Refurbishment and re-manufacturing of large industrial equipment

Inference of Refurbishment and Re-manufacturing plan

D5.1

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Abbreviations and Acronyms

Abbreviation	
AC/DC	alternative current / direct current
ADC	Analog to Digital Converter
AFC	average fixed costs
ATC	average total costs
AVC	average variable costs
C2C	Cradle to Cradle
CAGR	compound annual growth rate
CAN	Controller Area Network
CE	Circular Economy
Covid-19	Coronavirus disease 2019
CPU	Central Processing Unit
CRT	cathode ray tube
DFMA	Design for Manufacturing and Assembly
DSF	Decision Support Framework
Dx.y	Number of Deliverable
EEE	electrical and electronic equipment
EIT	European Institute of Innovation and Technology
EPR	extended producer responsibility
EU	European Union
EY	Ernest&Young
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GPS	Global Positioning System
HTTP	HyperText Transfer Protocol
ICT	Information and Communication Technology
IE	Industrial Ecology
IoT	Internet of Things
IR	Infrared
ISO	International Organization for Standardization
IT	Information Technology
IUPAC	International Union of Pure and Applied Chemistry
KPI	Key Performance Indicator

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LCA	Life Cycle Assessment
LCD	liquid crystal display
LED	light emitting diode
MCA	multi-criteria analysis
MFA	material flow analysis
MQTT	Message Queuing Telemetry Transport
OEM	Original Equipment Manufacturer
OPC UA	Open Platform Communications Unified Architecture
PCB	printed circuit board
pdf	Standard file format of Adobe Acrobat
PE	performance economy
PLC	programmable logic controller
PVP	photovoltaic panel
RE(E)	rare earth element
REST	Representational state transfer
RO	retention option
RoHS	Restriction of Hazardous Substances Directive
SW	Software
TCP/IP	Transmission Control Protocol / Internet Protocol
TV	television
Tx.y	Number of Task
UI	User Interface
WEEE	Waste Electrical and Electronic Equipment
WP	Workpackage
WTP	willingness to pay
YIG	yttrium-iron-garnet
YLF	yttrium-lanthanum-fluoride

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Summary

This deliverable is meant to present the activities carried out in task 5.1 with the aim of exporting the inference of refurbishment and re-manufacturing plan.

This task will instantiate concepts and approaches to the specific case of electromechanical machines. In this regard, specific issues such as e-waste, the presence of valuable materials (such as rare earths), and the interaction with services and aftersales functions will be taken into account.

§2 of this document presents the concepts of circular economies and its evolution during the years. This section is meant to give lecturers a full understanding of the actual scenario before introducing the most specific challenges related to refurbishment and remanufacturing. In the second part of the section strategies and challenges related to CE are presented.

§3 of the document addresses the main issue for the inference of refurbishment and re-manufacturing plan. A bibliographic research has been carried out in order to identify the main issues. The problems analysed are e-waste, valuable materials and sales and aftersales function.

§4 of the document is constructed to prove the above-mentioned problems. Pilots have answered specific questions regarding valuable materials, sales, and after-sales services. In addition, it has been asked to describe briefly their use cases, which elements have pushed them to invest in Remanufacturing and the KPI which the choice is based on.

§5 is the conclusive part of this deliverable and it was meant to catch possible inputs from the external scenario. A questionnaire has been developed and spread by task 5.1 partners. The results give an overview of how much refurbishment/remanufacturing techniques are used outside the consortium and their key drivers.

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1 Introduction

The current behaviour of consumption in industrialised and emerging countries is linked to the status of widespread well-being that begins to manifest itself following the development of both the secondary and tertiary sectors.

This phenomenon has led to less dependence of citizens on the primary sector, by leaving an agricultural and self-consuming society to access a new one more developed.

In the previous decades there has been a radical change in the demographic composition and social dynamics: living conditions have improved, technological development has reduced distances, leading to fewer information asymmetries and better communication, new industrial processes have made it possible to buy consumer and durable goods at accessible prices. In general, the greater wealth distributed among citizens has led to a better welfare status for all the citizens.

Considering also the process of globalisation and therefore the massive industrialization of extremely populated countries such as India and China, this phenomenon is causing the increasing process of the "middle" class, expected to be around three billion people within a few years.

Providing three billion people with substantial purchasing power means putting a strain on the capabilities of a production system that is already inadequate.

The reasons for this shortage are many and almost all stem from the persistence in wanting to apply a linear model that is no longer sustainable.

Unsustainability has not only an environmental but also an economic significance.

For example, in recent decades companies had to access a bigger volume of raw materials in order to respond to an increasing demand, often from non-renewable sources (for example, fossil fuels), causing over-exploitation of the soil and over-extraction of resources.

It sounds strange to notice that in the past years the increase of supply volumes has caused the reduction in prices and also the increase in large-scale extraction activities has caused a cost of supplies reduction.

In fact, the trend is now taking a reverse logic: the linear system is significantly increasing the risk exposure of players within the market due to greater price volatility.

Considering how the abuse of the aforementioned primary material is leading to a lower supply in the face of a stable demand in mature markets (and a growing demand in developing countries) it is easy to understand how this affects the increase in supply prices and production, with a consequent decrease in profit margins for companies.

All this can be further translated into social damage, since lower profits of companies means lower wealth, which in turn means lower capacity for employment and creation of well-being for workers.

Therefore, a revolutionary change is needed and has been brought forward by the concept of circular economy, whose discipline tries to support the development of business models which aim to create performing products while maintaining at the same time the focus on the reduction of environmental impact.

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So, the scope is to reach objectives in terms of reduction of waste, reuse of materials, access to renewable sources and respect for the constraints imposed by nature.

These actions are aimed at greater availability and cost-effectiveness of resources, which are the keys to accessing new models of business more performing than those currently spread on the market.

In addition, another element that has to be considered is the impact of Covid-19 on consumers behaviours. Covid-19 has drastically changed the way of leaving and people are becoming more conscious of the need for a sustainable production process.

An example of the actual change that is in progress is the EY survey of 2021 [1] on the consumers behaviour in Italy.

Consumers nowadays want to be the main actor on the scene and thus at the centre of the shopping experience where simplicity in the purchase operations and pleasantness of the experience are the two main desires.

The element that consumers take into consideration and expect from a brand are:

- quality, 46% of respondents
- price, 45% of respondents
- role of ethics towards employees, suppliers and the environment, 34% of respondents
- sustainable production, 27% of respondents

The evolution of the context implies for companies a timely transformation in the direction of a strategy as much as possible in line with the new value identity of the consumer. To grow, innovate and be competitive, companies should review their purpose on the basis of ethics, sustainability and authenticity, criteria increasingly requested by consumers in their relationship with a brand. Basically, it is a question of trying to empathise with the consumer and with his universe of values, starting from a deep and continuous listening.

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2 Context: Circular economy

Currently our economy is based on a "take-make-disposal" model, commonly called "linear" model. The linear economy is based on the production of products to make a profit, which is the result of the difference between production cost and market price. The primary objective of obtaining greater profits leads to innovating technologies to have an increase in production, and, at the same time, leads to selling products at the lowest possible cost.

The linear economy includes input flows, or production factors (capital, labour, land, raw materials, and energy sources) necessary to feed the production process, and output flows (products and services offered on the market).

The products of the linear economy soon become obsolete (planned obsolescence) in order to encourage the purchase of new ones by consumers, so much so that it is more convenient to buy and therefore own a new product, often responding to transitory fashions, rather than repair it. In this way a huge amount of raw materials are first transformed into products and then at the end of their useful life thrown by the final consumer.

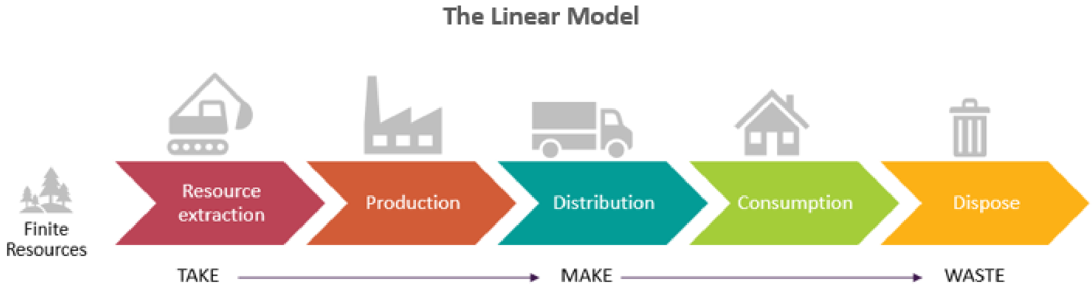

Figure 1: Linear Model

The issue lies mainly in the last phase of the process: Dispose. Wastes in fact are hardly recovered causing a dispersion in the environment that could lead to high environmental damage such as CO_2 emission or deterioration of natural ecosystems.

Taking in mind the unsustainability of the linear model in the long term, it has been necessary to develop a new production and consumption model.

The circular economy (CE) is a production and consumption model that involves sharing, lending, reusing, repairing, reconditioning, and recycling existing materials and products for as long as possible.

This extends the life cycle of products, helping to reduce waste to a minimum. Once the product has finished its function, the materials it is made of are in fact reintroduced, where possible, into the economic cycle. Thus, they can be continuously reused within the production cycle, generating additional value.

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Figure 2: EIT Raw Material Circular model

To summarise, the first chapter has provided an overview about Circular Economy (CE). A bibliographic research has been conducted to highlight the main features and strategies in the circular economy field.

In the first paragraph, the link between consumption evolution and the need to adopt a more sustainable way of living has been considered.

The second paragraph described the evolution of the circular economy concept over the years considering the external variables that have guided and driven the changes.

In the third part of this chapter the approaches that have driven the creation of the circular economy model are summarised in order to give to the audience the possibility to have full understanding about the concept.

In the fourth paragraph, an overview of the possible strategies to adopt for the circular economy is presented. There has been a distinction between biological nutrient strategies and technical nutrients strategies.

Lastly, at the end of the chapter the actual situation for a transition to a circular economy is presented. The focus is on the 10 European indicators that evaluate the progress to a circular economy.

2.1 Circular economy evolution

Until the 1970s the problem of adopting a more sustainable approach to production and consumption was never raised.

The problem is that the “take-make-disposal” system began to "creak" already at the time of the second post-war period, where the improvement of people's living conditions was

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associated with increasing consumption and, consequently, there was a growing difficulty in the management and regulation of processing waste.

This has led to paying greater attention to environmental issues and sustainability, highlighting the first ideas for the development of circular schools of thought as we know them today. However, according to the EU the discipline of the circular economy has evolved within three distinct stages:

- from the 1970s to 1990s, the first phase, characterised by the first requests for intervention in terms of regulation regarding waste, the Circular Economy 1.0
- from the 1990s to 2010, the second phase, characterised by greater attention and dissemination of circular practices and strategies, also known as Circular Economy 2.0
- from 2010 to now, the third phase, characterised by technological evolution in support of the industrial sector, is defined as Circular Economy 3.0.

2.1.1 Circular Economy 1.0

In the 1970s, environmental movements began to spread in the most industrialised countries.

This happened following a greater understanding of the long-term impact to which a frenetic industrial and technological development brought about.

Movements were asking for a regulation on industrial processes in which the recycling and reuse of materials had to be taken into consideration in order to depend less on the extraction of new raw materials.

The result has been the creation of the 3R concept: "reduce, reuse and recycling".

At that time, governments regulated the production sectors with a reactive and non-proactive approach, in their opinion there was no need for prevention.

The only focus was on the implementation of policies that could limit air pollution: the principle of "polluter pays" provided that the polluter pays a penalty proportional to the pollution product, in order to compensate for the negative externalities leveraging the social costs.

However, the approach was incomplete because it did not take into account the irreparable natural damage that was encountered, and above all, because it was based simply on a system of negative externalities cost estimation often difficult to achieve.

Moreover, waste management is delegated to landfills and incinerators: however, in order to save on disposal costs, companies often proceed to unload waste in other countries, even often in a dangerous way, due to a lower request for compensation.

Lastly, the concept of “thinking as a system” began to emerge. It is an enabling tool that can help us identify root causes and implement better solutions, and it provides the lens or frame for our conceptual understanding of it.

2.1.2 Circular Economy 2.0

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In the 90’s Environmental problems started to be considered as business opportunities. In particular, with regard to resource efficiency, a strong focus began to be placed on development of more sophisticated industrial processes, maximising the production of output in correlation to a minimization of the input. Beyond this, the greater attention to the issues of environmental impact (Green Economy / Carbon Footprint) and social impact (Corporate Social Responsibility) began to be perceived by the customer as an added value and therefore as a determinant of success for a company.

Those elements have brought firms to have a greater commitment not only in terms of industrial improvement, but also in terms of communication and brand development, considering them ways to increase profit margins.

Moreover, "System thinking" spread and was developed further and the design phase began to assume a fundamental role in terms of reducing the environmental impact and waste. In particular, "design for environment" and "design out waste" were spreading and the product was specifically designed not only to be discarded after its use, but also to extend its life cycle and enable thinking of appropriate solutions for the reuse of its materials.

In this period, philosophies relating to the circular economy developed, and issues related to this context became to obtain a certain weight also in political and administrative terms.

2.1.3 Circular Economy 3.0

In this phase, the circular economy assumes a very important weight: the awareness to intervene with a drastic change regarding the methods of production and consumption arises, as those undertaken so far are no longer sustainable and risk serious damage to the future of the planet and humanity.

In this phase, the intervention of technology assumes a significant weight, which is seen as decisive for overcoming the sustainability challenges that nowadays seem to be insurmountable.

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2.2 Philosophies of circular thinking

During the years different approaches have contributed to the development of the CE model. The approaches are summarised in the table below with a description of their key elements.

Approach	Description
Cradle to Cradle (C2C)	It is the school of thought that generates the consideration that the materials involved in industrial and commercial processes must be distinguished into technical and biological nutrients. The principle on which the C2C philosophy is developed is the minimization of waste, returning the biological nutrients to the soil and the technical nutrients to the production system, trying to eliminate landfill disposal and dispersion in the environment, and to limit incineration.
Performance economy (PE)	PE consists of an economy that focuses on the "sale of goods and molecules as a service or in the provision of operational guarantees", therefore of performance. It internalises responsibility for production costs, risks and waste, reducing transaction costs, increasing profit opportunities, taking advantage of sufficiency, system and efficiency.
Biomimicry	It is the school of thought that attempts to develop circular economic-industrial systems which are inspired by ecosystems or living organisms (considered as complex systems). Nature is therefore the model for the development of solutions to human problems (in this case, those of the environmental and social impact of pollution).
Industrial Ecology (IE)	It is the school of thought that, on the basis of the study and analysis of the reference industrial context, seeks solutions to be able to create closed-loops. The principle on which the philosophy is developed is to design industrial processes such as to favour the reuse of materials and such as to respect the ecological constraints of the reference context.
Natural Capitalism	The approach aims at resource efficiency in order to be able to produce more with less. Natural capitalism redesigns industry on the basis of a biological model that excludes waste production, shifts the economy from the episodic acquisition of goods towards a continuous flow of value and services, investing wisely in the protection and expansion of natural capital existing.

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Regenerative design	It is a recent approach, aimed at triggering "regenerative" processes, of restoration, renewal and revitalization of a context through the creation of relationships between the needs of society and the integrity of nature. The theories of regenerative design start from the concepts of sustainable development integrating environmental responsibility, social equity and economic sustainability to it. The theoretical principles of regenerative design have focused on the community scale where a continuous change and production of energy and materials is expected, through its functional processes.

Table 1 - Circular economy approaches

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2.3 Circular economy strategies

Based on the materials that make up the waste, two types of "nutrients" can be distinguished:

- biological nutrients (organic waste), which can be returned in a "natural" way to the soil, for example through anaerobic digestion or decomposition
- technical nutrients (inorganic waste), which are therefore suitable for being reused or reused in new products through remanufacturing, refurbishment, reuse, recycling, repurposing, and repair strategies.

