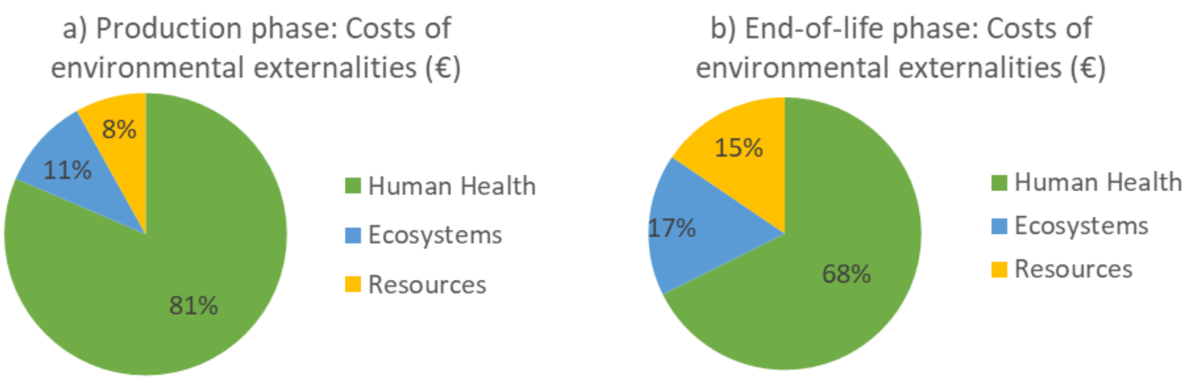

Figure 8. Contribution of each endpoint impact to total external costs of manufacturing and end-of-life phases for the C-SERVEES WM.

4.3.4 Total life cycle costs

Concluding, Table 16 shows the total life cycle cost including internal and external costs. Clearly, the cost of environmental externalities, and especially the external cost for the use stage, is the highest cost element. In contrast, the product waste management in the end-of-life phase is the one with the lowest cost, both for internal and external costs.

Table 16 Life cycle cost (TOTAL COST FOR LIFETIME)

Life cycle phase	Internal cost (€)	External cost (€)	Total cost (€)
Manufacturing	414.01	369.67 €	783.68
Use	1,816.89	5,246.00 €	7,062.89
End of life	3.86	8.32 €	12.18
TOTAL	**2,234.75**	**5.623,99 €**	**7.858,74 €**

4.4 WM comparative life cycle costing

Circularity enhancement of the C-SERVEES TV set is performed with the same internal cost amount than the linear Reference WM although with a very slight difference in the external cost. Table 17 and Figure 9 show the LCC of the reference and the C-SERVEES products for one functional unit. Recycled materials and mass reduction introduced in the C-SERVEES washing machine reduces the total cost by 0.01%, specifically the external costs of the production process by 0.24% and the external costs of the end-of-life by 1.18%.

Table 17 WM comparative life cycle costs.

Units: €		Reference	CSERVEES	Relative reduction
COSTS OF ENVIRONMENTAL EXTERNALITIES	Manufacturing	1,35E-01	1,34E-01	0,24%
	Use	1,91E+00	1,91E+00	0,00%
	End of Life	3,06E-03	3,03E-03	1,18%
INTERNAL COSTS	Manufacturing	1,51E-01	1,51E-01	0,00%
	Use	6,61E-01	6,61E-01	0,00%
	End of Life	1,40E-03	1,40E-03	0,00%
TOTAL		**2.8581**	**2.8577**	**0.01%**

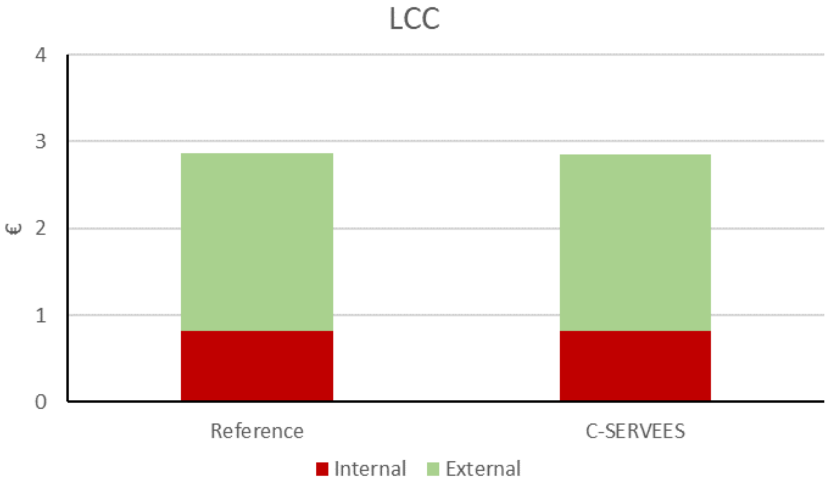

Figure 9. WM comparative life cycle costs.

5 Multifunctional laser printer

LEXMARK identified and selected several laser printer models to include in the demonstration, such as the following models: CX860dte, X950de, MS812 and CX510. All of them are multifunctional laser printers that were selected due to their suitability for refurbishment operations.

The laser printer selected as the reference for the life cycle sustainability assessment was the LEXMARK CX860dte. It is a network-ready, professional multi-function device with standard 2-sided printing and scanning, a 1.6 GHz quad-core processor and 2GB of standard memory that prints at up to 60 ppm black and colour. The printer fuses different colours to a medium (such as paper) to create hard copy images from electronic or hard copy originals. The printer product delivered to the customer consists of the printer, a power cord, printed setup instructions, a CD/DVD that includes the User Guide and Printer Drivers and an initial set of product supplies. The printer is delivered in packaging that can be recycled locally and is not needed for product operation. Product supplies include toner cartridges, imaging kits and the fusing mechanism. The power supply is internal to the product and the imaging kit and fusing mechanism are installed at the factory. Only the toner cartridges must be installed by the customer. More details on the current multifunctional laser printer selected for the sustainability assessment are shown in Table 18.

The functional unit considered in the present study is 1,000 printed pages with the one multifunctional laser printer LEXMARK CX860dte. The performance of this laser printer is 390,000 pages printed during its 5-year lifetime (assuming a standard business usage of 260 days/year and 300 pages per day). It should be noted that this product is a shared printing and copying device that is used by a pool of business users. The assessment was initially performed for one product and at the end converted to the functional unit.

Table 18. Technical specifications of the demo multifunctional laser printer.

MODEL	LEXMARK CX860dte
Image	
Product number	42K0071
Print technology	Colour Laser
Functions	Colour copying, colour faxing, colour printing, colour scanning, colour network scanning
Display	Lexmark e-Task 10-inch (25 cm) class colour touch screen
Size / Packaged size	1162 x 559 x 588 mm / 1380 x 762 x 830 mm
Weight / Packaged weight	131.3 kg / 157.4 kg
Print speed (up to)	Black: 60 ppm / Colour: 60 ppm (pages per minute)
Recommended monthly page volume	5,000 - 50,000 pages
Laser cartridges yield (up to)	55,000-page Black and Colour (CMYK) Ultra High Yield Cartridges

	22,000-page Colour (CMY) Extra High Yield Cartridges 33,000-page Black Extra High Yield Cartridge 17,000-page Colour (CMY) High Yield Cartridges 8,000-page Black and Colour (CMYK) Cartridges
Photoconductor estimated yield (up to)	175,000 pages, based on 3 average letter/A4-size pages per print job and ~ 5% coverage
Developer unit(s) estimated yield (up to)	300,000 pages, based on 3 average letter/A4-size pages per print job and ~ 5% coverage
Cartridge(s) Shipping with Product	8,000-page Black Return Program Toner Cartridge 17,000-page Colour (CMY) High Yield Return Program Toner Cartridges
Electricity consumption	0.391 kWh/1,000 pages (ENERGY STAR Certified)
Average power	0.3 W (Hibernate Mode), 3.3 W (Sleep Mode), 125 W (Ready Mode), 870 W (Printing), 650 W (Copying), 115 W (Scanning)
Country of origin	China

The activities conducted in the LCSA were derived from the PRINT-CIRCMODE short-term actions validated in WP2. The table below presents the PRINT-CIRCMODE canvas sub-components and their validated short-term CE actions, as presented in Table 24 in D2.3, and the selected strategies implemented in WP5 as C-SERVEES product.

Table 19. Validated short-term PRINT-CIRCMODE Canvas Key Circular sub-components and their associated Circular Economy Actions relevant for the LCSA.

PRINT-CIRCMODE Canvas Sub-Component	**PRINT-CIRCMODE validated short-term Circular Economy Actions**	**LCSA implemented**
PRINT_C2.3 Introduce and/or expand the use of ICT to foster circular economy	PRINT_A2.3.1 Use ICT to support information sharing across the supply chain related to recycled content	Remanufacturing
PRINT_C1.1 Diversify circular activities	PRINT_A1.1 2 Identify levers to reduce dismantling and refurbishing cost by setting various operating models	
PRINT_C1.5 Provide repair and maintenance services, including new technologies such as 3D printing	PRINT_A1.5.2 Salvage working and repairable parts from collected/return printers and use on E2N (Equal to New) printers	
PRINT_C1.6 Optimize end-of-life circularity	PRINT_A1.6.1 increase the flow of returned end-of-life printers by reducing the associated time and cost	
PRINT_C2.3 Introduce and/or expand the use of ICT to foster circular economy	PRINT_A2.3.1 Use ICT to support information sharing across the supply chain related to recycled content	
PRINT_C9.4 Implement and/or enhance strategies and/or practices to address the challenges of promoting options with lower lifetime rather than lower initial costs	PRINT_A9.4.2 Investigate economics of more CE suitable materials coming from end-of-life cartridges or printers	Remanufacturing toner cartridges

5.1 Functional unit and system boundaries

The main product function for the multifunctional laser printer is to create hard copy images from electronic or hard copy originals by fusing different colours to a medium like paper. The functional unit considered in this study is one multifunctional laser printer LEXMARK CX860dte, which has a maximum printing speed of 60 pages per minute and results in 390,000 pages printed during its 5-year lifetime (assuming a standard business usage of 260 days/year and 300 pages per day).