The focus of the following section are the technical nutrients strategies that are the one used for the electromechanical machinery.

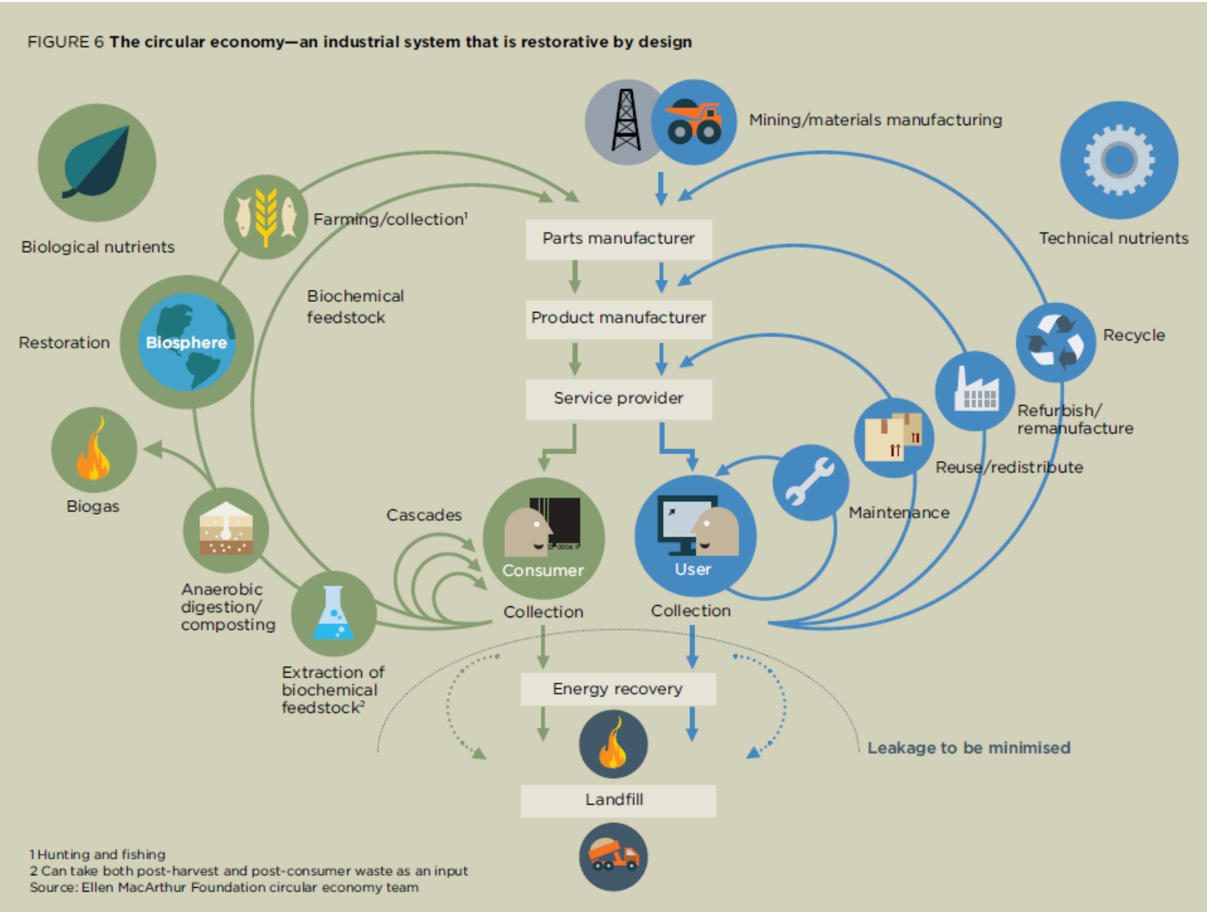

Figure 3: Ellen MacArthur Foundation Circular economy system

<u>Technical nutrients' strategies as per RECLAIM D4.1 [10]:</u>

Strategy	Revised Definition	Standard
Design for durability/reliability	The ability of a product to perform the function(s) it was designed and built for an extended period of time or a specified period without experiencing failure or excessive wear and tear, considering also its environmental performances.	

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Design for modularity and part standardization	Design approach that is meant to achieve the maximum level of simplification and standardization in product design with common product platform and more efficient use of resources. In manufacturing fields, universalization, serialization and modularization are the three most important metrics.	
Design for ease of maintenance and repair	This approach allows the products and parts to be maintained and repaired easily in order to retain the functional capability of a product or restore the working condition of a damaged product.	
Design for upgradability	Approach to the design meant to facilitate the enhancement of a product's functional as well as physical fitness for ease of upgrade.	
Design for disassembly and reassembly	The characteristics of this approach allow for the separation and reassembly of products and parts in the most efficient way, i.e., the most suitable sequence is determined with minimal removal of components, ensuring environmental safety and avoiding future costly environmental liabilities.	ISO 20887:2020(en), 3.13
Design for component recovery	It includes design for refurbishment and design for remanufacture. The concept of recovery stems from the fact that a certain number of parts or subassemblies have a design life that exceeds the life of the product itself, making the idea of reuse practical.	
Resell-Reuse	Reuse and resell can be defined as the activity of recovering components and materials (still in good condition) for further use without reprocessing, i.e. that does not require any correction or repair action. The resold or reused products in intended to be put into service for the same purpose for which it was conceived.	ISO/IEC 29142-1:2013(en), 3.59; ISO 21070:2017(en), 3.1.6.
Pay per use	In a classic pay-per-use model, the user of an industrial equipment does not purchase and own the product. Instead, customers pay a fee that depends on usage and is measured according to clearly specified consumption, output, or other indicators, which nowadays are more easily controllable through sensors connected to the IoT.	
Repair or Corrective Maintenance	Set of activities performed after occurrence of a failure, or detection of a fault, of a product so it can be restored to a state in which it can perform the original and required function. Repair is also making a broken product operational again through fixing/repair/replacing failed parts. The objective of repair is "bringing back to working order", "making it as good as new", "recreating its original function after minor defects", "replacing broken parts", "maintenance carried out to effect restoration", "eliminating the causes of failures".	ISO/IEC 14764:2006(en), 3.2 ; ISO 23815-1:2007(en), 3.3; ISO 19659-1:2017(en), 3.9.2; IEC 60050-192:2015, 192-06-06, modified; ISO/TR 12489:2013; ISO 14224:2016(en), 3.8; ISO/IEC 20926:2009(en), 3.13; ISO/IEC 2382-14:1997; ISO/IEC 2382:2015(en), 2123038; IEEE 14764-2006 3.2, 3.13;

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		ISO/IEC/IEEE 24765:2017(en), 3.891; IEC 60050-191-46-06; ISO/TR 12489:2013(en), 3.4.4; ISO 20815:2018(en), 3.1.7; ISO 6527:1982(en), 2.19.
Preventive maintenance	Preventive maintenance is the performance of inspection and/or servicing tasks that have been pre-planned for accomplishment at specific time schedule, and performed according to prescribed criteria, to retain the functional capabilities of operating equipment or systems and to reduce the probability of failure or prevent degradation of the functioning of a product. The activity precludes the maintenance of an object in a satisfactory operating condition, controlling degradation and failures to an acceptable level; in order to sustain or extend its useful life, it is often necessary to plan some corrective maintenance actions. Three types of preventive maintenance are recognized in literature: **Predictive maintenance**, **Time-based maintenance** and **Condition-based maintenance.**	ISO/IEC 14764:2006(en), 3.8 ; IEC 60050-192:2015, 192-06-12, modified; ISO 14224:2016(en), 3.76; ISO/TR 12489:2013(en), 3.4.3; ISO/IWA 28:2018(en), 3.3.3; ISO 26870:2009(en), 3.15; ISO 2710-2:2019(en), 3.1.3.6; ISO 23815-1:2007(en), 3.2; ISO 6527:1982(en), 2.18; ISO 19659-1:2017(en), 3.9.3; ISO 12749-5:2018(en), 3.9.12.4;
	Predictive maintenance – A condition-driven preventative maintenance program based on forecasting made on mathematical models. It uses direct monitoring of the mechanical condition, system efficiency, and other indicators to model and calculate the actual mean time to failure or loss of efficiency.	
	Time-based maintenance – A preventive maintenance consisting in restoring or replacing a component regardless of the condition of the product. This can happen based on time (predetermined time intervals) or based on the operating time of machines/components or on the remaining useful life (in this case a dedicated system is required to support data collection and maintenance planning). **Fehler! Verweisquelle konnte nicht gefunden werden.**	
	Condition-based maintenance – A strategy based on the component restoration or replacement, based on a measured condition compared to a defined standard (thresholds). Condition data can then be collected through non-invasive measurements, visual inspection, performance data, and scheduled testing.	
Remanufactur e	Remanufacture (or second-life production) is a strategy that implies using parts of discarded products in a new product with the same function. Used products are brought at least to original equipment manufacturer performance specification. Remanufactured products guarantee the same quality of original products. Remanufacture applies where the full structure of a multi-component product is disassembled, checked, cleaned and when necessary replaced or repaired in an industrial process.	ISO 13533:2001(en), 3.62.
Recondition	Reconditioning involves taking a product and restoring all critical modules that are inspected and upgrading it to specified quality level (with the same composition), typically correspond to approximate original design condition or less	ISO/TS 22002-4:2013(en), 3.16;

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	than virgin standard. Any warranties issued are typically less than a warranty given to a virgin product.	ISO 3977-9:1999(en), 3.92; ISO 2710-2:2019(en), 3.3.9.
Refurbish	Refurbish means restoring an old product and bringing it up to date, in order to maintain reliability or extend service life. In general, refurbished products are upgraded and brought back to specified quality standards or satisfactory working and/or cosmetic conditions and have to fulfil extensive testing. Occasionally, refurbishing is combined with technology upgrading by replacing outdated modules and parts with technologically superior ones.	ISO 26871:2020(en), 3.1.49.
Cannibalization	Cannibalization is the activity of recovering parts from returned products. Recovered parts are used in repair, refurbishing, reconditioning and remanufacturing of other products.	
Recycle	Recycling is activity of segregating and recovering components and materials for reprocessing. From the processing of materials, it is possible to obtain the same (high-grade) or lower (low-grade) quality of recycled materials. The purpose of recycling is to reuse or recover materials or waste materials from used products and components. These materials can be reused in production of original parts if the quality of materials is high, or else in production of other parts. Recycling begins when used products and components are disassembled into parts. These parts are separated into distinct material categories. These separated materials are subsequently reused in the production of new parts.	ISO 21070:2017(en), 3.1.5; ISO/TS 21929-2:2015(en), 3.33; ISO 8887-1:2017(en), 3.1.6.

Table 2: Technical nutrients' strategies

Smarter product use and manufacture	R0	Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1	Rethink	Make product use more intensive (e.g. through sharing products or by putting multi-functional products on market).
	R2	Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources
Extend lifespan of product and its parts	R3	Reuse	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
	R4	Repair	Repair and maintenance of defective product so it can be used with its original function
	R5	Refurbish	Restore an old product and bring it up to date
	R6	Remanufacture	Use parts of discarded product in a new product with the same function
	R7	Repurpose	Use discarded products or its part in a new product with a different function
Useful application of materials	R8	Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9	Recovery	Incineration of material with energy recovery

Figure 4: CE strategies. From [13].

- **Remanufacturing**

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It is the process of creating a new product using waste materials from other products. During the creation process it is assumed that in the future the final product is totally disassembled: this feature represents the biggest difference with the refurbishment process. [10]

In any case, it is assumed that the final product achieves performances of the same level of a completely "new" product.

- **Refurbishment**

  It is the process in which a product is reconditioned. This means that the defective parts of the product concerned are replaced by waste materials from other products.

  As mentioned previously, contrary to remanufacturing, total disassembly of the product is not required and even a partial disassembly is enough, however the performance of the refurbished product must be the same than the one of a new product.

Remanufacturing and refurbishment are the focal points of this report; therefore they will be analysed in a more detailed way in the next chapters.

- **Repair**

  It is the process in which a faulty product is made usable again, by replacing the faulty and no longer usable parts.

- **Repurpose**

  It is the process in which waste materials are used in other products, with a different purpose with the respect of the original starting product.

  However, more generally, the aim of the strategy is also to reuse a product in applications of a different nature than those of origin.

  Generally, all products that cannot be refurbished, remanufactured, repaired and reused are repurposed. Consequently, in the practical act, this strategy is combined with those mentioned above.

- **Reuse**

  It is the strategy where a product, in the case it is in functionally and aesthetically acceptable conditions, passes its ownership, maintaining the continuity of the life cycle instead of being discarded.

  There are different types of reuses, in particular three macro-categories can be identified such as: relocated or resold products, product-service-system and packaging reuse.

  - **Resold or relocated products**

    The relocated products are characterized by a transfer of ownership without money transaction (example: gift), while those resold are characterized by an onerous transfer of ownership (example: flea market).

  - **Product-service-system**

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Through this strategy we want to make the product an instrument for providing services. In this case, the ownership of the product is maintained by the manufacturer: indeed, by decoupling the service from the property, the manufacturer will install the product from the customer, who will only pay for the service on the basis of contractual schemes such as pay-for-performance. The advantages are many, as the customer will not have to bear the costs for the purchase and also less expenses for repairing / maintenance would be required. In this way, the manufacturer will be more encouraged to create durable products over time, subjected to few failures and with a high quality performance level. Other advantages are attributable to the exploitation of IoT technologies and in particular of Big Data Analytics, which allow to identify the access time to the customer's service, giving the possibility to "customize" the rates.

- **Packaging reuse**

  The dispersion of packaging and containers represent one of the major causes of pollution and damage of the environment. By designing the packaging and considering it an integral part of the product and not just a "superfluous" component in the process of value creation for the manufacturer, it is possible to structure reverse logistics processes such as to discharge the customer from disposal operations, stimulating him to make the packaging come back, in order to use it in countless cycles before being sent for recycling (example: returnable empty).

In summary, we can see how Refurbishment, Remanufacturing and Repairing are strategies that can be configured within the generic maintenance operations, mostly belonging to the cycle of use of the product by the same subject, while Reuse and Repurposing are configured as strategies aimed at feeding different cycles of use of the product associated with different owners.

However, all strategies focus on a specific purpose: that of expanding the life cycle of the product.

Strategies can be developed in such a way that they can also allow smarter use of the product. The strategies of Rethink, Reduce and Refuse fall into this area.

- **Rethink**

  Rethink refers to the reconceptualization of a product.

  Reconceptualization can be referred both to the architecture (for example greater modularity) and to the functionality of the product, but it could be also extended to the production processes or to the post-use activities of the product (example: reverse logistics processes to avoid disposal or offer customer service / assistance).

  Of course, to be considered a "circular" strategy, there should at least be a goal of reducing the negative externalities associated with the use of the product.

  The rethink of a product that does not lead to benefits due to the general creation of a closed loop, for example a reverse logistics process that favours the recycling of

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materials, and which inversely leads to a greater environmental impact related to its exploitation, is to be considered part of a linear system.

- **Reduce**

  The concept of reduce is closely linked to that of greater efficiency in the exploitation of resources, trying to maximize the output produced by exploiting the amount of input that is as small as possible.

  We should not think only of reducing the amount of input used, but in the same way, we should think that the types of outputs that are applied must be minimized.

  It can be noted that the concept of reduce can therefore be incorporated into the definition of rethink, since the reduction of the input necessary to produce a product necessarily passes from having to "rethink" it. An example of reducing is that of the modular product, characterized by a core component that can be equipped with specific tools as needed.

  The Reduce concept is widely applied in today's industry, but it is not yet fully exploited.

- **Refuse**

  The refuse action refers to the strategy of rejecting all those products from companies that adopt a linear model, in such a way to support companies that adopt a circular model.

There are two other strategies that fall within the circular framework and refer to the usability of materials: the recovery and recycle strategy are included here. These strategies can be applied to both biological nutrients (organic compounds) and technical nutrients.

- **Recovery**

  It is the process that involves "recovering" energy through materials: in particular, the incineration strategy falls within this scope, even if in fact all the conversion strategies of organic compounds such as to allow the obtaining of biofuels and compounds are to be considered as such biochemists. Recovery is applicable in all those cases in which it is not possible to proceed with the recycling of materials or other strategies.

  Although it is true that the circular economy aims at the goal of "zero waste", this proves to be a pure asymptotic reference, and therefore utopic.

- **Recycling**

  Recycling is the most common circular strategy: it represents the process used to obtain new materials from materials of the same type with a performance level that can be equal to that of a "virgin" material or lower.

  Recycling obviously refers to waste materials, which are then put back into circulation.

  When the scraps are subjected to a recycling operation, which brings them to a level of performance equal to that of virgin materials while maintaining the same functionality, we talk about "upcycling".

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Otherwise, we talk about "downcycling": the recycled material has lower performance than the original one and does not maintain the same functionality.

Furthermore, recycling must be differentiated according to the case of closed-loop and open-loop.

- **Closed-loop**

  This strategy requires the material to be reused only in the same product system, in order to replace the original material.

- **Open-loop**

  This strategy foresees that at least a part of the waste materials is reused to replace part of the original materials contained in different product systems.

Logically, closed-loops would be preferred over open-loops as in the latter the materials would require the application of much more complex reverse logistics processes, with the risk of dispersion of materials, increased emissions due to transport operations in geographically dispersed sites and therefore consequent environmental impact.

As already mentioned, recycling is the most common circular strategy. However, it has limits too, requiring a lot of energy to be realized. It should also be remembered that it is not possible to apply this type of strategy to all materials, as it is either not convenient, or it is not feasible: for example, electronic products are very complex and therefore very difficult and expensive to recycle, other materials such as plastics or paper can only be recycled a finite number of times.

Recycling is also often expensive for all the operations that are the basis of its value chain: an example is the organization of the collection activity, the separation, as well as the washing of waste materials.

In order to increase the efficiency of this type of strategy, one could think of an integration with the rethink and reduce strategies, looking for a simplification of the products regarding their complexity and at the same time increasing the focus either on the exploitation of materials with a high potential of recycling or on the improvement of recycling processes by overcoming the obstacles of contamination and impurities of materials.

As mentioned above, it is not always possible to apply circular strategies.

If all the strategies seen previously cannot be applied, it is possible to proceed with disposal in landfills: in this case there is the problem of disfigurement of the environment, because a large amount of space must be allocated for the construction of landfills, causing a loss of natural capital.

However, as mentioned above, the strategies can be integrated with each other and are not to be considered mutually exclusive. Therefore, it is sometimes possible to structure "mixed" systems, in which the different strategies are applied in synergy in order to contribute to circularity.

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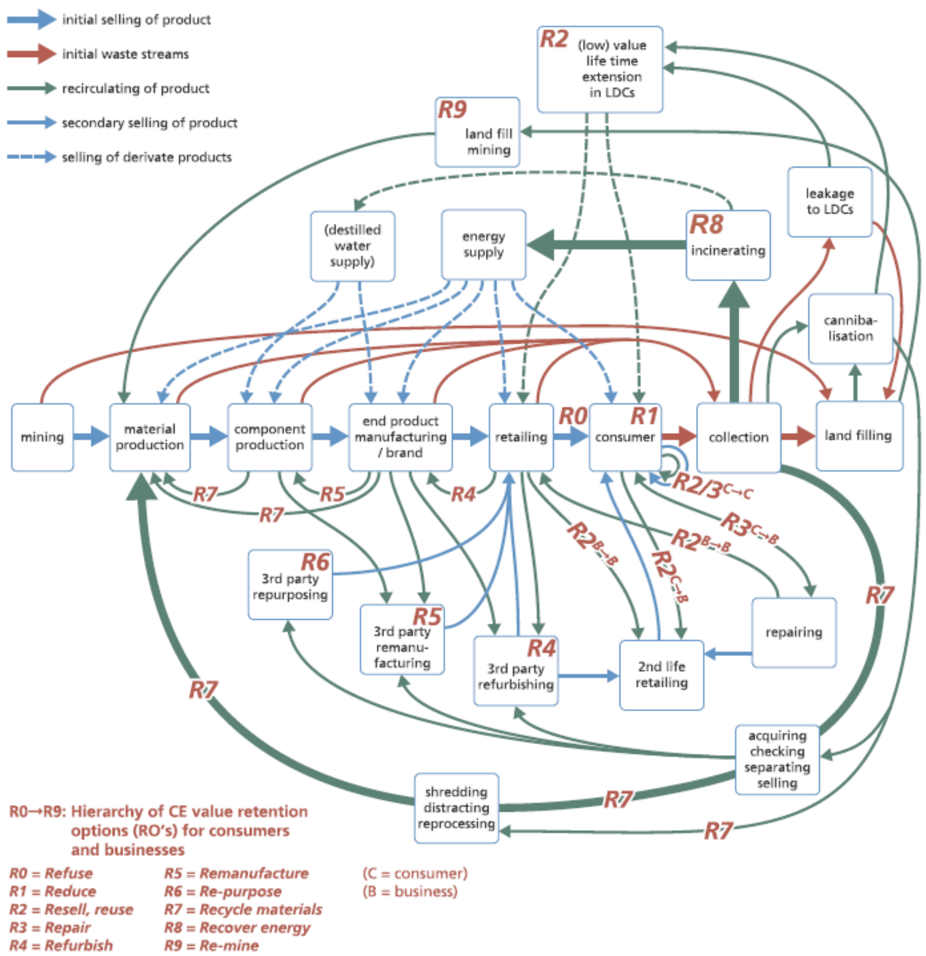

Figure 5: *The new CE 3.0*[1]

2.4 Models for the creation of value

There are numerous circular solutions, generally able to create value in the short and long term. Nevertheless, it is difficult to define a common guideline relating to the application of a circular strategy for products of different types.

However, the Ellen MacArthur foundation has identified 4 possible principles for the creation of value adopting a CE strategy that could lead to a comparative advantage over the years.

The principles for the competitive advantage that can be applied to all the cases are:

1. Inner circle
2. Circling longer
3. Cascaded use
4. Practical inputs and design

1 Image taken from [14].

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2.4.1 Inner circle

Inner cycle refers to the idea that the shorter the cycle, the more successful the strategy is. The short cycles keep more the integrity and the complexity of a product and energy. Furthermore, also the number of externalities generated, such as gas emissions or toxic substances, are reduced.

Applying it to the electromechanical machines a good example is a car in which the maintenance or refurbishment instead of recycling permit to retain the value of the product.

2.4.2 Circling longer

The principle of circling longer is focused on the idea that each prolonged life cycle of a machine avoids the use of material, energy and manpower needed to create a new product.

Value creation brings about an additional benefit from keeping more products, components and materials in the process of the circular economy.

This principle can be applied either by going through several consecutive cycles (e.g. refurbishment of an engine) or by making a single cycle last longer (e.g. extending the washing cycles of a washing machine). These prolonged uses replace flows of virgin material and counteract the dispersion of the material outside the active economy.

2.4.3 Cascading use

It mainly refers to the use of the same type of product or material in the original field of application, in which cycles of different nature are envisaged in which there is a change of ownership with each new iteration (example: purchase of used products).

However, a cascade use can also be applied in reference to a reuse of the product or material in fields of application of a different nature than the original one.

2.4.4 Practical inputs and design

Currently waste is often collected as a mix of different types of materials, therefore containing impurities that do not allow to reach a satisfactory quality level if they are reused.

This happens mainly for two reasons:

1. the products are composed of components of different nature
2. the discards are collected without being segmented or without paying attention to their level of quality and purity

Through the design of products, it is possible to try to overcome these problems, creating formats that reduce the quantity of materials used and their type, facilitating their separation, or by providing reverse logistics strategies such as to preserve the integrity of the products and avoid the intervention of contaminants.

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These interventions are decisive for the rapid and above all economic implementation of circular strategies, thus obtaining greater productivity from materials.

2.5 Actual scenario

Nowadays the challenges are concentrated in how to change the consumption model (production -> consumption -> waste) in a new circular one (production -> consumption -> reuse).

The concept of circular economy and new competition model has gained attention among policymakers.

The European Environment Agency has identified CE as the core of the Green Economy. Nevertheless, up to now the concept of Circular Economy can be seen as an umbrella concept that summarises and collects different approaches. To deal with this, a group of ISO Standards are currently under development by the Technical Committee.

Moreover, the European Commission has set a monitoring framework to capture the actual situation and the trend to a more circular economy. The framework consists of 10 indicators summarised in the picture below. These indicators can be grouped into 4 thematic areas:

1. Production and consumption
2. Waste management
3. Secondary raw materials
4. Competitiveness and innovation

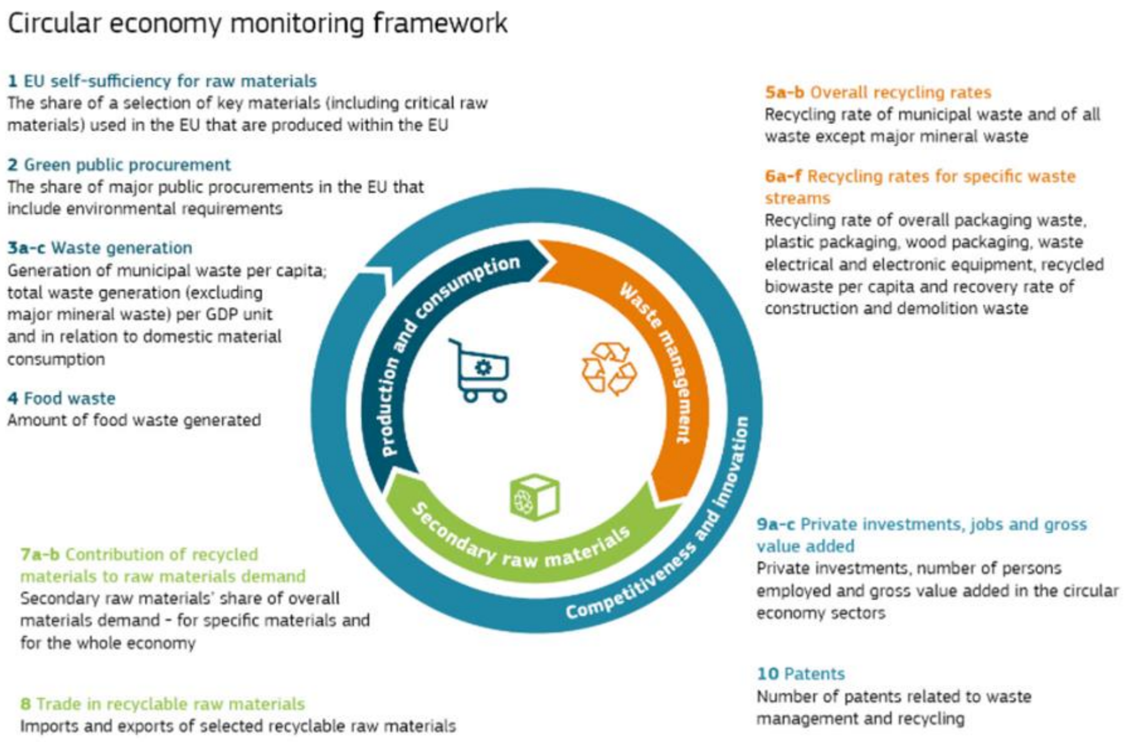

Figure 6: Circular economy Framework[2]

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2 Image taken from www.minambiente.it

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The production and consumption indicators are essential to monitor the transition to a circular economy.

The waste management thematic area focuses on the quantity of waste that is recycled. The last estimate shows a slowly increasing situation. More specifically, in the recycling rate of all waste excluding major mineral waste there is a slowly increasing pattern, most probably guided by the e-waste (in the next chapter their situation will be addressed more specifically since they are one of the objectives of the deliverable).

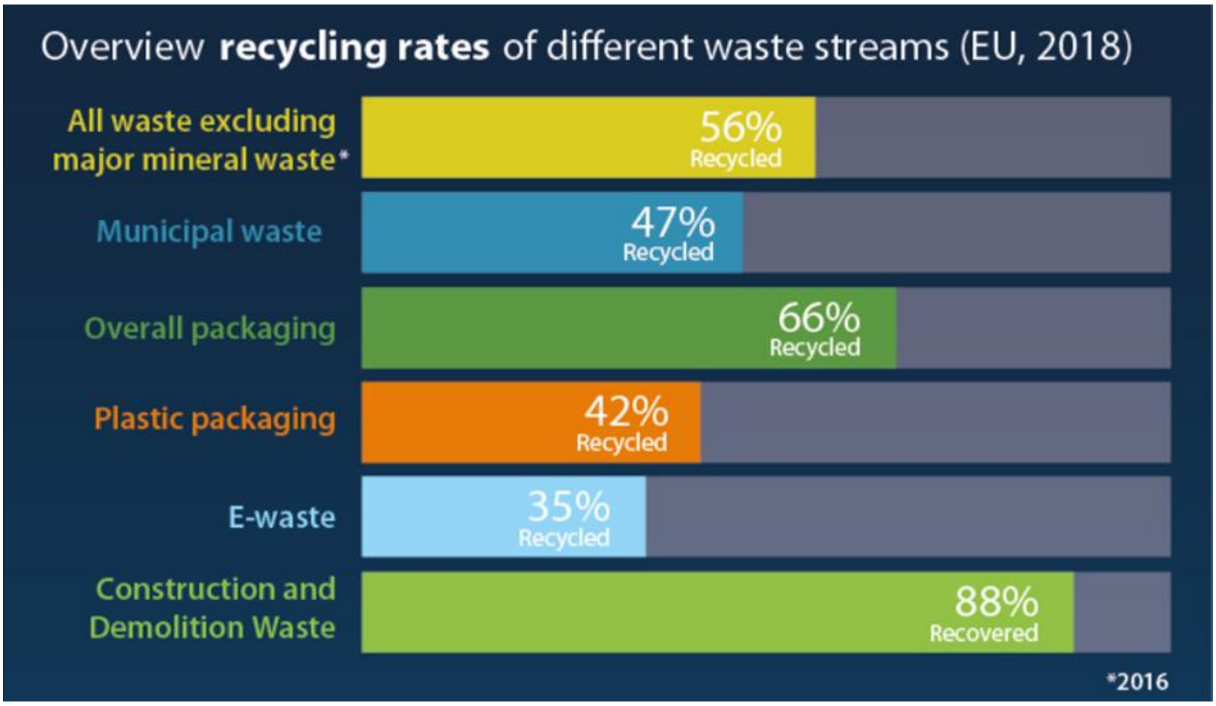

Figure 7: Overview recycling rates - ec.europa/eurostat

The thematic area of secondary raw material is necessary in order to address the quantity of recycled products that are traded among EU member states and outside the EU. Those indexes show that the import in the EU of recycled materials is decreasing while exports are increasing. Moreover, the circularity rate that evaluates the share of raw materials that are fed back into the economy once they are used shows an increasing pattern most probably pushed by the new various techniques that are able to recover the materials from the old products.

Lastly, in terms of competitiveness and innovation it can be noted that the score relative to Private investments, jobs and gross value added related to circular economy sectors is increasing strongly over the years while the number of patent index is unstable. The first result anyway demonstrates that the circular economy is contributing to creating wealth and it has to be considered as a new strong emerging sector.