Table 20 shows the system boundaries considered for the laser printer, identifying the life cycle phases, processes and other elementary flows included and excluded in the study.

Table 20. System boundaries considered for the laser printer.

Life cycle phase	Included	Excluded
Raw material extraction and processing	Extraction of natural resources Refining and raw material production Intermediate product manufacturing Waste treatment and transport	Infrastructure
Product manufacturing	Energy for product manufacturing/assembly Transport	Infrastructure Production losses Packaging
Product distribution	Transport	
Product use	Electricity consumption Paper consumption Consumption of toner cartridges (including manufacturing and transport) Maintenance, including other replacements like imaging kit, fuser kit and toner bottles (including manufacturing and transport)	Infrastructure Production losses Packaging
End of life	Transport EoL treatments for laser printer EOL treatments for replacements Landfilling of waste fraction not recycled	
Benefits and burdens beyond system boundaries	Recycling benefits (included as credits)	

5.2 MLP Reference cycle costing

The economic study for the multifunctional laser printer LEXMARK CX860dte was performed considering both internal and external costs and assuming a standard use in relation to the product use. Standard use is based on an average standard business customer that uses the printer 260 days/year for printing 300 pages/day, thus resulting in 390,000 pages printed during the 5-year lifetime.

Standard use was defined according to market analysis data provided by LEXMARK. The internal costs, external environmental costs and total costs are detailed and compared below.

5.2.1 Internal costs

The internal costs assessed for the laser printer includes the costs for:

(i) Acquisition of raw materials and components, including related transport operations.
(ii) Manufacturing of the product.
(iii) Distribution of the product to retailers or final customers.
(iv) Use, including product operation and required consumables (paper and toner cartridges).
(v) Maintenance, including the production and transport of replacements (toner bottles, imaging kits and fuser kits).
(vi) End of life, including WEEE management for the laser printer, consumables and replaced parts.

Table 21 shows the breakdown of the internal costs of the laser printer by life cycle phase, namely manufacturing (including i, ii and iii), use (iv and v) and end of life (vi), according to the standard use.

Retail price provided by LEXMARK was assumed herein to consider manufacturing costs. The retail price covers all the costs related to raw materials and components, product manufacturing and distribution, as well as other any other costs for product development (like R&D costs) and net revenues from sales.

The use phase includes the costs for electricity, consumables (paper and toner cartridges) and other parts replaced during maintenance throughout the printer lifetime (as detailed in Section 3.1.2). Total linked amounts were therefore estimated at 152.49 kWh of electricity, 390 thousand pages (1,322 kg paper), 9 black toners, 17 colour toners, 3 toner bottles, 1 imaging kit and 1 fuser kit. The average market prices for these consumables were assumed as follows: 0.117 €/kWh of electricity for year 2019, with a sustained annual growth factor of 1.022 for the following years; 9.20 €/1,000 paper pages; 458.51 €/black toner; 465.40 €/colour toner, 44.95 €/toner bottle; 511.59 €/imaging kit; 762.87 €/fuser kit.

The costs for WEEE management were estimated at 15.00 € for one laser printer, which corresponds to the fee paid by producers for the EoL management of each laser printer they put on the market. In addition, the costs for waste management of consumables and components were estimated similarly.

Table 21. Internal costs for the whole life cycle of one Reference MLP (cradle-to-grave).

Life cycle phase	Concept	Cost (€)	Total cost (€)
Manufacturing	Retail price (incl. costs for materials/components, manufacturing, distribution, other product development costs and net revenues)	8,459.00	8,459.00
Use	Electricity consumption	18.70	17,054.40
	Paper consumption	3,588.00	
	Toner cartridges	12,038.39	
	Toner bottle	134.85	
	Imaging kit	511.59	
	Fuser kit	762.87	
End of life	WEEE management fee, printer	15.00	24.06
	WEEE management fee, toner cartridges	7.28	
	WEEE management fee, replacements	1.78	
TOTAL		-	**25,537.46**

Figure 10 graphically shows the contribution of each life cycle phase to the total internal cost of the laser printer. It can be found that the use phase represents two-thirds of the total internal costs, while the remaining third is attributable to the manufacturing phase. The contribution of end of life to internal costs is negligible.

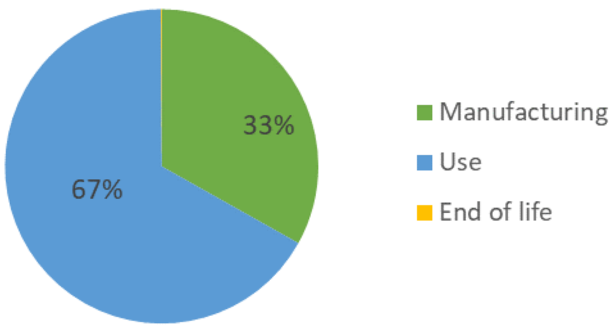

Figure 10. Contribution of each life cycle phase to the total internal costs for Reference MLP.

5.2.2 External costs

Monetary valuation of environmental impacts was applied to assess the costs of environmental externalities. To this end, LCA results obtained for the laser printer (see Deliverable 5.2) were combined with monetisation factors given for different environmental impact categories (see Section 3.2). External costs were estimated using two different approaches for monetary valuation: (1) monetisation of global warming impact and (2) monetisation of endpoint impacts. It should be noted that the economic costs obtained in each case cannot be added together since the global warming impact (as well as the other midpoint impacts) is included in the endpoint impacts.

The results from the monetary valuation of environmental impacts for the standard use are collected in Table 22. These are broken down by life cycle phases and impact categories monetized. It can be found that the use phase is the main responsible for the external costs, followed by the manufacturing phase. The costs of end-of-life phase are comparatively negligible.

Table 22. External costs for the whole life cycle of Reference MLP (cradle-to-grave).

Life cycle phase	Impact category	Total amount	Monetisation factor	Economic cost (€)
Manufacturing	Human health	3.56E-03 DALY	101,311 €/DALY	360.36
	Ecosystems	5.19E-06 species.yr	1.23E+07 €/species.yr	63.97
	Resources	72.12 USD2013	0.929 €/USD2013	67.03
	Sub-total endpoint impacts	-	-	**491.36**
	Global warming	846.39 kg CO_2 eq	130 €/tonne CO_2 eq	110.14
Use	Human health	6,60E-03 DALY	101,311 €/DALY	668,74
	Ecosystems	3,60E-05 species.yr	1.23E+07 €/species.yr	444,08
	Resources	164,97 USD	0.929 €/USD2013	153,33
	Sub-total endpoint impacts	-	-	**1,266.15**
	Global warming	1692.42 kg CO_2 eq	130 €/tonne CO_2 eq	220.22
End of life	Human health	1,64E-04 DALY	101,311 €/DALY	16,64
	Ecosystems	3,33E-07 species.yr	1.23E+07 €/species.yr	4,11
	Resources	5,58 USD	0.929 €/USD2013	5,18
	Sub-total endpoint impacts	-	-	**25.93**
	Global warming	66.65 kg CO_2 eq	130 €/ tonne CO_2 eq	8.67
TOTAL	Human health	1,03E-02 DALY	101,311 €/DALY	1045,74 €
	Ecosystems	4,16E-05 species.yr	1.23E+07 €/species.yr	512,15 €
	Resources	242,66 USD	0.929 €/USD2013	225,54 €
	Total external cost	-	-	**1,783.44**
	Total global warming	2,605.46 kg CO_2 eq	130 €/tonne CO_2 eq	339.03

Figure 11 graphically shows the contribution of each endpoint impact to the total external costs for each life-cycle phase. Most of the external costs are due to human health damages. The costs of damages to ecosystem diversity are especially relevant for the use phase, while the costs of damages to resource availability are important for the end-of-life phase.

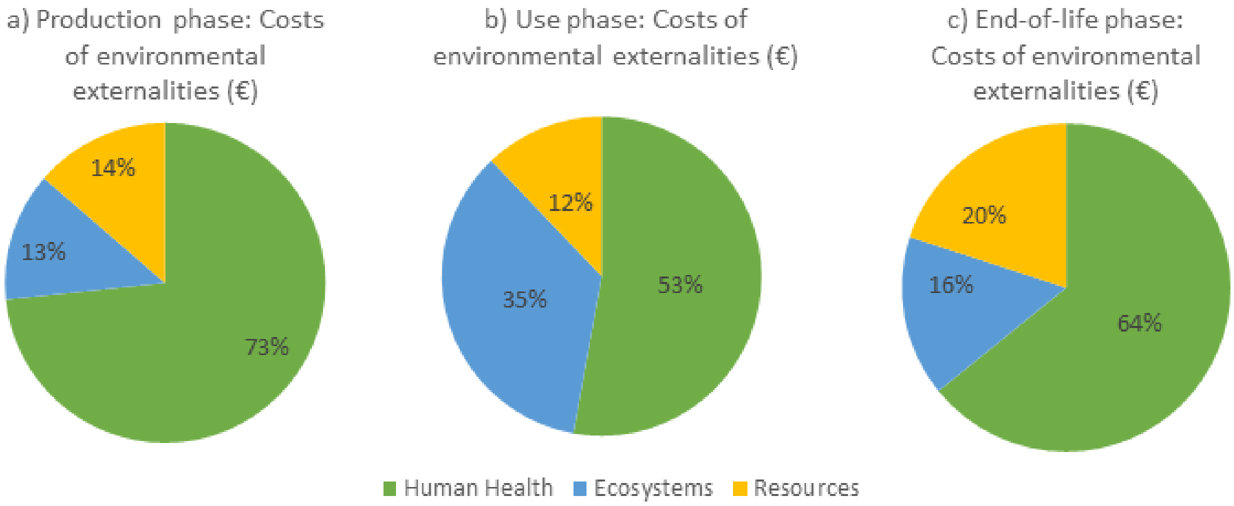

Figure 11. Contribution of each endpoint impact to total external costs of manufacturing, use and end-of-life phases for the Reference MLP.

5.2.3 Total life cycle costs

Concluding, Table 23 shows the total life cycle cost including internal and external costs. The internal costs are by far the highest cost element. This cost is mainly dominated by the use phase. Manufacturing and use phases together comprise most of the costs, both for internal and external costs, while the costs of end-of-life phases is comparatively negligible.

Table 23. Total costs for the whole life cycle of Reference MLP (cradle-to-grave).

	Internal cost (€)	External cost (€)	Total cost (€)
Manufacturing	8,459.00	491.36	8,950.36
Use	17,054.40	1,266.15	18,320.55
End of life	24.06	25.93	49.99
TOTAL	**25,537.46**	**1,783.44**	**27,320.9**

5.3 CSERVEES life cycle costing

5.4 Redesign changes

Redesign changes implemented in the LCSA as described in Table 19 are detailed in Table 24. Selected strategy in C-SERVEES MLP set is reusing part of the components for remanufacturing new printers.

Table 24. C-SERVEES MLP changes implemented in LCSA.

	Reference	CSERVEES	
Lifetime, years	5	5	
Functional units, printed pages	390000	390000	
Recycled content	Recycled plastics	Recycled plastics	
Remanufacturing	NO	**BoM Part Number(s)**	**Percentage of time replaced**
		17X7101	20%

Reference	CSERVEES	
	21K1191	30%
	21K2829	35%
	21K2809	35%
	21K2806	25%
	21K2830	35%
	21K1600, 21K1624, 21K2196	40%
	21K1520	35%
	21K2951	35%
	21K2975	35%
	21K2936	30%
	21K2969	35%
	21K2956	30%
	21K2801, 21K2988	60%
	21K2953	40%
	21K2952	40%
	21K2961	40%
	21K2967	40%
	21K2966	40%
	21K2965	40%
	21K2868, 21K2869	5%
	25B9160	10%
	21K8568	25%
	21K9000	10%
	21K8801	50%
	21K8804	50%
	21K8201	55%
	21K8021	20%
	3079274	45%
	21K8567	50%
	21K4211	45%

5.5 Internal costs

The internal costs assessed for the laser printer includes the costs for:

- (i) Acquisition of raw materials and components, including related transport operations.
- (ii) Manufacturing of the product.
- (iii) Distribution of the product to retailers or final customers.
- (iv) Use, including product operation and required consumables (paper and toner cartridges).
- (v) Maintenance, including the production and transport of replacements (toner bottles, imaging kits and fuser kits).
- (vi) End of life, including WEEE management for the laser printer, consumables and replaced parts.

Table 25 shows the breakdown of the internal costs of the laser printer by life cycle phase, namely manufacturing (including i, ii and iii), use (iv and v) and end of life (vi), according to the standard use.

Retail price provided by LEXMARK was assumed herein to consider manufacturing costs. The retail price covers all the costs related to raw materials and components, product manufacturing and distribution, as well as other any other costs for product development (like R&D costs) and net revenues from sales.

The use phase includes the costs for electricity, consumables (paper and toner cartridges) and other parts replaced during maintenance throughout the printer lifetime (as detailed in Section 3.1.2). Total linked amounts were therefore estimated at 152.49 kWh of electricity, 390 thousand pages (1,322 kg paper), 9 black toners, 17 colour toners, 3 toner bottles, 1 imaging kit and 1 fuser kit. The average market prices for these consumables were assumed as follows: 0.117 €/kWh of electricity for year 2019, with a sustained annual growth factor of 1.022 for the following years; 9.20 €/1,000 paper pages; 458.51 €/black toner; 465.40 €/colour toner, 44.95 €/toner bottle; 511.59 €/imaging kit; 762.87 €/fuser kit.

The costs for WEEE management were estimated at 15.00 € for one laser printer, which corresponds to the fee paid by producers for the EoL management of each laser printer they put on the market. In addition, the costs for waste management of consumables and components were estimated similarly.

Table 25. Internal costs for the whole life cycle of one C-SERVEES MLP (cradle-to-grave).

Life cycle phase	Concept	Cost (€)	Total cost (€)
Manufacturing	Retail price (incl. costs for materials/components, manufacturing, distribution, other product development costs and net revenues)	8,459.00	8,459.00
Use	Electricity consumption	18.70	17,054.40
	Paper consumption	3,588.00	
	Toner cartridges	12,038.39	
	Toner bottle	134.85	
	Imaging kit	511.59	
	Fuser kit	762.87	
End of life	WEEE management fee, printer	15.00	24.06
	WEEE management fee, toner cartridges	7.28	
	WEEE management fee, replacements	1.78	
TOTAL		-	**25,537.46**

Figure 12 graphically shows the contribution of each life cycle phase to the total internal cost of the laser printer. It can be found that the use phase represents two-thirds of the total internal costs, while the remaining third is attributable to the manufacturing phase. The contribution of end of life to internal costs is negligible.

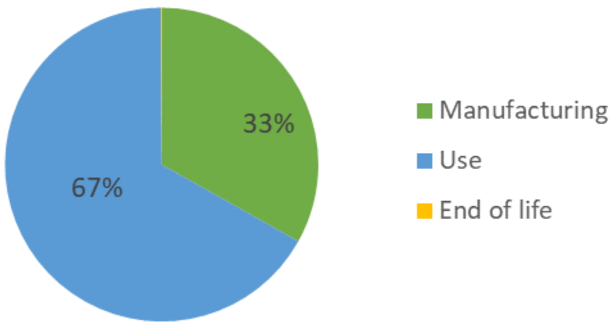

Figure 12. Contribution of each life cycle phase to the total internal costs for the C-SERVEES MLP.

5.6 External costs

Monetary valuation of environmental impacts was applied to assess the costs of environmental externalities. To this end, LCA results obtained for the laser printer (see Deliverable 5.2) were combined with monetisation factors given for different environmental impact categories (see Section 3.2 of the main document). External costs were estimated using two different approaches for monetary valuation: (1) monetisation of global warming impact and (2) monetisation of endpoint impacts. It should be noted that the economic costs obtained in each case cannot be added together since the global warming impact (as well as the other midpoint impacts) is included in the endpoint impacts.

The results from the monetary valuation of environmental impacts are collected in Table 26. These are broken down by life cycle phases and impact categories monetized. It can be found that the use phase is the main responsible for the external costs, followed by the manufacturing phase. The costs of end-of-life phase are comparatively negligible.

Table 26. External costs for the whole life cycle of one C-SERVEES MLP (cradle-to-grave).

Life cycle phase	Impact category	Total amount	Monetisation factor	Economic cost (€)
Manufacturing	Human health	3,28E-03 DALY	101,311 €/DALY	332,01
	Ecosystems	4,72E-06 species.yr	1.23E+07 €/species.yr	58,20
	Resources	64,28 USD	0.929 €/USD2013	59,75
	Sub-total endpoint impacts	-	-	**449.96**
	Global warming	767,34 kg CO2 eq	130 €/tonne CO_2 eq	99.85
Use	Human health	6,56E-03 DALY	101,311 €/DALY	665,00
	Ecosystems	3,60E-05 species.yr	1.23E+07 €/species.yr	443,22
	Resources	162,82 USD	0.929 €/USD2013	151,33
	Sub-total endpoint impacts	-	-	**1,259.55**
	Global warming	1676,23 kg CO2 eq	130 €/tonne CO_2 eq	218.12
End of life	Human health	1,84E-04 DALY	101,311 €/DALY	18,60
	Ecosystems	3,81E-07 species.yr	1.23E+07 €/species.yr	4,69
	Resources	7,54 USD	0.929 €/USD2013	7,00
	Sub-total endpoint impacts	-	-	**30.30**
	Global warming	75,45 kg CO2 eq	130 €/ tonne CO_2 eq	9.82
TOTAL	Human health	1,00E-02 DALY	101,311 €/DALY	1015,61
	Ecosystems	4,11E-05 species.yr	1.23E+07 €/species.yr	506,11
	Resources	234,64 USD	0.929 €/USD2013	218,08
	Total external cost	-	-	**1,739.81**
	Total global warming	2519,03 kg CO2 eq	130 €/tonne CO_2 eq	327.79

Figure 13 graphically shows the contribution of each endpoint impact to the total external costs for each life-cycle phase. Most of the external costs are due to human health damages. The costs of damages to ecosystem diversity are especially relevant for the use phase, while the costs of damages to resource availability are important for the end-of-life phase.

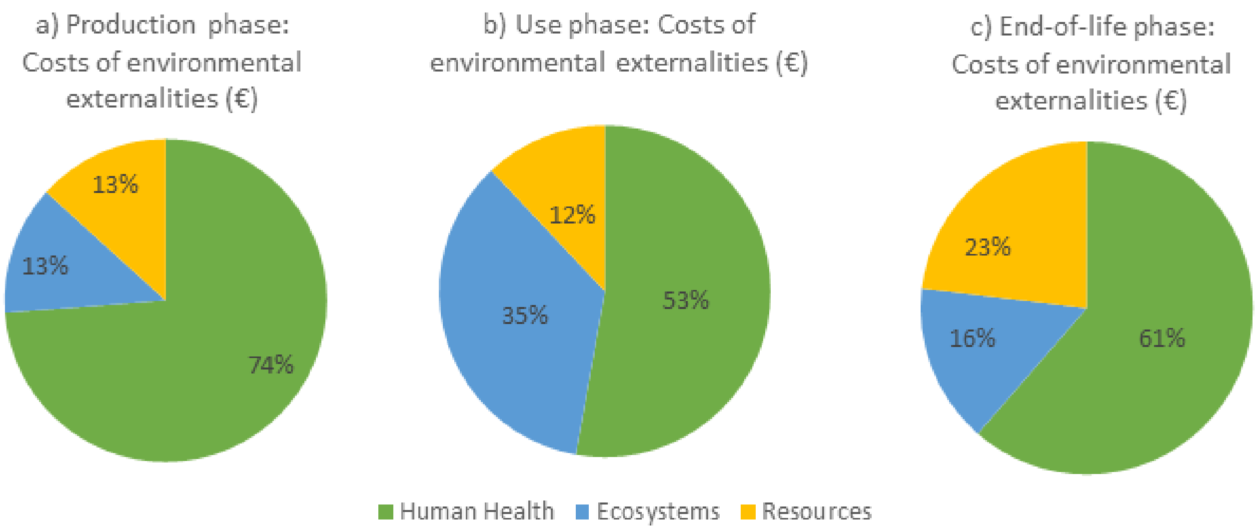

Figure 13. Contribution of each endpoint impact to total external costs of manufacturing, use and end-of-life phases for the C-SERVEES MLP.