The actual situation demonstrates that many steps have to be taken in order to adopt a more circular way of acting.

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3 The manufacturing sector

In the past decades the manufacturing sector has led the growth of national economies around the whole world. Nowadays the sector accounts globally for 16,51% of world GDP.

While a positive trend can be found in the service industry, this has not implied a downfall of the more traditional manufacturing sector.

This trend has been pushed up by the high middle-income countries and the middle-income countries. From the graph below it can be also noted that the manufacturing sector has decreased its importance due to the financial crisis of 2009; the fact that such a decrease was only dictated by the fact that the whole economy was shrinking, and not by a change of technology or demand can be also seen through the graph. After the stark decrease of 2009 the sector has returned to a higher value, that has indeed followed a decreasing trend in the past years – with a plummeting point between 2019 and 2020 probably due to the Covid-19 pandemic – but has shown a newly important increase in 2020.

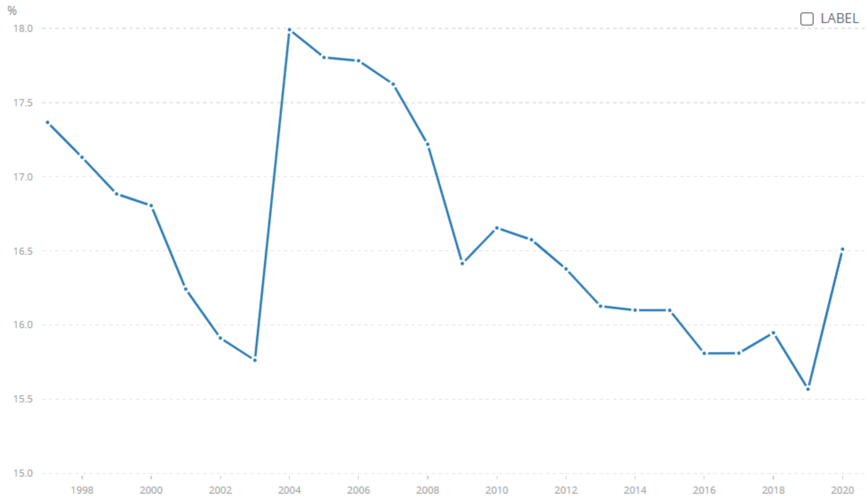

Figure 8 - The manufacturing sector and the GDP

The increase in the production of the manufacturing sector is also reflected by the total waste production of this sector because the production of new goods directly implies a higher production of waste materials.

The need nowadays is to find a more sustainable way to handle the quantity of waste produced, since continuous growth cannot imply carelessness in doing so.

New ways of tackling the issue of waste production must be created and invented in order to make growth sustainable, and not something beneficial only in the short run and detrimental in a long-term perspective.

Some of the main strategies that can be put in place have been already presented in the previous chapter, while the goal of this chapter is to address the problem related to the electromechanical machinery sector and to highlight its main characteristics focusing on the possible impact of refurbishment and remanufacturing strategies in this context.

The first subsection of the chapter contains an overview of the electromechanical machinery sector, with the aim of providing an overview of the subject. The goal is to capture the

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trends and describe the main features of the electromechanical machinery sector with a specific focus on the application of remanufacturing and refurbishment strategies on it.

In the second section the waste (e-waste) produced by the electromechanical sector is taken into account with the possibility to reduce it through the strategy of remanufacturing and refurbishment.

The third section contains data regarding the presence of valuable materials in electromechanical products providing an overview of the expected value that can be saved. It is important to focus on this theme since such materials are difficult and costly to locate, with the added burden of the resources needed to extract them and the pollution created to achieve this purpose. The possibility to reuse them implies a reduction in costs and in terms of environmental impact.

The last subsection considers the impact on consumers in the moment in which they buy a refurbished/remanufactured product. The subsection has the aim of understanding the pre-sale and after-sale services that are offered previously to the potential customer and later to the actual customer when they decide to purchase a machine that has gone through a process of refurbishing or remanufacturing.

This last analysis is conducted with the aim of understanding which the main points that should be considered when taking themes of refurbishing or remanufacturing into account are and comprehending which their weakest and strongest points are.

3.1 Electromechanical machinery sector

The electromechanical machinery sector is characterised by the fact that it is a merge of two different technologies that must be considered fundamental for the third and fourth industrial revolution, and at the same time must be considered rather new.

This sector is defined by the fact that its nature is defined by the collaboration of processes and procedures that come from the world of mechanical engineering and the world of electronic engineering. As far as electricity is concerned, this technology can be considered to be widespread only after the last decade of the 19th century, and an integration between these two different types of technologies has seen the light with the early development of the telegraph.

Nowadays the electromechanical machinery sector is predominant in the technology that is being used in everyday interactions and more so in the production of goods.

As of now, the majority of machineries and equipment can be considered to be part of the electromechanical machinery sector, since by definition even a laptop can fall in this category.

The technology that is used by many companies nowadays, especially in the manufacturing sector, presents a combination between elements that must be considered electronic, and elements that must be considered mechanical, thus electromechanical machineries can be considered the norm in terms of machineries.

The fact that a type of product that embraces both of these technologies is considered to be the standard implies that machines only using one of the two cannot be considered equally efficient.

The need for efficiency that characterises firms implies that in order to achieve it, companies are more oriented to purchase machineries that embed both mechanical and

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electric technologies, and while this idea can be considered optimal in terms of output, the same cannot be said about sustainability.

Electromechanical machinery implies a high number of rare materials to be used in order to have such technologies work, so the fact that more and more companies strive toward adopting these technologies can only be translated into a higher environmental impact.

Unless a way to reuse the materials of old tools is found, the environmental footprint of the manufacturing sector will grow and will become less sustainable.

The global electronic products market reached a value of nearly $1,191.2 billion in 2020, having increased at a compound annual growth rate (CAGR) of 5.4% since 2015. The market is expected to increase from $1,191.2 billion in 2020 to $1,653.2 billion in 2025 at a rate of 6.8%. The increase is mainly due to the lockdown increasing demand for various electronic products as employees and students have switched to the online mode. The electronic products market is expected to grow from $1,653.2 billion in 2025 to $2,169.6 in 2030 at a CAGR of 5.6%.

The sector had just a slight decrease during the last years due to the difficulty of finding chips available on the market. The Covid-19 pandemic has increased the demand for electronic products such as tablets, smartphones and televisions. People in fact have been pushed to work from home in order to reduce the risk of infecting others. On the other hand, the pandemic situation has caused difficulties to find raw materials due to the restrictions in international trade.

The two main solutions that can be found on this front are refurbishment and remanufacturing. The picture below summarises the refurbishment process of a smartphone [5]. The used phone is collected and transported to the recycling site. Once the phone reaches the recycling site is sorted and components are divided into broken, obsolete and usable. Subsequently the phone is reassembled after having substituted the obsolete and broken parts and it is tested. If the tests provide positive results, the phone will be transported back to the shop and sold as a refurbished product.

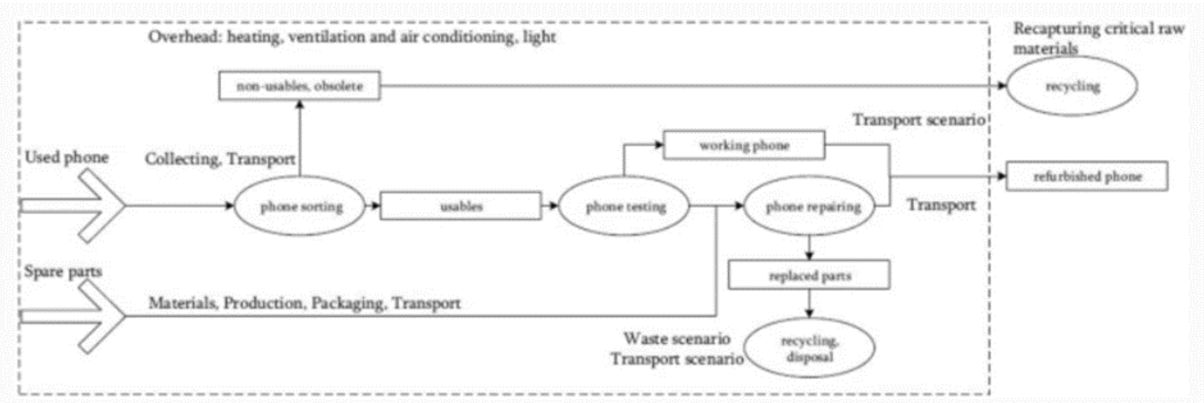

Figure 9- refurbishment process of a smartphone

On the other hand, in the following picture the remanufacturing process of a phone is summarized [5].

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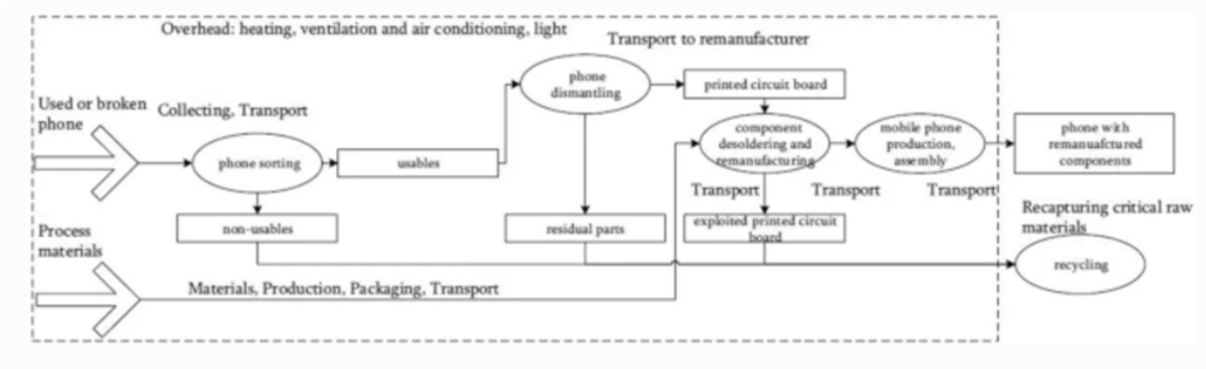

Figure 10 - Remanufacturing process of a phone

Broken phones are collected and transported to the recycling site. Once the phones reach it, they are sorted, semi-automatically dismantled and de-polluted (removal of battery), and the printed circuit boards (PCB) are extracted. The PCBs are then transported to the remanufacturer. At the remanufacturing site, the relevant parts (semiconductors) are de-soldered, cleaned, and remanufactured. At that time the valuable material saved will be used to produce new phones. In this way some parts of the phone such as cameras and microphones can be reused diminishing mainly the cost of the semiconductors which are the most expensive materials to process.

3.2 E-Waste management

The increase in production of electronic devices in the last decades has also increased the creation of e-waste that nowadays is becoming one of the challenges of our age. The ability to recycle/reuse those materials could have impact on:

- saving natural resources which in most of the case are non-renewable resources
- saving landfill space
- reducing business cost with efficient actions and business plans
- company imagine, nowadays consumers are much more interested in buying products from eco-friendly companies
- job market, the increase in the demand of recycled/reused products will shift many workers in this sector.

Electronic waste, or e-waste, refers to all items of electrical and electronic equipment (EEE) and its parts that have been discarded by its owner as waste without the intent of re-use. E-waste is also referred to as WEEE (Waste Electrical and Electronic Equipment). The products have been grouped in 6 general categories that are summarised in the table below:

Product category	Description
Temperature exchange equipment	More commonly referred to as cooling and freezing equipment. Typical equipment includes refrigerators, freezers, air conditioners, and heat pumps.
Screens and monitors	Typical equipment includes televisions, monitors, laptops, notebooks, and tablets.

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Lamp	Typical equipment includes fluorescent lamps, high intensity discharge lamps, and LED lamps.
Large equipment	Typical equipment includes washing machines, clothes dryers, dishwashing machines, electric stoves, large printing machines, copying equipment, and photovoltaic panels.
Small equipment	Typical equipment includes vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, electric shavers, scales, calculators, radio sets, video cameras, electrical and electronic toys, small electrical and electronic tools, small medical devices, small monitoring, and control instruments.
Small IT and Telecommunication equipment	Typical equipment includes mobile phones, Global Positioning System (GPS) devices, pocket calculators, routers, personal computers, printers, and telephones.

Table 3: 6 product categories

The 2020 Global e-waste monitor report **Fehler! Verweisquelle konnte nicht gefunden werden.** estimates that in 2019 the world generated 53.6 Mt of e-waste with an average of 7.3 kg per capita and with an average consumption increase of 2.5 Mt per year. Those data are driven by the Asian continent where in addition the level of recycling products is quite low.

The recycling rate is still below 50% so this element stresses the need for initiatives to help promote the recovery of precious resources. This can be accomplished through:

- Policies that promote design for recycling
- Policies and incentives to increase the e-scrap recycling rate, encouraging the public to recycle their end of life devices rather than stockpiling them in residences where as much as 75% of end-of-life devices is estimated to be inventoried
- Preventing export of e-scrap to countries that will use processes resulting in a low recovery rate
- Promoting investment in best practices to ensure that recovery will be maximised in both developed and developing countries.

The most common strategies in order to reduce the risk of an environment impact due to hazardous raw material present in the e-waste are:

Life cycle assessment (LCA) represents one of the fundamental tools for the implementation of an Integrated Product Policy, as well as the main operational tool of "Life Cycle Thinking": it is an objective method of assessing and quantifying energy and environmental loads and the potential impacts associated with a product / process / activity along the entire life cycle, from the acquisition of raw materials to the end of life.

The relevance of this technique lies mainly in its innovative approach, which consists in evaluating all the phases of a production process as related and dependent.

Material flow analysis (MFA) is a tool used to study the path of materials (electronic waste) that flow into recycling sites, or into disposal areas and material stocks, in space and time. Connect sources, routes and intermediate and final destinations of material. Material flow analysis is a decision support tool for environmental and waste management. This tool can be applied to develop adequate e-waste management.

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This includes a consideration of the e-waste stream and its evaluation in terms of environmental, economic and social values.

Multi-criteria analysis (MCA) is a tool through which the consideration of different points of view, builds criteria that represent the paths along which the decision-making actors justify, transform and argue their preferences. This tool has been applied positively to waste management strategies for solid waste anyway positive results can emerge in using it also for e-waste especially if it is used in combination with other tools.

Extended producer responsibility (EPR) is that instrument by which the producer of a given artefact cannot be disinterested, but on the contrary must take care of the product even after the end of its useful life.

The goal is to ensure that producers internalise the environmental costs generated at the end of their life from its own products, thus encouraging them to opt for more virtuous products that generate minor damages at the end of their life cycles.

It has emerged from previous research that LCA, MFA and MCA have overlapping elements on the analysis of the e-waste impact, while EPR is a completely different strategy with no common features. The best e-waste management strategy could then be to combine EPR with one of the other 3 strategies under consideration (LCA, MFA, MCA).

3.3 Valuable materials

The term “valuable materials” refers to any resource that can be found on the land and has a value. Examples of the most expensive valuable materials are: Antimatter, that only to be produced costs around 25 million, or Californium, that is a chemical element that has been synthesised only once in human history. Nevertheless, even in products that are used in everyday life there are some valuable materials that can be recycled reducing the impact on the environment.

The focus of this section is to assess which the variable materials that can be found in the electromechanical machinery are. From the 2020 Global e-waste monitor report can be noticed that the composition of the waste is very complex, in fact more than 50 elements from the periodic table can be found, including precious metals (e.g., gold, silver, copper, platinum, palladium, ruthenium), critical raw materials (e.g., cobalt, palladium, indium, germanium, bismuth, and antimony), and noncritical metals, such as aluminium and iron. In the Table 4 below the main materials that can be found in e-waste are summarised and associated with the risk of supply and the possible use.