5.7 Total life cycle costs

Concluding, Table 27 shows the total life cycle cost including internal and external costs. The internal costs are by far the highest cost element. This cost is mainly dominated by the use phase. Manufacturing and use phases together comprise most of the costs, both for internal and external costs, while the costs of end-of-life phases is comparatively negligible.

Table 27. Total costs for the whole life cycle of one C-SERVEES MLP (cradle-to-grave).

Life cycle phase	Standard use		
	Internal cost (€)	**External cost (€)**	**Total cost (€)**
Manufacturing	8,459.00	449.96	8,908.96
Use	17,054.40	1,259.55	18,313.95
End of life	24.06	30.30	54.36
TOTAL	**25,537.46**	**1,739.81**	**27,277.27**

5.8 MLP Comparative life cycle costing

Circularity enhancement of the C-SERVEES MLP is performed with the same internal cost amount although with different external cost than the linear Reference MLP. Table 28 and Figure 14 show the LCC of the reference and the CSERVEES products for 1,000 printed pages. It is clear that reusing part of the product modules for remanufacturing reduces the external cost of the production process by 8.4%, although this requires increasing the cost of the end-of-life phase by 16.9%, leaving the total reduction at 0.2%.

Table 28. Laser printers comparative LCC for 1,000 printed pages.

Units: €		**Reference**	**C-SERVEES**	**Relative reduction**
COSTS OF ENVIRONMENTAL EXTERNALITIES	Manufacturing	1.26E+00	1.15E+00	8.4%
	Use	3.25E+00	3.23E+00	0.5%
	End of Life	6.65E-02	7.77E-02	-16.9%
INTERNAL COSTS	Manufacturing	2.17E+01	2.17E+01	0.0%
	Use	4.37E+01	4.37E+01	0.0%
	End of Life	6.17E-02	6.17E-02	0.0%
TOTAL		**70.05**	**69.94**	**0.2%**

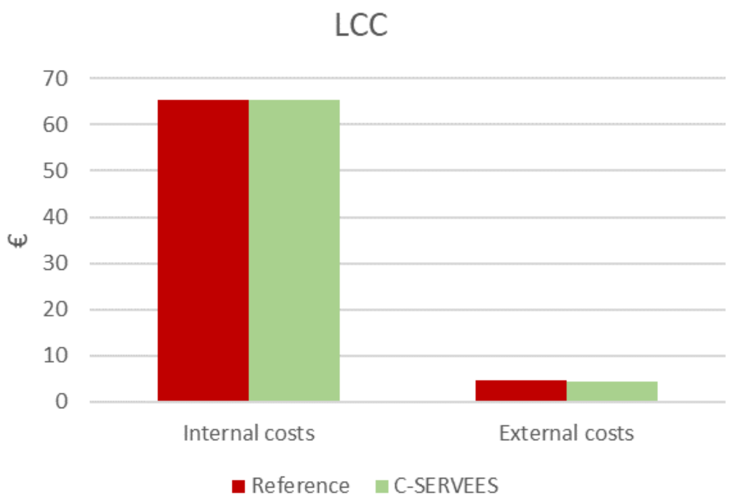

Figure 14. Laser printers comparative LCC for 1,000 printed pages.

6 Telecom equipment

The telecommunications equipment selected by ADVA for demonstration belongs to their ALM line (Advanced Link Monitoring) for optical networks, which is a relatively new and still upraising product line. It splits into an (electrically) active unit and passive sensors for fibre monitoring tasks like real-time information on fibre integrity, fast and easy localization of user traffic and remote active fire detection in sites accessed with a fibre. The novelty in the ALM product line makes it suitable for the demonstration purposes since it makes it simpler to introduce changes on the product line. Two variants of the active ALM units were considered for the demonstration, namely 16ALM and 64ALM. In addition, two different configurations were considered for the active sensors. The ALM product selected as the reference for the life cycle sustainability assessment was the ADVA 16ALM/#1650D/AC, while one sensor configuration for door-opening detection was included in the assessment. More details on the current ALM product selected for the sustainability assessment are shown in Table 29.

The functional unit considered in the present study is one hour of one ALM product monitoring, including the active unit (ADVA 16ALM/#1650D/AC) and 50 passive sensors. This combined system offers continuous monitoring throughout its 8-year lifetime (i.e., 365 days/year and 24 h/day) in the Reference version. The assessment was initially performed for one product and at the end converted to the functional unit.

Table 29. Technical specifications of the demo telecom product.

MODEL	ADVA 16ALM/#1650D/AC
Image	
Product number	1043709841-02
Description	Advanced Link Monitor (ALM), 16 ports with LC/APC connectors, AC powered
Colour	Grey
Size	44 × 215 × 213 mm
Weight / Packaged weight	< 2 kg / 11.6 kg
Power typical / maximum	10 W / 13 W
Country of origin	Germany

The activities conducted in the LCSA were derived from the ALM-CIRCMODE short-term actions validated in WP2. The table below presents the ALM-CIRCMODE canvas sub-components and their validated short-term CE actions, as presented in Table 24 in D2.4, and the selected strategies implemented in WP5 as C-SERVEES product.

Table 30. Validated short-term ALM-CIRCMODE Canvas Key Circular sub-components and their associated Circular Economy Actions relevant for the LCSA.

ALM-CIRCMODE Canvas Sub-Component	ALM-CIRCMODE validated short-term Circular Economy Actions	LCSA implemented
ALM_C1.1 Diversifying circular activities	ALM_A1.1.1 Design for longevity, in particular better maintainability	Lifetime from 8 to 15 years
ALM_C1.2 Embrace eco-design to ensure products circularity across life-cycle stages	ALM_A1.2.2 Devise an eco-design approach in production and Design for Recycling	Recycled passive sensors
ALM-C9.2: Introducing and/or enhancing manufacturing and sales processes to account for	ALM_A9.2.1 Reduce costs of manual disassembly for recycling	10% reuse in central unit

ALM-CIRCMODE Canvas Sub-Component	ALM-CIRCMODE validated short-term Circular Economy Actions	LCSA implemented
costs associated with the end-of life and second life of materials, components and products		

6.1 Functional unit and system boundaries

The product function for the ALM product is fibre monitoring. The product considered in the study is one ALM product, including the active unit (ADVA 16ALM/#1650D/AC) and 50 passive sensors, which offers continuous monitoring throughout its 8-year lifetime for the Reference Product (i.e., 365 days/year and 24 h/day) and 15-year lifetime for the C-SERVEES Product. The functional unit for the comparative assessment is 1 hour of monitoring network.

Table 31 shows the system boundaries considered for the ALM product, identifying the life cycle phases, processes and other elementary flows included and excluded in the study.

Table 31. System boundaries considered for the ALM product.

Life cycle phase	Included	Excluded
Raw material extraction and processing	Extraction of natural resources Refining and raw material production Intermediate product manufacturing Waste treatment and transport	Infrastructure
Product manufacturing	Energy for product manufacturing/assembly Transport	Infrastructure Production losses Packaging
Product distribution	Transport	
Product use	Electricity consumption Maintenance	
End of life	Transport EoL treatments Landfilling of waste fraction not recycled	
Benefits and burdens beyond system boundaries	Recycling benefits (included as credits)	

6.2 Reference TE life cycle costing

6.2.1 Internal costs

The internal costs assessed for the ALM product includes the costs for:

(i) Acquisition of raw materials and components, including related transport operations.
(ii) Manufacturing of the product.
(iii) Distribution of the product to retailers or final customers.
(iv) Use, including product operation.
(v) End of life, including WEEE management.

Table 32 shows the breakdown of the internal costs of the ALM product by life cycle phase, namely manufacturing (including i, ii and iii), use (iv) and end of life (v).

Retail price provided by ADVA was assumed herein to consider manufacturing costs. The retail price covers all the costs related to raw materials and components, product manufacturing and distribution, as well as other any other costs for product development (like R&D costs) and net revenues from sales.

The use phase includes the costs for the electricity consumed by the ALM product for operation during its whole lifetime. Total electricity consumption was estimated at 700.8 kWh. The average market price of electricity for non-household customers was assumed as 0.117 €/kWh for the year 2019, while a sustained annual growth factor of 1.022 was applied for the following years (see Section 3.1.2). No maintenance operations were considered for the ALM product.

The costs for WEEE management was estimated at 0.19 € (for one ALM product), which corresponds to the fee paid by producers for the EoL management of each ALM product they put on the market.

Table 32. Internal costs for the whole life cycle of one Reference TE (cradle-to-grave).

Life cycle phase	Concept	Total cost (€)
Manufacturing	Retail price (incl. costs for materials/components, manufacturing, distribution, other product development costs and net revenues)	25,035.88
Use	Electricity consumption	163.58
End of life	WEEE management fee	0.19
TOTAL		**25,199.64**

Figure 15 graphically shows the contribution of each life cycle phase to the total internal cost of the ALM product. It can be found that the manufacturing phase is the most expensive by far, comprising 98% of the total internal cost.

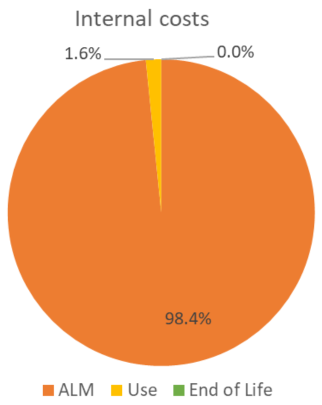

Figure 15. Contribution of each life cycle phase to the total internal costs for the Reference TE.

6.2.2 External costs

Monetary valuation of environmental impacts was applied to assess the costs of environmental externalities. To this end, LCA results obtained for the ALM product (see Deliverable 5.2) were combined with monetisation factors given for different environmental impact categories (see Section 3.2). External costs were estimated using two different approaches for monetary valuation: (1) monetisation of global warming impact and (2) monetisation of endpoint impacts. It should be noted that the economic costs obtained in each case cannot be added together since the global warming impact (as well as the other midpoint impacts) is included in the endpoint impacts.

The results from the monetary valuation of environmental impacts are collected in Table 33. These are broken down by life cycle phases and impact categories monetized.

Table 33. External costs for the whole life cycle of one Reference TE (cradle-to-grave).

Life cycle phase	Impact category	Total amount	Monetisation factor	Economic cost (€)
Manufacturing	Human health	5.63E-04 DALY	101,311 €/DALY	58.29
	Ecosystems	8.59E-07 species.yr	1.23E+07 €/species.yr	10.83

	Resources	3.93 USD	0.929 €/USD2013	3.83
	Sub-total endpoint impacts	-	-	72.95
	Global warming	85 kg CO_2 eq	130 €/tonne CO_2 eq	11.55
Use	Human health	7.40E-08 DALY	101,311 €/DALY	863.19
	Ecosystems	4.83E-05 species.yr	1.23E+07 €/species.yr	595.68
	Resources	13.62 USD	0.929 €/ USD2013	12.73
	Sub-total endpoint impacts	-	-	1471.60
	Global warming	313 kg CO_2 eq	130 €/tonne CO_2 eq	40.83
End of life	Human health	4.76E-06 DALY	101,311 €/DALY	0.50
	Ecosystems	1.02E-08 species.yr	1.23E+07 €/species.yr	0.13
	Resources	0.14 USD	0.929 €/USD2013	0.15
	Sub-total endpoint impacts	-	-	0.78
	Global warming	1.43 kg CO_2 eq	130 €/tonne CO_2 eq	0.20
TOTAL	Human health	5.68E-04 DALY	101,311 €/DALY	921.98
	Ecosystems	4.92E-05 species.yr	1.23E+07 €/species.yr	606.64
	Resources	17.70 USD	0.929 €/USD2013	16.71
	TOTAL EXTERNAL COST	-	-	**1545.33**
	Total global warming	399.45 kg CO_2 eq	130 €/tonne CO_2 eq	52.59

Figure 16 graphically shows the contribution of each endpoint impact to the total external costs for the manufacturing and end of life, since these are the life cycle phases in which the project is expected to achieve higher improvements. Most of the external costs are due to human health damages, while the costs of damages to ecosystem diversity and resource availability are lower and comparable with each other.

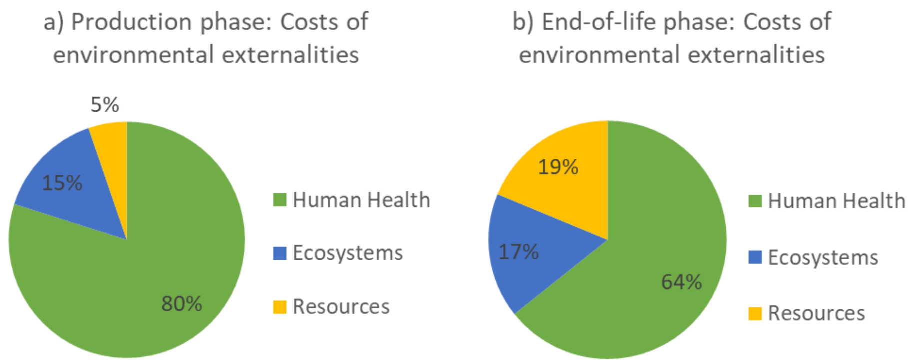

Figure 16. Contribution of each endpoint impact to total external costs of manufacturing and end-of-life phases for the Reference TE.

6.2.3 Total life cycle costs

Concluding, Table 34 shows the total life cycle cost including internal and external costs. The internal cost is in this case much higher than the cost of environmental externalities. The internal cost is clearly dominated by the product manufacturing cost, while the use phase shows the highest contribution to external cost. The product waste management in the end-of-life phase is the one with the lowest cost, which is negligible both for internal and external costs.

Table 34. Total costs for the whole life cycle of one Reference TE (cradle-to-grave).

Life cycle phase	Internal cost (€)	External cost (€)	Total cost (€)
Manufacturing	25,035.88	72.95	25,108.82
Use	163.58	1,471.60	1,635.18
End of life	0.19	0.78	0.97
TOTAL	**25,199.64**	**1,545.33**	**26,744.97**

6.3 CSERVEES life cycle costing

6.3.1 Redesign changes

Redesign changes implemented in the LCSA as described in Table 30 are detailed in Table 35. The inclusion of ICT improves maintenance monitoring and allows for a longer service life of 8 to 15 years and also the 10 % reuse of the components for the central ALM unit. Circularity is also improved with the use of secondary aluminium for passive sensors.

Table 35. C-SERVEES TE redesign changes.

	Reference	C-SERVEES
Lifetime, years	8	15
Functional units, hours	70080	131400
Passive units	50	50
Recycled content	No recycled materials	Passive units with secondary aluminum
Remanufacturing	No	10% reuse in central active unit

6.3.2 Internal costs

The internal costs assessed for the ALM product includes the costs for:

(i) Acquisition of raw materials and components, including related transport operations.
(ii) Manufacturing of the product.
(iii) Distribution of the product to retailers or final customers.
(iv) Use, including product operation.
(v) End of life, including WEEE management.

Table 36 shows the breakdown of the internal costs of the ALM product by life cycle phase, namely manufacturing (including i, ii and iii), use (iv) and end of life (v).

Retail price provided by ADVA was assumed herein to consider manufacturing costs. The retail price covers all the costs related to raw materials and components, product manufacturing and distribution, as well as other any other costs for product development (like R&D costs) and net revenues from sales.

The use phase includes the costs for the electricity consumed by the ALM product for operation during its whole lifetime. Total electricity consumption was estimated at 700.8 kWh. The average market price of electricity for non-household customers was assumed as 0.117 €/kWh for the year 2019, while a sustained annual growth factor of 1.022 was applied for the following years (see Section 3.1.2). No maintenance operations were considered for the ALM product.

The costs for WEEE management was estimated at 0.19 € (for one ALM product), which corresponds to the fee paid by producers for the EoL management of each ALM product they put on the market.

Table 36. Internal costs for the whole life cycle of one C-SERVEES TE (cradle-to-grave).

Life cycle phase	Concept	Total cost (€)
Manufacturing	Retail price (incl. costs for materials/components, manufacturing, distribution, other product development costs and net revenues)	26,039.46
Use	Electricity consumption	258.37
End of life	WEEE management fee	0.19
TOTAL		**26,298.03**

Figure 17 graphically shows the contribution of each life cycle phase to the total internal cost of the ALM product. It can be found that the manufacturing phase is the most expensive by far, comprising 98% of the total internal cost.

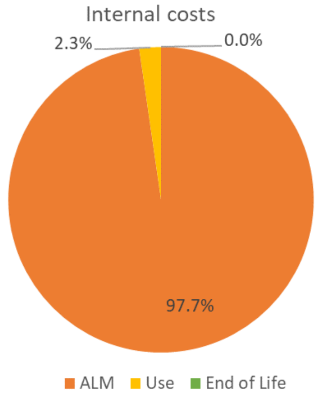

Figure 17. Contribution of each life cycle phase to the total internal costs for the C-SERVEES TE.

6.3.3 External costs

Monetary valuation of environmental impacts was applied to assess the costs of environmental externalities. To this end, LCA results obtained for the ALM product were combined with monetisation factors given for different environmental impact categories (see Deliverable 5.2). External costs were estimated using two different approaches for monetary valuation: (1) monetisation of global warming impact and (2) monetisation of endpoint impacts. It should be noted that the economic costs obtained in each case cannot be added together since the global warming impact (as well as the other midpoint impacts) is included in the endpoint impacts.

The results from the monetary valuation of environmental impacts are collected in Table 37. These are broken down by life cycle phases and impact categories monetized.

Table 37. External costs for the whole life cycle of one C-SERVEES TE (cradle-to-grave).

Life cycle phase	Impact category	Total amount	Monetisation factor	Economic cost (€)
Manufacturing	Human health	5.63E-04 DALY	101,311 €/DALY	57.72
	Ecosystems	8.59E-07 species.yr	1.23E+07 €/species.yr	10.76
	Resources	3.93 USD	0.929 €/USD2013	3.76
	Sub-total endpoint impacts	-	-	72.24
	Global warming	85 kg CO_2 eq	130 €/tonne CO_2 eq	12.16
Use	Human health	7.40E-08 DALY	101,311 €/DALY	1,584.00
	Ecosystems	4.83E-05 species.yr	1.23E+07 €/species.yr	1,098.48
	Resources	13.62 USD	0.929 €/ USD2013	24.04
	Sub-total endpoint impacts	-	-	2,706.51
	Global warming	313 kg CO_2 eq	130 €/tonne CO_2 eq	70.52
End of life	Human health	4.76E-06 DALY	101,311 €/DALY	0.55
	Ecosystems	1.02E-08 species.yr	1.23E+07 €/species.yr	0.15
	Resources	0.14 USD	0.929 €/USD2013	0.16
	Sub-total endpoint impacts	-	-	0.86
	Global warming	1.43 kg CO_2 eq	130 €/tonne CO_2 eq	0.22
TOTAL	Human health	5.68E-04 DALY	101,311 €/DALY	1,642.27
	Ecosystems	4.92E-05 species.yr	1.23E+07 €/species.yr	1,109.38
	Resources	17.70 USD	0.929 €/USD2013	27.96
	TOTAL EXTERNAL COSTS	-	-	**2,779.61**

Total global warming	399.45 kg CO_2 eq	130 €/tonne CO_2 eq	82.89

Figure 18 graphically shows the contribution of each endpoint impact to the total external costs for the manufacturing and end of life, since these are the life cycle phases in which the project is expected to achieve higher improvements. Most of the external costs are due to human health damages, while the costs of damages to ecosystem diversity and resource availability are lower and comparable with each other.