It has been chosen to use the table from [8], since it has been considered the most complete. The information summarised is the most complete.

In the first column the table presents the valuable materials and it provides information regarding whether it is a rare earth element (REE or RE) or a hazardous substance one.

According to the IUPAC definition, REE indicates the following 17 elements: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), scandium (Sc), and yttrium (Y). Those elements are actually abundant in the Earth’s crust, anyway they are usually discovered in small

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quantities mixed with other elements. Those materials are also considered critical for a greener economy.

RoHS (Restriction of Hazardous Substances Directive) is a directive adopted by the EU in February 2003. This legislation imposes restrictions on the use of certain hazardous substances in the construction of various types of electrical and electronic equipment. The directive had to be applied to all the member states.

In the second column the risk of supply has been calculated; this statistic gives a full understanding of the risk of having troubles in extracting that material and trading it.

Lastly, in the third column a brief description of the main products containing the element is presented.

Element	Risk of supply	Use in EEE
Li	6.7	As Li-ion battery, they are the most common battery type used in portable electronic devices.
Be	8.1	Used in EEE as Be-Al alloy, typically containing 2 % Be. It is used in springs, relays, connections and historically computer mother board.
Al	4.8	Because of its lightweight, structural strength and thermal characteristics, Al is typically used as casing and frames of several electronics equipment. Often used as an alloy with Cu, Mn, Mg, and Si. Al is also good electrical conductors and can be found as metallisation in printed circuit boards, computer motherboards, hard drives, rotors and connectors. It is often recovered due to its economic values.
Si	No data	One of the most common semiconductors in Information and Communication Technology (ICT)-related equipment, e.g., cathode ray tube (CRT), printed circuit board. Very often, Si is selectively doped with tiny amounts of B, Ga, P, or As to control its electrical properties.
Ar	No data	Present in incandescent light bulbs, fluorescent tubes and low-energy light bulbs.
Sc§	9.5	A rare Earth element (REE); due to its photophysical properties, it is often used as lasers in dentistry and high-intensity discharge lamps.
Ti	4.8	Commonly used as an alloy with Al, Mo and Fe as casing and is also increasingly used in electronic circuits and optical micro-devices (e.g., laser diodes) in multilayer metallisations, often paired with Pt.
V	6.7	Used in rechargeable flow battery. VO_2 is used as semiconductors and in transistors.
Cr*	6.2	Cr^{6+} is widely used as a corrosion inhibitor in corrosion protection in metal housing. Cr is a crucial component of stainless steel (where it is present at least at 10.5 %) which is widely employed for EEE production. It can be also used in form of NiCr alloy, in multilayer metallisations in printed circuit

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		boards, smart card chips and microdevices for ensuring adherence between metallic layers and between Au finishing and the device surface.
Mn	5.7	As an alloy with steel, Al or Cu, it has important metallurgical applications. As manganese oxides, they are used as a depolarizer in batteries, sensors and super capacitors.
Fe	5.2	There are numerous uses e.g., as electrical steel used in magnetic cores for transformers, generators and motors. As Fe_2O_3, it is used in hard drive and printed circuit boards. Widely recycled.
Co	7.6	As a magnetic alloy with Fe, Ni, Al, Nd, Sm (e.g., AlNiCo, SmCo, etc. magnets). It is widely used in Li-ion batteries. Often found in CRT, printed circuit boards and hard drives. It is often recovered due to its economic value.
Ni	6.2	As an alloy with steel, Cr, Mn, or Fe for corrosion protection in housing. Ni is widely used in batteries and CRT. It is employed as a coating in preserving NdFeB magnets from oxidation. It is often recovered due to its economic value.
Cu	4.3	Commonly used in electrical wiring. Copper wire is found in most electrical equipment and electronic circuitry. It is used for printed circuit boards pathways and as bulky material in multilayer connections where Au is the external finishing (e.g., smart card chips, printer cartridge connections and pathways). It represents the most abundant non-ferrous metal in de-manufactured printed circuit boards and small electronic equipment. Also forms important alloy with Al and Ti. It is often recovered due to its economic value.
Zn	4.8	Used in die-castings in electrical industries. As alloys such as Ni, Ag and Al solder. ZnO is widely used in the manufacture of rubber, plastics, inks, batteries and electrical equipment. ZnS is used in making luminous paints, fluorescent lights and X-ray screens. It is often recovered due to its economic value.
Ga	7.6	High purity Ga is used in the manufacturing of semiconductors. GaAs and GaN are used in electronic components e.g., integrated circuit, high speed logic chips, diode lasers and light emitting diodes (LEDs).
Ge	8.1	Commonly used in fluorescent lamps, LEDs, and transistors (historically). Si-Ge alloy, it is used in the manufacturing of semiconductor for high-speed integrated circuits.
As	7.6	As alloys with Pb or Ga. GaAs is a semiconductor material used in printed circuits boards and laser diodes.
Se	7.1	Used in Li-Se battery and ZnSe has been used in the manufacturing of LEDs and laser diodes.
Sr	8.6	Primarily used in the manufacturing of glass for CRT.

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Y§	9.5	A REE that is a key ingredient of Ba2Cu3YO7 superconductor. Europium-doped yttrium oxide and oxysulfide (Y2O2S:Eu) are widely used in CRT and fluorescent lamps.
Nb	7.6	Used in the manufacturing of capacitors. As alloy with Ge, Sn, or Ti, it is used as superconductor wires. $LiNbO_3$ is ferroelectric and used in mobile phones and optical modulators. It is often recovered due to its economic value.
Mo	8.6	Commonly used multilayer ceramic circuits and thermal-management applications when paired with Cu. Also used in diodes and rectifiers as well as field-emitter components in flat-panel displays. It is sometimes recovered due to its economic value.
Ru	7.6	Commonly alloyed with Pt and Pd to make electrical contacts and to coat electrodes. Pb2Ru2O6.5 is used in the manufacturing of electrochemical capacitor. Bi2Ru2O7 is used in chip resistors. It is often recovered due to its economic value.
Rh	7.6	Commonly alloyed with Pt and Pd to make electrical contacts in printed circuit boards and to coat electrodes. It is often recovered due to its economic value.
Pd	7.6	Often used as soldering materials and as electrodes in multilayer ceramic capacitors in laptops and mobile phones. It is often recovered due to its economic value.
Ag	6.2	Widely used in membrane switches and pathways, it is often present in printed circuit boards, plasma display panels and photovoltaic panels (PVPs). Powdered Ag and its alloys are used in paste preparations for conductor layers and electrodes, ceramic capacitors, and other ceramic components. It is often recovered due to its economic value.
Cd**	6.7	Commonly used in contacts, switches and rechargeable Ni-Cd batteries. CdS is used in CRT.
In	7.6	Extensively used in liquid crystal display (LCD) as transparent electrodes (indium tin oxide) and thin-film transistors in the production of flat screen monitors, TVs and solar panels. GaInN and GaInP are used in LEDs and laser diodes.
Sn	6.7	Used in alloys with Pb as solder for electric circuits in historic electric and electronic equipment. Nb3Sn is used in coils of superconducting magnets. Also used as electrode in Li-ion batteries. Stannate aqueous solutions are used to produce electrically conductive and corrosion resistant coatings on glass by electroplating and Zn_2SnO_4 is a fire-retardant used in plastics housing.
Sb	9	Used in antifriction alloys in electrical cable sheathing, as lead-free solder as well as fining agent in glass for TV screens. As semiconductor materials, it is used in infrared detectors and diodes.

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Te	No data	Used in the manufacturing of solar panels. It is often doped with Ag, Au, Cu or Sn in semiconductor applications.
Ba	8.1	BaO is used as coating on the electrodes in fluorescent lamps and $BaCO_3$ are used in the manufacturing of CRT.
La§	9.5	It is widely used for anodic material of nickel-metal hydride batteries, alone or, mostly, as the main component (>50 %) of mischmetal. Used in carbon lighting applications such as studio lighting and cinema projection.
Ce§	9.5	An important component of phosphors in CRT and fluorescent lamps. It is also used in flat-screen TVs, low-energy light bulbs and floodlights.
Pr§	9.5	It is commonly used to produce magnets in small equipment such as printers, headphones and loudspeakers. It is also applied as activators in phosphors for lighting.
Nd§	9.5	It is the most abundant lanthanoid element in $Fe_{14}Nd_2B$ permanent magnets, widely used for electronics e.g., in hard drives, mobile phones, headphones and loudspeakers. Neodymium-doped crystals are used in hand-held laser pointers.
Sm§	9.5	Used in carbon arc lighting for studio and projection. It is used to produce SmCo permanent magnets used in electronic equipment.
Eu§	9.5	Eu_2O_3 is widely used as a red phosphor in TV and fluorescent lamps.
Gd§	9.5	It has been used to produce magnets for miniaturisation in electronic equipment and as dopant in optical fibres.
Tb§	9.5	Terbium is used as Tb_4O_7 in green phosphors in fluorescent, low energy light bulbs, Mercury lamps, CRT and as dopant in optical fibres.
Dy§	9.5	Widely used in the manufacturing of data-storage devices, e.g., hard drives (it is contained in a 1 % amount in NdFeB-magnets where its presence preserves the magnetic properties at high temperature). It is also used in high-intensity metal-halide lamps and white LED.
Ho§	9.5	Used in yttrium-iron-garnet (YIG) and yttrium-lanthanum-fluoride (YLF) solid-state lasers found in microwave equipment.
Er§	9.5	Widely used in optical fibre cables.
Lu§	9.5	$Al_5Lu_3O_{12}$ is used as a phosphor in LED. It is also used as a dopant in computer memory devices.
Hf	No data	Used as electrical insulator in integrated circuits
Ta	7.1	Used in the production of electronic components, e.g., capacitors and resistors for mobile phones and laptops. It has also found uses as electrodes for neon lights and AC/DC rectifiers.

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W	9.5	Widely used in old-style incandescent light bulbs, CRT, fluorescent lighting, and heating element. It is also used as an interconnection material in integrated circuits.
Re	6.2	It is used as an electrical contact material. It is often recovered due to its economic value.
Os	7.6	It is used as an electrical contact material. It is often recovered due to its economic value.
Pt	7.6	It is a component of the Co-Cr-Pt alloy used for hard drive platters coating; also found in fibreglass, liquid-crystal and flat-panel displays, and CRT. It is often recovered due to its economic value.
Au	5.7	Widely used in the production of corrosion-free connectors in electronic devices, cables and integrated circuits. It is often recovered due to its economic value.
Hg*	8.6	Historically used in mercury-vapour lamps and cold-cathode fluorescent lamps. It has also been used in switches, relays of older mainframe computers, LCD and batteries.
Tl	No data	Used by the electronic industry in photoelectric cells.
Pb*	6.2	Historically used in electrical solder with Sn on printed circuit boards and PbO is used in CRTs.
Bi	9	Used as a replacement of Pb as low melting point solders in printed circuit board.

Table 4: Main materials found in e-waste

**According to the EU Restriction of Hazardous Substances (RoHS) regulation, new equipment should not contain a level greater than 0.1 % by weight since 2006.*

***According to the EU RoHS regulation and new equipment should not contain a level greater than 0.01 % by weight since 2006.*

§ A rare Earth element.

3.4 Interaction with sales and aftersales functions

The processes of refurbishment and remanufacturing have shown to have a positive impact on sales due to a number of different reasons.

The first one can be identified in the budget constraints that customers – as individuals or as companies – may face. Offering a product that has been constructed starting from an already existing product that was destined to be discarded can decrease the price at which it is sold, since the cost of production has already decreased.

The offer of a refurbished/remanufactured product can thus lead to an increase in sales, without the risk of cannibalising them. The customer who will buy the refurbished/remanufactured product would not have bought a new one at full price but would have rather opted for the product of a competitor who could sell at a lower price.

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The increase in sales is not only linked to a decrease in price, but also to the rising desire for sustainability that customers have. The trend of being more conscious about one's own purchase habits makes people more careful during their buying decision, pondering the effect that their choice will have on a broader scale that includes the environment.

Selling a refurbished/remanufactured product thus has a positive effect on sales not only because it allows to reach a broader pool of customers that would not have decided to buy the product at full price, but also because it has a positive effect on the brand image of the company.

A company that is perceived to pay attention to the environment by actively shifting their ways of producing in order to reduce their waste level and emissions achieves a better image in the mind of customers; such perception may thus bring people to favour a company that adopts refurbishment/remanufacturing processes over a company that does not include circular economy into its strategy.

In the sale phase, another factor that influences the remanufactured/refurbished product is the distribution channel. It has been demonstrated that companies, in order to trade the remanufactured/refurbished products, should develop secondary distribution channels.

This element is because the consumers with a higher WTP for this kind of products represent the lower-end market, so they do not have the same characteristics as the usual customers of companies.

In the after sales phase a flexible return policy has to be a must. Customers willing to buy a remanufactured and refurbished product feels a flexible return policy as a guarantee of product quality.

The second element that tends to increase the willingness to buy remanufactured/refurbished products is a long-term warranty that again is perceived by customers as an assurance of product quality.

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4 Refurbishment and Remanufacturing strategies

The following chapter represents the core of this deliverable by presenting the Refurbishment and Remanufacturing strategies.

In the first part, the definition of Remanufacturing from D4.1: “Circular Economy Driven lifetime-extension strategies” is taken as an input and subsequently is extended through the Remanufacturing strategy subsection. This subsection could be used as an input for D5.4: “Re-manufacturing process for electromechanical machines”. The last subsection of the first part deals with interviews that have been conducted with the pilots in order to access the specific issue for this strategy.

The second part is devoted to the Refurbishment strategy. As for the Remanufacturing part, the Refurbishment strategy definition is taken as an input from D4.1 and subsequently extended through the Refurbishment strategy subsection. This subsection could be used as an input for D5.3: “Refurbishment Process for electromechanical machines”. The last subsection (“Industrial scenarios”) deals with interviews that have been conducted with the pilots in order to assess the specific issue affecting this strategy.

4.1 Remanufacturing

4.1.1 Remanufacturing definition

The definition of Remanufacturing is taken as input from D4.1.

Remanufacturing (or second-life production) is a strategy that implies using parts of discarded products in a new product with the same function. Used products are bought at least to original equipment manufacturer performance specifications. Remanufactured products guarantee the same quality of original products. Remanufacturing applies where the full structure of a multi-component product is disassembled, checked, cleaned and when necessary replaced or repaired in an industrial process.

4.1.2 Remanufacturing strategy

Remanufacturing is a form of recycling that reuses machines that do not work. This process is done by taking a machine apart to repair it, recycle it, or collect parts. Remanufactured equipment is available in many types of machines, including home computers, office equipment, and appliances.

One way to rebuild a machine is to refurbish it and another is to remanufacture it. Refurbishing a machine means repairing a machine by inspecting it for broken or worn parts and restoring the machine to like-new condition. Remanufacturing a machine means reusing the parts through a technician who disassembles it and removes the parts that are still functional for use in other machines.

Remanufacturing helps to reduce the amount of waste released into the environment due to broken machines. It can save space as well as reduce harmful chemicals that come from the disposal of electronic devices such as computer monitors. The regeneration of equipment is considered a socially and ecologically responsible operation for a company that deals with many electronic components. For expensive parts, remanufacturing can be cost-effective,

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but sometimes the effort and manpower involved in recycling hardware costs more than replacing the hardware.

The Remanufacturing process can be summarised in 6 steps, as you notice from the picture below:

1. Disassembly
2. Cleaning
3. Inspection, diagnosis and sorting
4. Reconditioning
5. Reassembly
6. Final testing

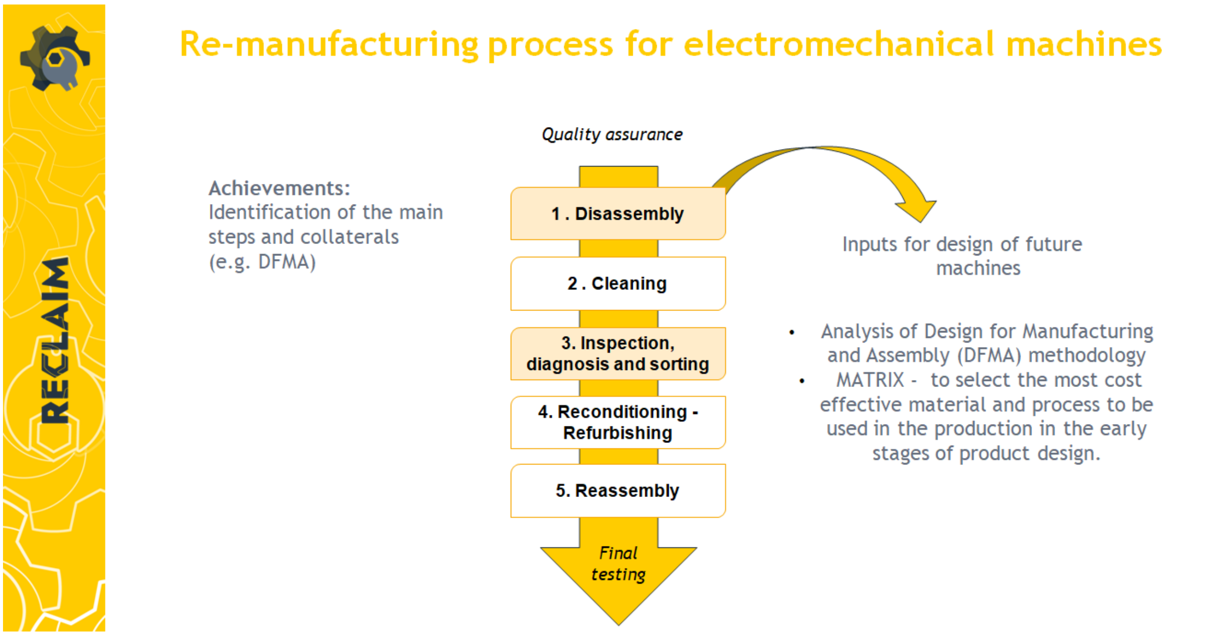

Figure 11: Remanufacturing process for the electromechanical machines

Firstly, old products, named cores, are disassembled completely into single parts. Parts which cannot be reused or remanufactured are sorted out. This step is done manually by operators that disassemble the product and in this way they evaluate the degree of usage of the single parts and it are able to decide which part to keep and which to sort out. In this case, it can be really useful to have a product matrix in order to disassemble it in the easiest way possible.

The second step includes the cleaning, degreasing, deoiling and derusting of all parts. The cleaning process is one of the most important steps, on the contrary the actual techniques are quite polluting, so nowadays the adoption in this step of new techniques, such as supercritical CO_2 cleaning and liquid blasting cleaning, is evaluated.

In the third step the parts are classified according to their future use. The three categories are:

- Reusable without reconditioning
- Reusable after reconditioning
- Not reusable / to be exchanged

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Moreover, during this step all the parts are inspected in order to ensure the quality of the product and avoid possible issues.

In the fourth step, parts are reconditioned. Metal treatment processes, such as drilling, milling, turning, grinding and honing, are applied.

During the fifth step, parts, after having been disassembled, cleaned, inspected and reconditioned, are reassembled into the product. In this stage the assembly line is usually used with the same equipment needed for new products.

In the last step, the final remanufactured product is tested in order to prove at 100% its quality. Remanufactured products in fact have to pass the same tests and inspections of new products; in this way, the quality of the products can be ensured, reducing possible reclaims by the final consumers.

In the picture below the generic remanufacturing process for consumer goods and electronic products is summarised.

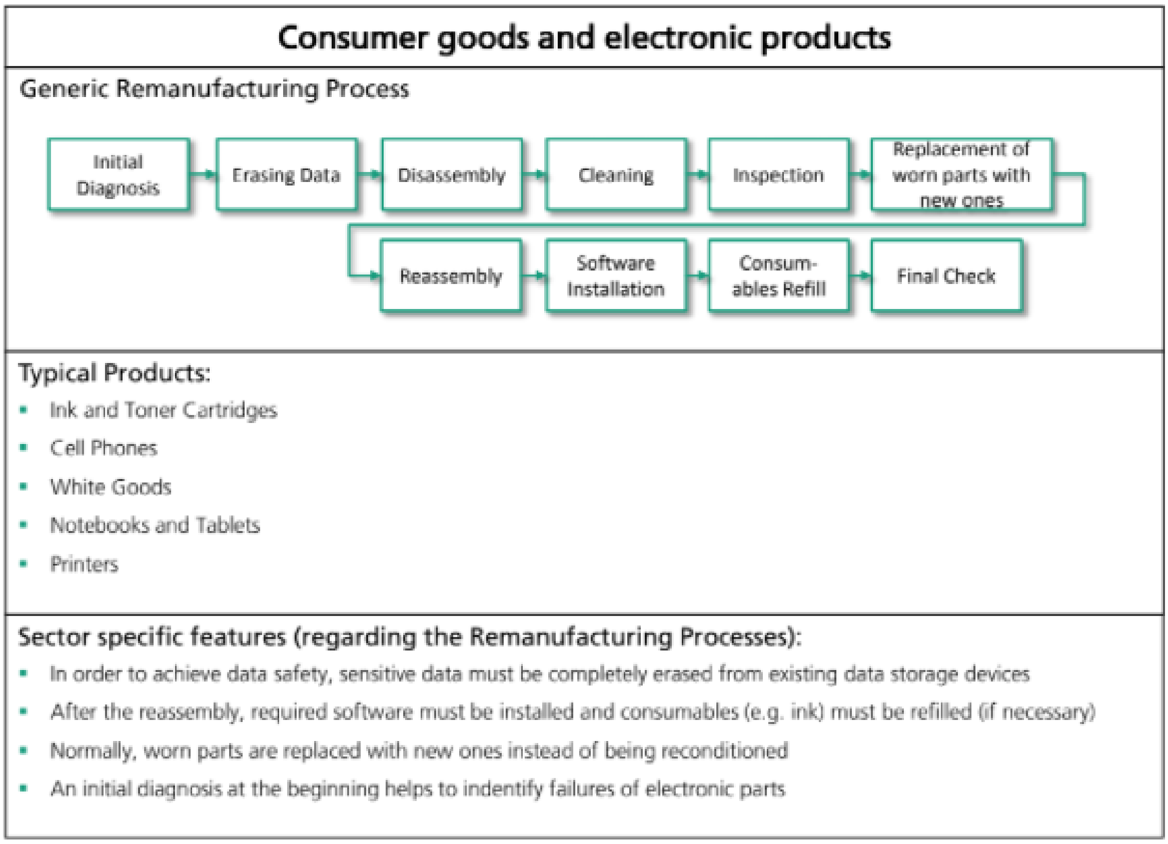

Figure 12: Consumer goods and electronic products[3]

Sector-specific features (regarding the Remanufacturing Processes):

- In order to achieve data safety, sensitive data must be completely erased from existing data storage devices.
- After the reassembly, required software must be installed and consumables (e.g. ink) must be refilled (if necessary).
- Normally, worn parts are replaced with new ones instead of being reconditioned.

[3] *D3.3 - D3.4 Map of Remanufacturing Processes Landscape, For Horizon 2020, grant agreement No 645984, 2016*

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- An initial diagnosis at the beginning helps to identify failures of electronic parts.

Nevertheless, one of the main objectives in order to adopt an efficient remanufacturing strategy is to have in mind how to disable it. Electromechanical machine manufacturers should build the product with a clear and efficient way on how to disassemble it.

A matrix summarising the main elements inside the machine and the best way to extract them without damaging them could solve the waste in time and resources of the technician that will complete the task. Another important aspect that could be added to each product specific matrix is the cost per unit and the overall impact of the specific unit on the total cost of production.

4.1.3 Industrial scenarios

In this section, an overview of the Pilot scenarios related to remanufacturing is described.

4.1.3.1 GORENJE Pilot B Remanufacturing of White Enamelling Line

Technological equipment for the white enamelling line had been purchased in 1998 and since that time enamelled parts have been manufactured. In the last years the main problem of the line became exposed – lack of origin spare parts and big danger that factory can stop due to failure which we are not able to repair. Main problem are spare parts for spraying guns and for control unit for spraying booth. In the furnace, there are main issues with burners, burner tubes and isolation of furnace. These were reasons for refurbishment and remanufacturing of furnace and spraying booth. With the refurbishment within the context of the RECLAIM project and RECLAIM partners' technologies with advanced sensorial network, higher level of modernization of the pilot's equipment could be implemented.

Actual technology is 1-side spraying of powder enamel (one piece is hanging on the hook). With the upgrading of actual line to 2 pieces (cooktops) per hook, big increase of efficiency of the enamelling line is expected.

Generally, it was needed to:

- renew and update very old parts of furnace (isolation, burners and burner tubes, PLC control system),
- renew and update old parts of the spraying cabin (spraying guns, reciprocator, PLC control unit),
- equip the whole enamelling line with temperature and humidity sensors to have on-line data about these important parameters for the enamelling process. These data will be stored for future comparison in case of technological problems with quality of enamelling process,
- implement new sensors with sensorial network, visual cameras for recognizing of different types of cooktops, output registration board (touchscreen) and connected SW.

4.1.3.2 ZORLUTEKS Remanufacturing of Bleaching Machine

When taking into consideration Zorluteks' product range, there are 250 million square meters of home textile production per year. The raw cotton fabric comes from different suppliers; therefore, the whiteness of raw cotton fabric has a wide range of whiteness degree due to variation of cotton color depending on the season, geographic region, climate and

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soil diversity. Whiteness degree variation leads to undesired results especially on the fabric to be painted and printed.

There are several parameters (temperature, time, fabric construction and amount of bleaching chemicals etc.) that affect the quality of the bleaching process and the whiteness degree variation. It is quite problematic to arrange these parameters in an optimum level for different characteristics of cotton fabric. This causes rise in the number of re-processes in the bleaching operation. That’s why, to achieve desired whiteness degree at the end of the bleaching operation, there is a need to design a system which is able to work unmanned and decide its working parameters by itself.

The other issue is lifetime extension of the bleaching machine. The bleaching machine in Zorluteks is a 1996-year Küsters model bleaching machine. Its useful life time is about 20 years. The mean time between failures is about 2 days (0.5 failure/day). The failures are categorized as mechanical, electronics and electrical. Currently, the maintenance procedure in the factory is made following the instructions of periodic maintenance (1times/year) given by the machinery manufacturers, and the active maintenance is implemented when the failure occurs. There is no predictive maintenance strategy implemented, so the maintenance is carried out without a strict and planned control.

In the bleaching machine, there has been lack of sensors dedicated to measure the conditions of the machine and collect data focused on maintenance, lifetime and productivity. With the help of refurbishment and re-manufacturing, which is being implemented in the bleaching machine, it is possible to extend the system remaining useful life.

4.1.3.3 HWH Remanufacturing of Friction Welding Machine

HWH has the intention to update and to significantly enhance the welding equipment by predictive maintenance features. The pilot scope is the remanufacturing and upgrading of the friction welding machine RSM401, including the use of advanced sensors and the analysis of the gathered data. Within the remanufacturing and upgrading processes, the focus is on the following aspects given below:

- Sustainable system design to produce future-proof welding systems.
- Use of identical parts to reduce production costs and improve services as well as maintenance of the welding systems.
- Proactive and tailored service through predictive maintenance.
- Ensuring holistic resource efficiency.
- Fast, user friendly, energy-efficient system design.
- Smart management and operation.

4.1.3.4 Issues affecting the choice

The answers to the questions of the questionnaire regarding remanufacturing strategies of each involved pilot is given below:

Question	1. Which elements push a company to invest in Remanufacturing?

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Pilot answers	
GORENJE B	In the last years, the main problem of the line became exposed: lack of origin spare parts and big danger that factory can stop due to failure which we are not able to repair.
ZORLUTEKS	Machines, for which we are satisfied with the working performance, but the manufacturer no longer produces spare parts, encourage a company to invest in remanufacturing. Procuring the parts of such machines from other discarded machines of the same model ensures the sustainability of the quality in production.
HWH	HWH is focused on the financial side of decision, because its primary goal is to sell product and get profit/salary. So requirements of customers have financial implications/dimension. Therefore, the main reasons are mainly financial and economic. From the technical perspective, HWH has some requirements of their customers to update the software or/and update hardware elements of the machines in order to work effectively, so these are the reasons for remanufacturing or refurbishment of their machines. However, these actions are costly because they have to suit with the relevant standards (e.g. security standards, communication protocol, etc.). HWH is focused on refurbishment activities, because according to definition in D4.1 refurbishment and remanufacturing are quite close, with one major distinction: refurbishment implies change of equipment function, i.e. it has new functionality, like storing sensor data, performing additional operation, etc. This is exactly the case with this pilot, and this is the justification why HWH is focused on refurbishment and not remanufacturing.

Table 5: Pilot answers to remanufacturing question 1

Question	2. Which information do you rely on to assess the opportunity of adopting Remanufacturing?
Pilot answers	
GORENJE B	There was information from Maintenance Department about very bad condition of very old and obsolete equipment and it's not possible to get spare parts.
ZORLUTEKS	Reasons such as not wanting to make new investments, being satisfied with the machine and not being able to reach the spare part, the production made on a particular machine is no longer made (there is no order for the product produced in the machine and it is thought that it will not happen again) are the main reasons for companies to evaluate the opportunities in the implementation of remanufacturing activities.
HWH	There is no reliable information from customer, so HWH is doing their own estimations on the opportunities

Table 6: Pilot answers to remanufacturing question 2

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Question	3. Which valuable materials are you saving by applying the Remanufacturing strategy in your use case for: (a) Quantity per each type of valuable material and (b) Economic value? Please, if possible add additional information.
Pilot answers	
GORENJE B	Worn spare parts like small plastic parts (valves, nozzles, electrodes, ...), enamel powder, energy and ecological savings.
ZORLUTEKS	In the current situation, we do not have to store valuable material in this sense, since we can provide spare parts from manufacturers. If such a requirement arises in the future, it can be considered.
HWH	On average, HWH could reuse about 60% of the components of our machines.

Table 7: Pilot answers to remanufacturing question 3

Question	4. In the past have you ever tried to Remanufacture your electromechanical machinery? (If yes, answer the questions 4.1 - 4.5. If "No", go to question 5)
Pilot answers	
GORENJE B	No
ZORLUTEKS	No
HWH	No

Table 8: Pilot answers to remanufacturing question 4

Question	5. Are you planning to Remanufacture your electromechanical machinery? (If "Yes", answer the questions 5.1 - 5.3)
Pilot answers	
GORENJE B	No
ZORLUTEKS	No. At the moment, we do not have any specific plans regarding remanufacturing for Bleaching 2. Because there is no possible machine element to be discarded. If machine elements such as motor, roller, inverter, will be discarded in the future, we can consider remanufacturing the Bleaching 2 machine.
HWH	*No*

Table 9: Pilot answers to remanufacturing question 5

Question	5.1 In case of positive answer, describe the type of machine, its size (small, medium, large) and the age and condition of the machine.
Pilot answers	
GORENJE B	-

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ZORLUTEKS	-
HWH	-

Table 10: Pilot answers to remanufacturing question 5.1

Question	5.2 In case of positive answer, what is the total cost suggested by original manufacturer for the Remanufacture activity?
Pilot answers	
GORENJE B	-
ZORLUTEKS	-
HWH	-

Table 11: Pilot answers to remanufacturing question 5.2

Question	5.3 In case of positive answer, what is the total time suggested by original manufacturer for the Remanufacture activity?
Pilot answers	
GORENJE B	-
ZORLUTEKS	-
HWH	-

Table 12: Pilot answers to remanufacturing question 5.3

4.2 Refurbishment

4.2.1 Refurbishment Definition

The definition of Refurbishment is taken as input from D4.1.