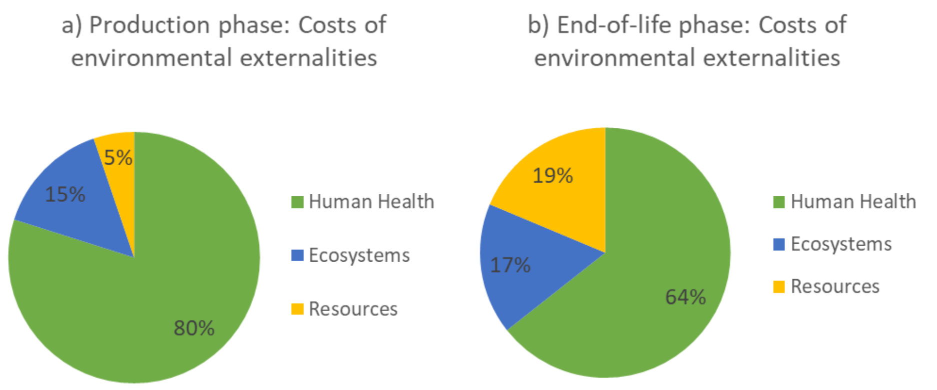

Figure 18. . Contribution of each endpoint impact to total external costs of manufacturing and end-of-life phases for the C-SERVEES TE.

6.3.4 Total life cycle costs

Concluding, Table 38 shows the total life cycle cost including internal and external costs. The internal cost is in this case much higher than the cost of environmental externalities. The internal cost is clearly dominated by the product manufacturing cost, while the use phase shows the highest contribution to external cost. The product waste management in the end-of-life phase is the one with the lowest cost, which is negligible both for internal and external costs.

Table 38. Total costs for the whole life cycle of one ALM CSERVEES product (cradle-to-grave).

Life cycle phase	Internal cost (€)	External cost (€)	Total cost (€)
Manufacturing	26,039.46	72.24	26,111.70
Use	258.37	2,706.51	2,964.89
End of life	0.19	0.86	1.05
TOTAL	**26,298.03**	**2,779.61**	**29,077.64**

6.4 TE comparative life cycle costing

Circularity enhancement of the C-SERVEES telecom equipment is performed at the same internal manufacturing cost to the linear Reference. However, the introduction of ICT has improved the maintenance of the TE increasing the lifetime from 8 to 15 years and making feasible the 10% reuse of the central ALM unit. Table 39 and Figure 19 show the economic impact of the reference and the CSERVEES products for one hour of monitoring network. It can be clearly seen how increasing the lifetime and reusing parts of product modules for remanufacturing reduces all life cycle cost categories and on average by 42%.

Table 39. Telecom equipment comparative live cycle costs for functional unit.

Units: €		Reference	C-SERVEES	Relative reduction
COSTS OF ENVIRONMENTAL EXTERNALITIES	Manufacturing	1.04E-03	5.50E-04	47.2%
	Use	2.10E-02	2.06E-02	1.9%
	End of Life	1.12E-05	6.53E-06	41.7%

Units: €		Reference	C-SERVEES	Relative reduction
INTERNAL COSTS	Manufacturing	3.57E-01	1.98E-01	44.5%
	Use	2.33E-03	1.97E-03	15.8%
	End of Life	2.71E-06	1.45E-06	46.7%
TOTAL		**0.38**	**0.22**	**42.0%**

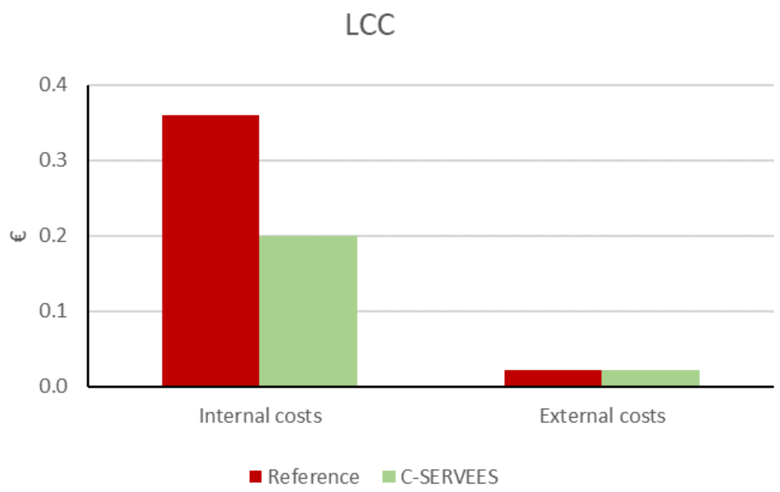

Figure 19. Telecom equipment comparative live cycle costs for functional unit.

7 TV set

The TV set selected for demonstration is GRUNDIG G43C 891 5A, which is a 43” smart-TV model with energy efficiency class A⁺ and connectivity features. This product is manufactured in Tekirdağ (Turkey) and currently on sale in Turkey and the EU. ARÇELIK selected this model because it has convenient size (43”) for hospitality customers targeted in the demonstration. The selected TV has enclosure and stand made of halogen-free plastics. More details on the current TV set selected for demonstration are shown in Table 40.

The functional unit considered in the present study is one watched hour of the 43” TV set GRUNDIG G43C 891 5A. The performance of this TV set is 10,784 hours of viewing during its 8-year lifetime (assuming an average use of 337 days/year and 4 h/day). The assessment was initially performed for one and at the end converted to the functional unit.

Table 40. Technical specifications of the demo TV set.

MODEL	**GRUNDIG G43C 891 5A**
Image	
Product (EAN) number	8690842398605
Description	43" / 108 cm, UHD (3.840 x 2.160), 50 Hz, HEVC/H.265, Smart
Colour	Black
Size	625 × 231 × 976 mm
Weight / Packaged weight	9.2 kg / 12.0 kg
Features	Picture features: Picture Noise Reduction, DLTI, DCTI, DNR, Digital Comb Filter (3D) Colour system: Multisystem USB supported files: .mp3, .m4a, .aac, .jpg, .jpe, .bmp, .png, .mov, .mpg, .mpe, .vob, .dat, .trp, .ts, .avi, .mp4, .mkv, .div
Energy class	A^+
Electricity consumption per year	53.3 kWh
Average power	0.15 W (Stand-by), 38.8 W (Nominal)
Country of origin	Turkey

The activities conducted in the LCSA were derived from the TV-CIRCMODE short-term actions validated in WP2. The table below presents the TV-CIRCMODE canvas sub-components and their validated short-term CE actions, as presented in Table 24 in D2.5, and the selected strategies implemented in WP5 as C-SERVEES product.

Table 41. Validated short-term TV-CIRCMODE Canvas Key Circular sub-components and their associated Circular Economy Actions relevant for the LCSA.

TV-CIRCMODE Canvas Sub Component	TV-CIRCMODE validated short-term Circular Economy Actions	LCSA implemented
TV_C1.1 Diversify circular activities	TV_A1.1.1 Increase recycled plastic content in TV components	rPC-ABS (30%) back cover
	TV_A1.1.2 Decrease packaging waste	100% recycled cardboard
TV_C2.3 Introduce and/or expand the use of ICT to foster circular economy	TV_A2.3.1 Use QR codes to provide information about materials and company's circularity to all the value chain	Remanufacturing
TV_C5.3 Change traditional relationships with customers, for instance: can a customer become a supplier?	TV_A5.3.1 Initiate a take back collection system in Europe with a partner	
	A1.1.5, A1.4.1, A2.1.1, A2.2.1, A5.3.1	

7.1 Functional unit and system boundaries

The product function for the TV set is to play multimedia content with image and sound. The functional unit considered in the study is one 43" TV set (GRUNDIG G43C 891 5A) with 10,784 hours of viewing during its 8-year lifetime (assuming an average use of 337 days/year and 4 h/day).[15]

Table 42 shows the system boundaries considered for the TV, identifying the life cycle phases, processes and other elementary flows included and excluded in the study.

Table 42. System boundaries considered for the TV set.

Life cycle phase	Included	Excluded
Raw material extraction and processing	Extraction of natural resources Refining and raw material production Intermediate product manufacturing Waste treatment and transport	Infrastructure
Product manufacturing	Energy for product manufacturing/assembly Transport	Infrastructure Production losses
Product distribution	Transport	
Product use	Electricity consumption Batteries for remote control	
End of life	Transport EoL treatments Landfilling of waste fraction not recycled	
Benefits and burdens beyond system boundaries	Recycling benefits (included as credits)	

7.2 Reference TV set life cycle costing

7.2.1 Internal costs

The internal costs assessed for the TV set includes the costs for:

(i) Acquisition of raw materials and components, including related transport operations.
(ii) Manufacturing of the product.
(iii) Distribution of the product to retailers or final customers.

(iv) Use, including product operation and required consumables.
(v) End of life, including WEEE management.

Table 43 shows the breakdown of the internal costs of the TV set by life cycle phase, namely manufacturing (including i, ii and iii), use (iv) and end of life (v).

Retail price provided by ARÇELIK was assumed herein to consider manufacturing costs. The retail price covers all the costs related to raw materials and components, product manufacturing and distribution, as well as any other costs for product development (like R&D costs) and net revenues from sales.

The use phase includes the costs for electricity and for remote control batteries consumed for the whole lifetime of the TV. Total consumption values were therefore estimated at 426 kWh of electricity and 6 AA-type batteries. The average market prices for electricity were assumed as 0.216 €/kWh of electricity for year 2019, with a sustained annual growth factor of 1.022 for the following years. The cost for the 6 batteries was assumed to be 5 €, considering average market price.

The costs for WEEE management were estimated at 1.20 € (for one TV set), which corresponds to the fee paid by producers for the EoL management of each TV set they put on the market.

Table 43. Internal costs for the whole life cycle of one Reference TV set (cradle-to-grave).

Life cycle phase	Concept	Cost (€)	Total cost (€)
Manufacturing	Retail price (incl. costs for materials/components, manufacturing, distribution, other product development costs and net revenues)	343.59	343.59
Use	Electricity consumption Batteries for remote control	99.43 5.00	104.43
End of life	WEEE management fee	1.20	1.20
TOTAL		-	**449.22**

Figure 20 graphically shows the contribution of each life cycle phase to the total internal cost of the TV set. It can be found that the manufacturing phase is the most expensive, followed by the use phase, whereas the contribution of end-of-life phase is negligible.

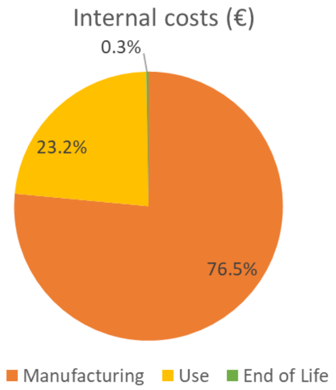

Figure 20. Contribution of each life cycle phase to the total internal cost for the Reference TV set.

7.2.2 External costs

Monetary valuation of environmental impacts was applied to assess the costs of environmental externalities. To this end, LCA results obtained for the TV set (see Deliverable 5.2) were combined with monetisation factors given for different environmental impact categories (see section 3.2). External costs were estimated using two different approaches for monetary valuation: (1) monetisation of global warming impact and (2) monetisation of endpoint impacts. It should be noted that the economic costs obtained in each case cannot be added together since the global warming impact (as well as the other midpoint impacts) is included in the endpoint impacts.

The results from the monetary valuation of environmental impacts are collected in Table 44. These are broken down by life cycle phases and impact categories monetized.

Table 44. External costs for the whole life cycle of one Reference TV set (cradle-to-grave).

Life cycle phase	Impact category	Total amount	Monetisation factor	Economic cost (€)
Manufacturing	Human health	1.30E-03 DALY	101,311 €/DALY	131.67
	Ecosystems	1.51E-06 species.yr	1.23E+07 €/species.yr	18.56
	Resources	16.85 USD2013	0.929 €/USD2013	15.69
	Sub-total endpoint impacts	-	-	165.86
	Global warming	226 kg CO2 eq	130 €/tonne CO2 eq	29.41
Use	Human health	226 kg CO2 eq	130 €/tonne CO2 eq	29.41 €
	Ecosystems	6.55E-03 DALY	101311 €/DALY	663.81 €
	Resources	3.72E-05 species.yr	1.23E+07 €/species.yr	458.20 €
	Sub-total endpoint impacts	-	-	1,131.42 €
	Global warming	239 kg CO2 eq	130 €/tonne CO2 eq	31.06 €
End of life	Human health	1.85E-05 DALY	101,311 €/DALY	1.90
	Ecosystems	4.00E-08 species.yr	1.23E+07 €/species.yr	0.50
	Resources	0.51 USD2013	0.929 €/USD2013	0.48
	Sub-total endpoint impacts	-	-	2.88
	Global warming	8 kg CO2 eq	130 €/ tonne CO2 eq	1.02
TOTAL	Human health	7.87E-03 DALY	101311 €/DALY	797.38 €
	Ecosystems	3.87E-05 species.yr	1.23E+07 €/species.yr	477.26 €
	Resources	27.51 USD	0.929 €/USD	25.57 €
	Total endpoint impacts	-	-	1,300.21€
	Total global warming	**472 kg CO2 eq**	**130 €/tonne CO2 eq**	**61.48 €**

Figure 21 graphically shows the contribution of each endpoint impact to the total external costs for the manufacturing and end of life since these are the life cycle phases in which the project is expected to achieve higher improvements. Most of the external costs are due to human health damages, while the costs of damages to ecosystem diversity and resource availability are lower and comparable with each other.

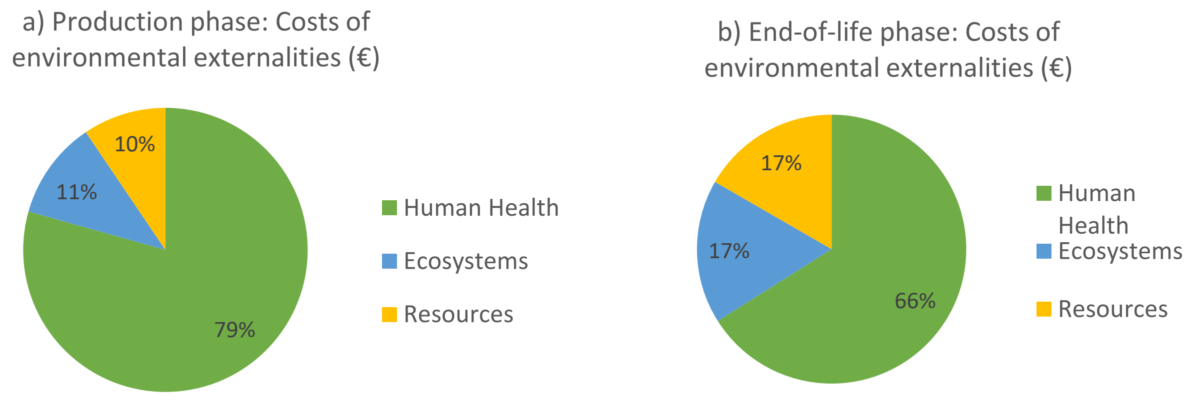

Figure 21. Contribution of each endpoint impact to total external costs of manufacturing and end-of-life phases for the Reference TV set.

7.2.3 Total life cycle costs

Concluding, Table 45 shows the total life cycle cost including internal and external costs. The cost of environmental externalities, and especially the external cost for the use stage, is the highest cost element. In contrast, the product waste management in the end-of-life phase is the one with the lowest cost, both for internal and external costs.

Table 45. Total costs for the whole life cycle of one TV set (cradle-to-grave).

Life cycle phase	Internal cost (€)	External cost (€)	Total cost (€)
Manufacturing	343.59	165.86	509.45
Use	104.43	1131.42	1,235.85
End of life	1.20	2.88	4.08
TOTAL	**449.22**	**1,300.21**	**1,749.38**

7.3 CSERVEES TV set life cycle costing

7.3.1 Redesign changes

Redesign changes implemented in the LCSA as described in Table 41 are detailed in Table 46. Recycled PC-ABS is used for the TV back cover and 100% recycled cardboard is used for the TV box. Most significantly, in C-SERVEES TV set, several components are reused for remanufacturing new TVs.

Table 46. C-SERVEES TV set changes implemented in LCSA.

	Reference	**C-SERVEES**	
Lifetime	8 years	8 years	
Functional units	10784	10784	
Recycled content	No recycled materials	30% recycled PC-ABS - Halogen Free	
		100 % recycled Cardboard	
Remanufacturing	No remanufacturing	**Components**	Replaced rate
		Power cable	50%
		Back Cover	50%
		Plastic Stand Bracket	50%
		Wall Mount Bracket	50%
		Cable	50%
		T-con Board	50%
		Main Board	50%
		PSU Power Supply Unit	50%
		Loudspeaker	50%
		Wi-fi/Bluetooth Board	50%
		Front Plastic Cover	50%
		Display	50%
		Display Plastic Frame	50%
		Reflectiv plastic film	50%
		Led bar	50%
		Remote control	50%

7.3.2 Internal costs

The internal costs assessed for the TV set includes the costs for:

(i) Acquisition of raw materials and components, including related transport operations.
(ii) Manufacturing of the product.
(iii) Distribution of the product to retailers or final customers.
(iv) Use, including product operation and required consumables.
(v) End of life, including WEEE management.

Table 47 shows the breakdown of the internal costs of the TV set by life cycle phase, namely manufacturing (including i, ii and iii), use (iv) and end of life (v).

Retail price provided by ARÇELIK was assumed herein to consider manufacturing costs. The retail price covers all the costs related to raw materials and components, product manufacturing and distribution, as well as any other costs for product development (like R&D costs) and net revenues from sales.

The use phase includes the costs for electricity and for remote control batteries consumed for the whole lifetime of the TV. Total consumption values were therefore estimated at 426 kWh of electricity and 6 AA-type batteries. The average market prices for electricity were assumed as 0.216 €/kWh of electricity for year 2019, with a sustained annual growth factor of 1.022 for the following years. The cost for the 6 batteries was assumed to be 5 €, considering average market price.

The costs for WEEE management were estimated at 1.20 € (for one TV set), which corresponds to the fee paid by producers for the EoL management of each TV set they put on the market.

Table 47. Internal costs for the whole life cycle of one TV set (cradle-to-grave).

Life cycle phase	Concept	Cost (€)	Total cost (€)
Manufacturing	Retail price (incl. costs for materials/components, manufacturing, distribution, other product development costs and net revenues)	343.59	343.59
Use	Electricity consumption Batteries for remote control	99.43 5.00	104.43
End of life	WEEE management fee	1.20	1.20
TOTAL		-	**449.22**

Figure 22 graphically shows the contribution of each life cycle phase to the total internal cost of the TV set. It can be found that the manufacturing phase is the most expensive, followed by the use phase, whereas the contribution of end-of-life phase is negligible.

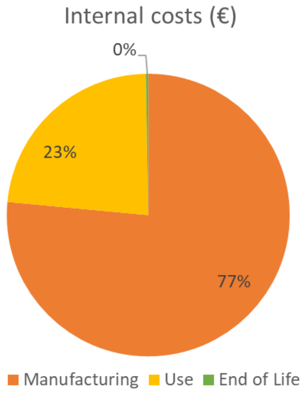

Figure 22. Contribution of each life cycle phase to the total internal cost for the C-SERVEES TV set.