Refurbishment means restoring an old product and bringing it up to date, in order to maintain reliability or extend service life. In general, refurbished products are upgraded and brought back to specified quality standards or satisfactory working and/or cosmetic conditions and have to fulfil extensive testing. Occasionally, refurbishing is combined with technology upgrading by replacing outdated modules and parts with technologically superior ones.

4.2.2 Refurbishment strategy

The following 2 subsections are meant to present the refurbishment strategy. In the first subsection a distinction is made between when and how is necessary to adopt a refurbishment strategy. In the second section a classification of cost-based Refurbishment decision strategies is presented, considering variables such as labour, maintenance cost and consumable components.

4.2.2.1 Importance of Refurbishment and distinction between when and how to refurbish

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The refurbishment strategy can be of high importance in a number of industrial fields, since equipment or production lines are designed such that they consist of long-living core components and a large number of short-living subcomponents, which allow profitable exchange of sub-components and updating the equipment to almost new state. Nowadays refurbishment strategies gain importance in process of time for several frequent reasons:

- Many expensive and old/used industrial pieces of equipment are constructed with significant life-time reserve of their mechanical parts/components, while development progress of electronics and software technologies are so fast, that equipment gets outdated because of lack of digitalization, modern networking technologies, data communication and storage systems, CO_2 footprint, security, and other standards.
- Also, there is significant progress in construction of mechanical components (e.g. new composite materials or new solutions), sensors (which were not available before), motors (e.g. linear motor or servo motor). Replacement of small amounts of such modern mechanical components can significantly update the functionality of old equipment and thereby justify the Refurbishment.

The life cycle of a production line consists of several evolution phases. It the beginning, one typically starts from a new or nearly new production line. This corresponds to newly bought or refurbished/remanufactured production lines. Then, the phase of active production and usage comes, which ends at some point, and new life of the production line may start after refurbishment/remanufacturing/upgrade etc. (this depends on the profitability of refurbishment in comparison to buying a new production line), as is shown in the figure below. In order to implement continuous circular economy at the end of production lifetime, two main questions should be answered, and corresponding decisions are necessary:

1. When shall one stop Production and perform Refurbishment, i.e., what is the optimal time-point? Obviously, this is the time when production is no longer economically profitable. This decision is made by the decision support framework (DSF) of T4.4 during the end-phase of production.
2. What are the next optimal Refurbishment options, in order to insure long-term economically profitable future production? I.e., how to do Refurbishment?

These questions might be set and answered independently. However, a reasonable manager/planner will ask both of these questions simultaneously, because the end of production life is usually the beginning of new production life in a circular economy. Moreover, these two questions might be even coupled, such that the end of the production line may depend on future decisions on the Refurbishment process. Here we focus on the second question, since the first question is answered by the DSF, as mentioned above.

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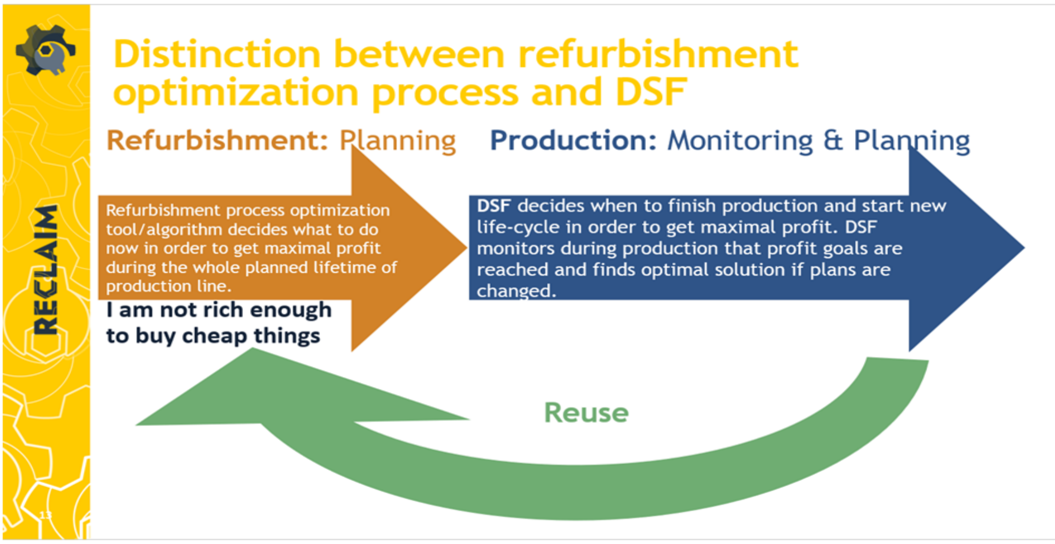

Figure 13: Lifecycle of a production and distinction between decision on when to Refurbish and how to Refurbish.

4.2.2.2 Classification of cost-based Refurbishment decision strategies, costs, and generalised business model

A primary decision motivation in a private company is cost, since the central goal of the company is to gain income by doing a certain work, and thereby contributing to economic growth of a country.

Below we outline a cost-based model for making decisions on refurbishment. Any other factors, which are not directly related to cost, should be projected to the economic plane and expressed in cost units, e.g., in Euros. Examples of such factors are, e.g., implementation of certain state requirements, like CO_2 footprint minimization, dangerous waste reduction, minimal security standard implementation, etc., one of the cost components related to not implementing it (e.g., the fine one gets from the state or other organisation).

In general, we subdivided all Refurbishment use cases into two major categories depending on reasoning/justifying of Refurbishment.

- In the first category of use cases refurbishment is needed because of degradation of a large amount of equipment or production line components, leading to reduction of important production key performance indicators (KPIs).
- In the second category of use cases refurbishment is performed because of outdated equipment technologies, such that current or potential future business models if the usage of the equipment is no more profitable. I.e., it does not meet modern standards.

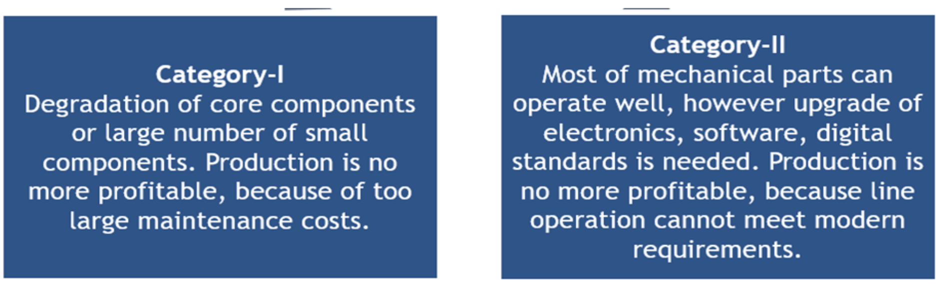

Figure 14: Two major categories of Refurbishment reasoning.

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Of course, there are also use cases which represent combinations of both of these categories. The first category can be further subdivided into two cases:

1. In the first case, Refurbishment is performed when accidentally, during production, equipment (or production line) reaches a point when many sub-components require simultaneous maintenance. In this case, it is worthwhile to evaluate whether deep maintenance which is equivalent to refurbishment is more profitable than regular planned maintenance plan.
2. In the second case, we have a situation when long-living core components significantly degrade, and for that reason “cosmetic” maintenance of short-living subcomponents does not help in effective reduction of maintenance costs and improvement of production efficiency.

Both of these cases of the first category can be considered by maintenance optimization algorithms. In this case, Refurbishment is basically deep maintenance. No consideration of business model details is needed for Refurbishment. In this case, business is performed as usual.

The second category of Refurbishment reasoning is more complex and requires detailed analysis of factors, leading to non-profitable production. I.e., non-profitable business model. In general, business model costs are divided into two major categories:

1. In the first category, we have fixed initial costs. These are costs related to development, modelling, installation, purchasing, etc. of production line components. This is an investment which is performed only once and on average their contribution decreases with time, since it is distributed on a large amount of produced goods on a production line. We denote them as average fixed costs (AFC) in figure below.
2. In the second category, we have average variable costs (AVC), which are related to permanent costs needed during production. These are maintenance and repair costs, salary for employees, costs for raw materials and consumables, etc. Their contribution increases with time, because of increased degradation of the production line and typically increased prices for raw materials and salaries of employees.

The sum of these two cost categories (AFC+AVC) is the average total cost (ATC). One of the basic methodologies of making decisions on Refurbishment time and also on Refurbishment design (as will be clarified later) is finding the optimal (minimal) ATC.

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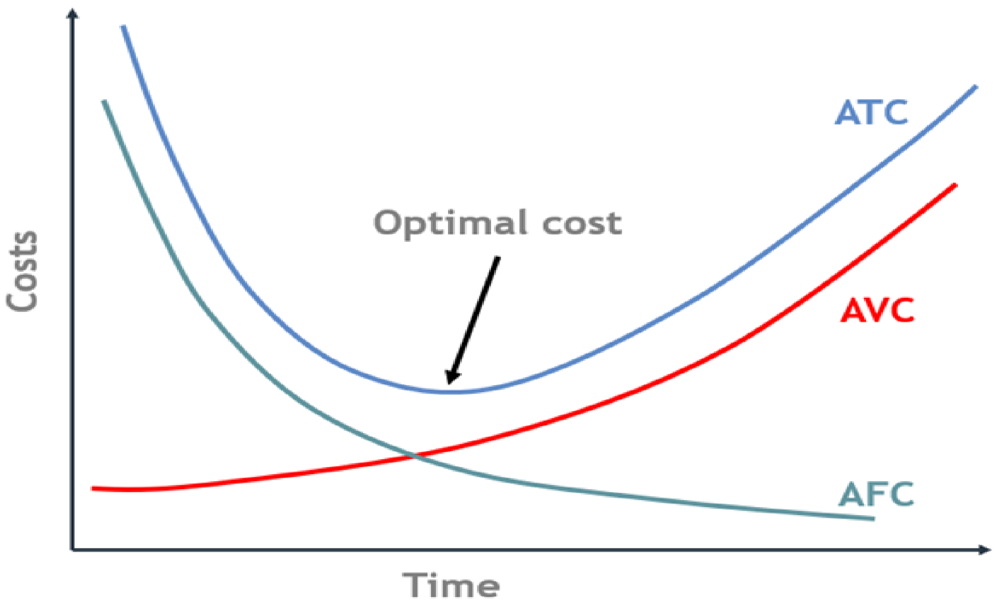

Figure 15: Temporal evolution of average fixed cost (AFC), average variable cost (AVC), and average total cost (ATC = AVC + AFC).

In the Refurbishment decision model, which will be further elaborated in T5.3, we also optionally consider the impact of production income (positive costs), and explicitly subdivide average variable cost into three major cost sub-categories:

1. Consumable components
2. Maintenance
3. Labour work

The generalised business model which optimises all these factors is summarised in the figure below.

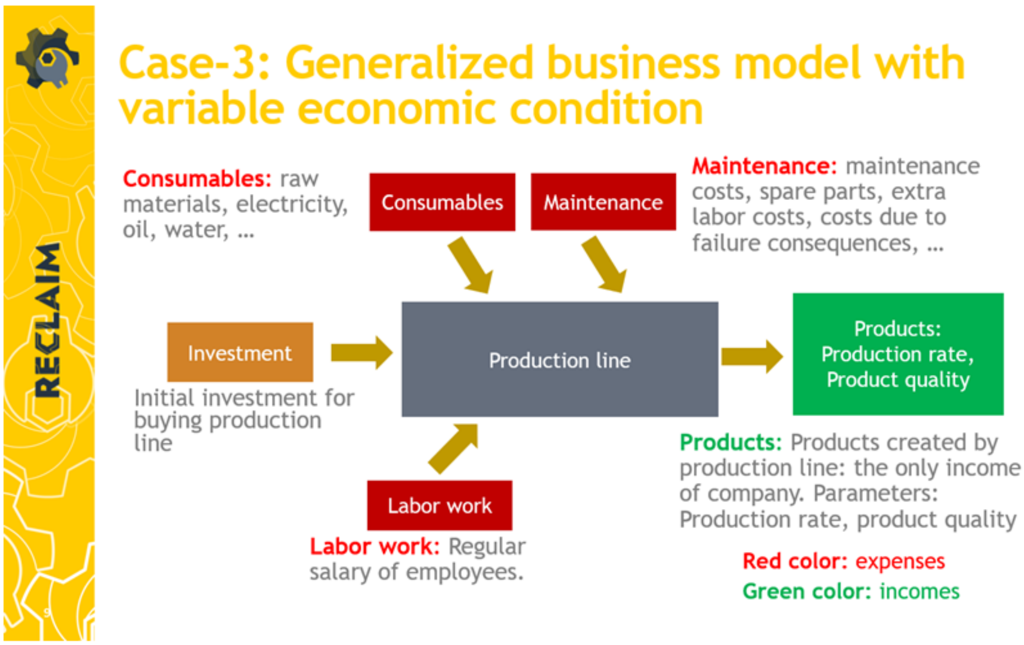

Figure 16: Generalised business model for decision on Refurbishment based on economic criteria

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4.2.3 Industrial scenarios

In the paragraphs below an overview of the Pilots scenarios related to refurbishment is presented.

4.2.3.1 GORENJE Pilot A Refurbishment of Robot Cells

The technology of the stainless-steel tub manufacturing process was purchased in 1993. Some equipment was refurbished and some robots were replaced in 2013 with renewed ones. In general, due to lack of real and historical data, no reliable machine's status is available, control units are obsolete. The condition and the age of the robots, other machines and controllers cause many problems regarding spare parts, so therefore the pilot is planning to continue refurbishing and manufacturing.

It was estimated that the machinery can still produce good products, but in addition to robots, welding processes and other supporting equipment such as punching, bending, double bending need to be restored. With the refurbishment within the RECLAIM project the pilot will be able to meet future requirements according to the Industry 4.0 initiative. The RECLAIM partners' technologies with advanced sensorial network, as well as integrated prognostic and health assessment and maintenance methodologies, will raise old equipment to a higher level of modernization.

To summarize, before the project the pilot needed to:

- renew and upgrade old robots,
- renew and upgrade the spot and seam welding system,
- renew and upgrade other machines (punching, bending, double bending, hydraulic system, IR ovens, etc.),
- reconstruct of the cooling water system,
- perform PLC upgrade with new interface and communication standard (Profinet).

4.2.3.2 GORENJE Pilot B Refurbishment of White Enamelling Line

As presented in section 4.1.3.1, the refurbishment within the context of the RECLAIM project and RECLAIM partners' technologies with advanced sensorial network, higher level of modernization of the pilot's equipment could be implemented.

Actual technology is 1-side spraying of powder enamel (one piece is hanging on the hook). With the upgrading of actual line to 2 pieces (cooktops) per hook, big increase of efficiency of the enamelling line is expected.

Generally, it was needed to:

- renew and update very old parts of furnace (isolation, burners and burner tubes, PLC control system),
- renew and update old parts of the spraying cabin (spraying guns, reciprocator, PLC control unit),
- equip the whole enamelling line with temperature and humidity sensors to have on-line data about these important parameters for the enamelling process. These data will be stored for future comparison in case of technological problems with quality of enamelling process,

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- implement new sensors with sensorial network, visual cameras for recognizing of different types of cooktops, output registration board (touchscreen) and connected SW.