7.3.3 External costs

Monetary valuation of environmental impacts was applied to assess the costs of environmental externalities. To this end, LCA results obtained for the TV set (see deliverable 5.2) were combined with monetisation factors given for different environmental impact categories. External costs were estimated using two different approaches for monetary valuation: (1) monetisation of global warming impact and (2) monetisation of endpoint impacts. It should be noted that the economic costs obtained in each case cannot be added together since the global warming impact (as well as the other midpoint impacts) is included in the endpoint impacts.

The results from the monetary valuation of environmental impacts are collected in Table 48. External costs for the whole life cycle of one C-SERVEES TV set (cradle-to-grave).These are broken down by life cycle phases and impact categories monetized.

Table 48. External costs for the whole life cycle of one C-SERVEES TV set (cradle-to-grave).

Life cycle phase	Impact category	Total amount	Monetisation factor	Economic cost (€)
Manufacturing	Human health	7.87E-04 DALY	101311 €/DALY	79.78 €
	Ecosystems	9.26E-07 species.yr	1.23E+07 €/species.yr	11.41 €
	Resources	10.83 USD	0.929 €/USD	10.07 €
	Sub-total endpoint impacts	-	-	101.26 €
	Global warming	141 kg CO2 eq	130 €/tonne CO2 eq	18.39 €
Use	Human health	6.55E-03 DALY	101311 €/DALY	663.81 €
	Ecosystems	3.72E-05 species.yr	1.23E+07 €/species.yr	458.20 €
	Resources	10.11 USD	0.929 €/USD	9.40 €
	Sub-total endpoint impacts	-	-	1,131.42 €
	Global warming	239 kg CO2 eq	130 €/tonne CO2 eq	31.06 €
End of life	Human health	1.65E-05 DALY	101311 €/DALY	1.68 €
	Ecosystems	3.62E-08 DALY	1.23E+07 €/species.yr	0.45 €
	Resources	0.64 USD	0.929 €/USD	0.59 €
	Sub-total endpoint impacts	-	-	2.71 €
	Global warming	7 kg CO2 eq	130 €/tonne CO2 eq	0.94 €
TOTAL	Human health	7.36E-03 DALY	101311 €/DALY	745.27 €
	Ecosystems	3.81E-05 species.yr	1.23E+07 €/species.yr	470.06 €
	Resources	21.59 USD	0.929 €/USD	20.06 €
	Total	-	-	**1,235.39 €**
	Total global warming	387 kg CO2 eq	130 €/tonne CO2 eq	50.40 €

The Figure below graphically shows the contribution of each endpoint impact to the total external costs for the manufacturing and end of life since these are the life cycle phases in which the project is expected to achieve higher improvements. Most of the external costs are due to human health damages, while the costs of damages to ecosystem diversity and resource availability are lower and comparable with each other.

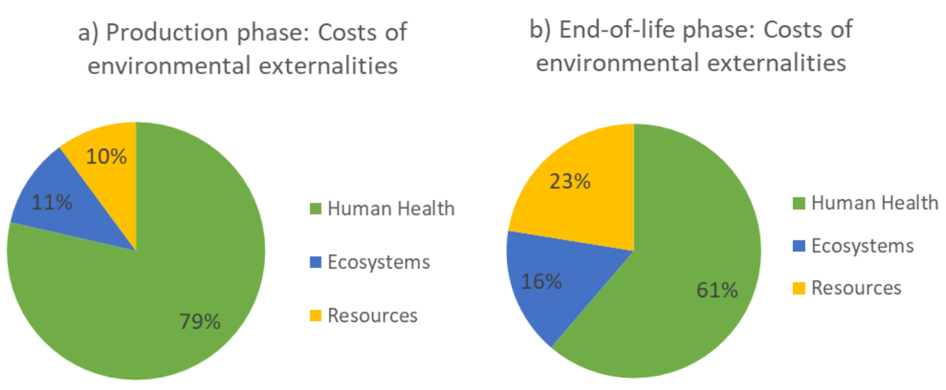

Figure 23. Contribution of each endpoint impact to total external costs of manufacturing and end-of-life phases for the C-SERVEES TV set.

7.3.4 Total life cycle costs

Concluding, Table 49 shows the total life cycle cost including internal and external costs. The cost of environmental externalities, and especially the external cost for the use stage, is the highest cost element. In contrast, the product waste management in the end-of-life phase is the one with the lowest cost, both for internal and external costs.

Table 49. Total costs for the whole life cycle of one C-SERVEES TV set (cradle-to-grave).

Life cycle phase	Internal cost (€)	External cost (€)	Total cost (€)
Manufacturing	343.59	101.26	444.85
Use	104.43	1,131.42	1,235.85
End of life	1.20	2.71	3.91
TOTAL	**449.22**	**1,235.39**	**1,684.61**

7.4 TV sets comparative life cycle costing

Circularity enhancement of the C-SERVEES TV set is performed with the same internal cost amount although with different external cost than the linear Reference TV set. Table 50 and Figure 24 show the LCC of the reference and the CSERVEES products for one functional unit. It can be clearly seen how the reuse of part of the product modules for remanufacturing reduces the external cost of the production process by 39% and, to a lesser extent, the end-of-life cost by 5.6%. Therefore, total costs are reduced by 3.7%.

Table 50. TV sets comparative LCC for one watched hour.

Units: €		Reference	C-SERVEES	Relative reduction
COSTS OF ENVIRONMENTAL EXTERNALITIES	Manufacturing	1.54E-02	9.39E-03	39.0%
	Use	1.05E-01	1.05E-01	0.0%
	End of Life	2.67E-04	2.52E-04	5.6%
INTERNAL COSTS	Manufacturing	3.19E-02	3.19E-02	0.0%
	Use	9.68E-03	9.68E-03	0.0%
	End of Life	1.11E-04	1.11E-04	0.0%
TOTAL		**0.162**	**0.156**	**3.7%**

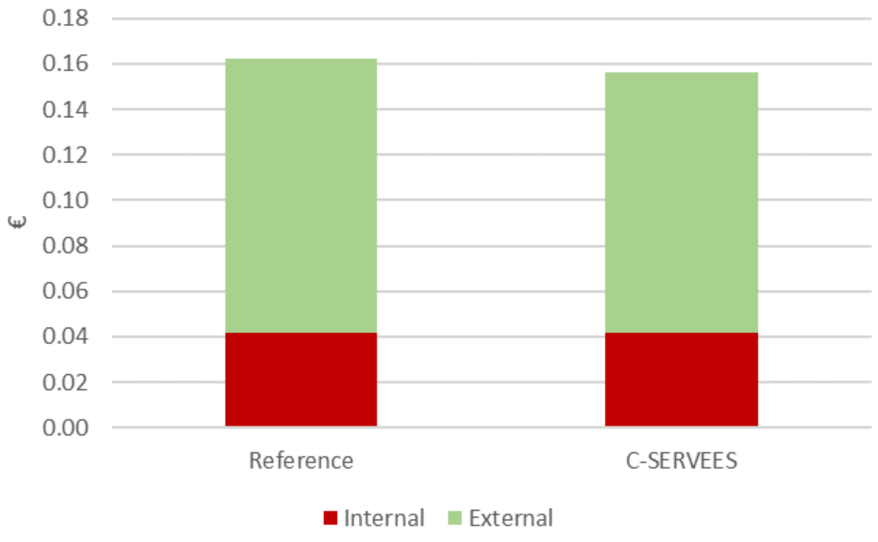

Figure 24. TV sets comparative LCC for one watched hour.

8 Conclusions

This Deliverable 5.3 validates the economic feasibility of the target products and related eco-services of the new business circular models developed in the C-SERVEES project that aims to boost a resource-efficient circular economy in the electrical and electronic sector by means of demonstrations involving four target products: washing machines, multifunctional laser printers and their toner cartridges, telecom equipment and TV sets. These products belong to different EEE categories that jointly account for 77% of the WEEE collected in the EU.

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

Two different types of scenarios are assessed and compared for each target product to validate the sustainability of the new circular business models:

- A conventional scenario, in which the products are produced and consumed under linear economy models.
- The C-SERVEES scenario, in which the products are produced and consumed under the new circular economy models relying on the eco-innovative services demonstrated in the project.

This Deliverable 5.3 shows the life cycle costs of each target product under the conventional scenario, called Reference product, and under the C-SERVEES scenario, called C-SERVEES product. The impacts of the C-SERVEES scenario are also compared to those for the conventional scenario to calculate the economic benefits that can be achieved with the solutions developed in the project.

The main conclusion of this Deliverable 5.3 is that the four target products under the new circular economy models relying on the systemic eco-innovative services demonstrated in the project have reduced life cycle costs by an average of 11.5%. Conclusions for each target product are as follow:

Washing machine: Circularity enhancement of the C-SERVEES WM set is performed with the same internal cost amount than the linear Reference WM although with a very slight difference in the external cost. Recycled materials and mass reduction introduced in the C-SERVEES washing machine reduces the total cost by 0.01%.

Laser printer: Circularity enhancement of the C-SERVEES multifunction laser printer is performed with the same internal cost amount although with different external cost than the linear Reference MLP. Reusing components for remanufacturing reduces the external cost of the production process by 8.4%, although this requires increasing the cost of the end-of-life phase by 16.9%, leaving the total reduction at 0.2%.

Telecom equipment: Circularity enhancement of the C-SERVEES telecom equipment is performed at the same internal manufacturing cost to the linear Reference. However, the introduction of ICT has improved the maintenance of the TE increasing the lifetime from 8 to 15 years and making feasible the 10% reuse of the central ALM unit. Increasing the lifetime and reusing parts of product modules for remanufacturing reduces all life cycle cost categories and on average by 42%.

TV set: Circularity enhancement of the C-SERVEES TV set is performed with the same internal cost amount although with different external cost than the linear Reference TV set. Components reused for remanufacturing reduces the external cost of the production process by 39% and, to a lesser extent, the end-of-life cost by 5.6%. Therefore, total costs are reduced by 3.7%.

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