4.2.3.3 FLUCHOS Refurbishment of Shoes production line

Fluchos is a family business created in the early 1960s which manufactures shoes for women and men. It is in Arnedo, La Rioja, in a very important footwear region from Spain. They were pioneers with the latest technical advances, but also, they wanted to maintain the artisan character which is their quality seal. Nowadays, their annual production is over the 2 million of pairs, and half of them are exported. Their factory is organized in 5 different plants, where they fit, cut, form, set up and finish. In every section, there are a lot of machines with very different parameters that should be controlled.

The main objective in the Fluchos company is to reduce the number of incidents and accidents due to failures, errors and other causes that could be predicted. Also, they want to reduce the death times between breakage and maintenance, with the aim of increasing their productivity.

In this project, some of these parameters will be monitored, for designing a predictive and proactive system of maintenance that would help to increase the production, reduce the failures, and be more respectful with the environment. All these things can be achieved without losing quality and keeping their artisan character.

4.2.3.4 HWH Refurbishment of Friction Welding Machine

The HWH pilot represents a friction welding machine, which was used for a long period by the LUFTHANSA company. The friction welding machine is used for joining various, typically cylindrically symmetric, metallic pieces. It has number of merits in comparison to other joining techniques, such as electric spot welding, or cold welding:

1. It can join broader combinations of metallic materials, which have significantly different electrical and thermal conducting characteristics. E.g. silver or copper, which have very high conductivity.
2. Its joining quality is stronger and is more reproducible for specific complex material combinations.

Despite of numerous advantages of the friction welding methodology, this pilot requires deep refurbishment, primarily not because of its degradation, but mostly because of need of its technological upgrade to newest state. Competition in this field is high and the pilot needs permanent improvement of its equipment in order to cope with new welding applications and competitive prices. Below we list typical customer requirements which are expected from the pilot's friction welding machine:

1. Update of number of sensors in the friction welding machine: Sensors which are installed in the machine should allow properly and fully to evaluate all important welding parameters in the current machine. There should not be limitations because of number of available ADC channels, etc.
2. These sensors should be digitalized, in order to be capable of transferring and using sensor information over network computing systems.

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3. Modern networking Bus-System capabilities, which implements standard industrial protocols in order to be able to communicate with surrounding equipment. This implies also implementation of widely used protocols, like TCP/IP, OPC UA, MQTT, HTTP/REST, CAN-bus, etc.
4. Capability of storing of large amount of sensorial information into databases is one of the most important requirements. It is needed for various purposes:
    a. documenting each welding,
    b. re-evaluation of each welding independent of the pilot's e.g. quality control system,
    c. third-party machine learning and artificial intelligence systems - big data analysis,
    d. number of other specialized algorithms, which might be beyond standard use cases.
5. Modern quality evaluation system is also frequent requirement. The pilot should provide reasonable quality evaluation, in order to document and automatize welding production. Automatic quality control is also important for early production failure detection.
6. Convenient user interface (UI) for various user-roles (like operator, manager, administrator, etc.) or at least capability of providing such interface.
7. Modern trend is to have remote access for UI with web-based technology in order to have UI on various operating system platforms and pieces of equipment (like computers, tablets, smartphones, or in future perspective in augmented reality glasses).
8. A management system is one of the frequent requirements of customers. In order to automatize production and reduce human involvement, various routine operations can be automatically performed.
9. A self-diagnosis system is useful for detection of reasons of production stops or problems on equipment/production line.
10. All points listed above require corresponding increased CPU and electronics performance.
11. Last, but not least, important is high configuration flexibility of the pilot's products, in order to provide to its customers optimized system with minimal number of additional LICENSES for using various technologies.

HWH is original equipment manufacturer, i.e. HWH produces equipment which is used for production in other companies. For that reason, HWH has to look in future and constructs equipment which should be operated for long time period in future. However, due to rapid technological development, HWH periodically needs to upgrade/Refurbish used equipment of our customers due to:

1. Degradation of some of the mechanical components
2. Need to upgrade electronics hardware or software to modern state

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Obviously, in order to have profitable Refurbishment scenario, Refurbishment operations should cost less than production of new equipment. This is only possible if there are at least some of the core components, which have long lifetime, and only some of the mechanical, electronic, and software components need to be replaced/updated.

4.2.3.5 PODIUM Refurbishment of Woodworking Machinery

PODIUM has a specialization in the creation of design kitchens, with attention to the uniqueness of the product and the quality of natural raw materials. The company, in line with the latest market trends, is specialized in offering solutions aimed at the philosophy of "essential living", then furniture for small apartments, up to larger sizes. Furthermore, the company provides all need services such as: installation, test, maintenance and production of spare parts.

The market has a volume of about 500 pieces of furniture equivalent to about 45 kitchens per week, to which the rest of the furniture range, consisting of wardrobes, bathroom furniture and complete furnishings, must be added. The market is divided by 50% for furniture for the German-speaking part of Switzerland, 35% for furniture for the French-speaking part of Switzerland and the remaining 15% for furniture for the Italian-speaking part of Switzerland.

Looking to the future, PODIUM has increased its revenues investing regularly in technology, automation and innovation, and the business outlook is positive in line with the growth of recent years.

4.2.3.6 ZORLUTEKS Refurbishment of Bleaching Machine

As presented in section 4.1.3.1, when taking into consideration Zorluteks' focus in RECLAIM project is the bleaching machine with the objective of extending its useful life time.

4.2.3.7 Issues affecting the choice

The answers to the questions of the questionnaire regarding refurbishment strategies of each involved pilot is given below:

Question	1. Which elements push a company to invest in Refurbishment?
Pilot answers	
GORENJE A	The condition and the age of the robots, other machines and controllers cause many problems regarding spare parts, so we are planning to continue refurbishing and manufacturing.
GORENJE B	The most important reason was lack of spare parts and danger of stopping of the line and whole production for longer time.
FLUCHOS	Save time and reduce defects.
HWH	Main motivation of investing now in Refurbishment of used equipment in a private company is future economic profit. This economic profit on the other

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	hand has multiple dimensions and depends on production use cases. However, for typical anticipated use cases, the following criteria are in focus of HWH: • Lower/competitive price of refurbished equipment, • Higher reliability and consequently smaller costs for warranty service, • High quality of produced products • Upgrade of used product beyond the original specifications • All this finally leads to increased profitability of our equipment
PODIUM	Respect of environment, characteristics of the current machine (it was developed specially for our company, based on our needs), economical aspects
ZORLUTEKS	Reasons such as the development of technology, the desired increase in productivity, keeping the machines up to date, and sustainability can be considered as the driving force for a company to implement refurbishment strategies.

Table 13: Pilot answers to refurbishment question 1

Question	2. Which information do you rely on to assess the opportunity of adopting a Refurbishment strategy?
Pilot answers	
GORENJE A	There was information from Maintenance Department about very bad condition of very old and obsolete equipment and it's not possible to get spare parts.
GORENJE B	There was information from Maintenance Department about very bad condition of very old and obsolete equipment and it's not possible to get spare parts.
FLUCHOS	The lifetime of the machinery increases.
HWH	One of the important components of production costs is maintenance cost, which in turn depends on such characteristics: mean time between failures, mean time to repair and overall efficiency. All these machine characteristics when a large number of machine components approach end of the Useful life, causing increased maintenance costs.
PODIUM	Generally, if the revamping costs are less than the 40%/50% of a new machine, the probability of revamping success is very high. Anyway, we are doing a specific analysis of costs and about environmental aspects with SUPSI and SCM.
ZORLUTEKS	Existence of worn out parts in the machine affects the costs and product quality. It is very important for a company to keep the machines up to date, also considering the changing product range, at the point where we think that the needs are not fulfilled.

Table 14: Pilot answers to refurbishment question 2

Question	3. Which valuable materials are you saving by applying the Refurbishment strategy in your use case for: (a) Quantity per each type of valuable material and (b) Economic value? Please, if possible add additional useful information.

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Pilot answers	
GORENJE A	More efficient production process with fewer stops due to failures of old machinery, consequently less scrap and waste.
GORENJE B	Wear spare parts like small plastic parts (valves, nozzles, electrodes, ...), enamel powder, energy and ecological savings.
FLUCHOS	We do not know yet.
HWH	HWH may use brushless/servo motors which may contain valuable rear earth components and they can be recycled together with complete motor. The rest of materials are typically made of iron, aluminium, and copper, which are recycled by standard recycling methods. Electronic boards are also recycled separately.
PODIUM	These results will be available when the analysis of SUPSI is finished.
ZORLUTEKS	Currently, we do not have such material saving; when necessary, valuable machinery equipment is researched and evaluated in the relevant machine, taking into account the necessary features for refurbishment.

Table 15: Pilot answers to refurbishment question 3

Question	4. In the past have you ever tried to Refurbish your electromechanical machinery? (If "Yes", answer the questions 4.1 - 4.5. If "No", go to question 5)
Pilot answers	
GORENJE A	No
GORENJE B	No
FLUCHOS	No
HWH	Yes
PODIUM	No
ZORLUTEKS	Yes

Table 16: Pilot answers to refurbishment question 4

Question	4.1 In case of positive answer, describe the type of machine, its size (small, medium, large) and the age and condition of the machine.
Pilot answers	
GORENJE A	-
GORENJE B	-
FLUCHOS	-
HWH	HWH has long history of performing Refurbishment of old/used equipment when it is requested/needed by our customers. However, this is not primary business model of HWH.

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PODIUM	-
ZORLUTEKS	Large, over 15 years old and in operation.

Table 17: Pilot answers to refurbishment question 4.1

Question	4.2 In case of a positive answer, which kind of service has been performed by original manufacturer or third party?
Pilot answers	
GORENJE A	-
GORENJE B	-
FLUCHOS	-
HWH	-
PODIUM	-
ZORLUTEKS	Various remanufacturing processes have been carried out for machines with various functions in our production line until now. For example, PLC system was included in the machines, old type motors were replaced with inverter motors, sensors and flowmeters were integrated in some parts of the machines.

Table 18: Pilot answers to refurbishment question 4.2

Question	4.3 In case of a positive answer, which kind of after sales service has been performed by original manufacturer or third party?
Pilot answers	
GORENJE A	-
GORENJE B	-
FLUCHOS	-
HWH	HWH is OEM/supplier. HWH provides service and warranty to new and refurbishment equipment depending on contract with its customers.
PODIUM	-
ZORLUTEKS	After-sales support was received by a third party for the conversion of steam-powered machines to gas.

Table 19: Pilot answers to refurbishment question 4.3

Question	4.4 In case of positive answer, what was the total cost of the Refurbishment activity?
Pilot answers	
GORENJE A	-

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GORENJE B	-
FLUCHOS	-
HWH	-
PODIUM	-
ZORLUTEKS	Our company invests in almost 2 million € in a year for refurbishment activities.

Table 20: Pilot answers to refurbishment question 4.4

Question	4.5 In case of positive answer, what was the total time the Refurbishment activity lasted?
Pilot answers	
GORENJE A	-
GORENJE B	-
FLUCHOS	-
HWH	-
PODIUM	-
ZORLUTEKS	The time required for refurbishment varies according to the activity. For example, adding a PLC to the machines takes 1 month, while the renewal of the motors takes about 15 days.

Table 21: Pilot answers to refurbishment question 4.5

Question	5. Are you planning to Refurbish your electromechanical machinery? (If "Yes", answer the questions 5.1 - 5.4)
Pilot answers	
GORENJE A	Yes
GORENJE B	Yes
FLUCHOS	Yes
HWH	Yes
PODIUM	Yes
ZORLUTEKS	Yes

Table 22: Pilot answers to refurbishment question 5

Question	5.1 In case of positive answer, describe the type of machine, its size (small, medium, large) and the age and condition of the machine.

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Pilot answers	
GORENJE A	The existing equipment includes robotic cells with small upgrades that have been installed in the factory since 1993. Although Gorenje has replaced five robots with renewed in 2013, a B-cell disc-welding station has been restored and in A-cell one press has been renovated, many robotic systems need refurbishment because they reach the end of their life and have a large number of failures in their operation, unexpected stoppages and delays in the production line. In general it's medium to large type of machines, all together 15 robots, spot and seam welding machines, punching and bending machines, IR ovens, with all periphery, etc.
GORENJE B	Furnace for firing of enameled parts (830°C) - large machine of age of 22 years, at the end of its life. Application cabin for powder enamel - large machine of age of 22 years, at the end of its life.
FLUCHOS	Mechanical machine, medium-size and about 15-20 years old
HWH	
PODIUM	It is a drilling machine of small size, bought in 2005. Currently, it works well but it is not updated and upgraded anymore, it does not have the last innovation of operations. Moreover, it is not possible to connect this machine to a management software of the company and it is a huge limit for us.
ZORLUTEKS	As you know, we selected a large, 1996 model, in operation Küsters bleaching machine for the RECLAIM project and its activities.

Table 23: Pilot answers to refurbishment question 5.1

Question	5.2 In case of a positive answer, describe the machinery part(s) that will be Refurbished.
Pilot answers	
GORENJE A	In order to improve the process and operational data system we plan to upgrade control units for all robot cells.
GORENJE B	Furnace: • Gas burners - old burners with low efficiency cannot reach the combustion limits for NO_x and CO_x - must be upgraded by new ones. • Burner tubes (inside these tubes burners are placed) - tubes are damaged with corrosion, and with many repaired holes - must be upgraded by new ones. • Isolation and inside lining of furnace - after 22 years lost its features - must be upgraded by new ones. • Control unit - very old, there are not spare parts for repairs - must be upgraded by new one. Application cabin: • Spraying guns - old and worn out, there are not spare parts for repairs - must be upgraded by new one. • Reciprocator - old and worn out, there are not spare parts for repairs - must be upgraded by new one. • Control unit - very old, there are not spare parts for repairs - must be upgraded by new one.

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FLUCHOS	Membrane in Talonadora.
HWH	
PODIUM	We will introduce a new mechanical guide to automatically insert an equipment that until the start of the project was inserted manually by the operator.
ZORLUTEKS	In scope of the RECLAIM, the most important things for Zorluteks are standardization of the bleaching process and reduction of very frequent machine failures. In this direction we mounted whiteness measuring sensors and an industrial camera at the exit of the machine. Besides that, we are adding vibration sensors to some of the selected components (motors and bearings) of the machine. Also, a device for data extraction from machine's PLC and chemical sensors will be mounted at the machine.

Table 24: Pilot answers to refurbishment question 5.2

Question	5.3 In case of positive answer, what is the total cost that original manufacturer or third party suggested for the Refurbishment activity?
Pilot answers	
GORENJE A	Approximately 700.000 EUR evaluated.
GORENJE B	Furnace: 684 000 €, Application cabin: 195 000 €
FLUCHOS	We do not know yet.
HWH	
PODIUM	About 105 000 CHF.
ZORLUTEKS	We worked with a third party for the Shade Bar Whiteness Measuring Sensors and Global Shutter Industrial Camera. Total cost for those equipment is 29.000 €. We also worked with another third party for the vibration sensors and the total cost for these sensors is 10.000 $. For PLC data extraction device and chemical sensors, we are working with our technology partners within RECLAIM.

Table 25: Pilot answers to refurbishment question 5.3

Question	5.4 In case of positive answer, what is the total time suggested by original manufacturer or third party for the Refurbishment activity?
Pilot answers	
GORENJE A	Approximately 2-3 years.
GORENJE B	Furnace: 5 weeks, Application cabin: 5 weeks
FLUCHOS	We do not know yet.
HWH	

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PODIUM	If we only consider the implementation of the new mechanical component, one week of work (5 days).
ZORLUTEKS	Implementation of Shade Bar Whiteness Measuring Sensors and Global Shutter Industrial Camera took 1 day each. Data recording studies has been going on for Shade Bar for 6 months and data recording studies for industrial camera took about 1 month. We didn't receive an information about how much time is needed for chemical sensors and PLC device implementation to the machine.

Table 26: Pilot answers to refurbishment question 5.4

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5 External scenario

The aim of the following section is to pay attention to the external scenario, besides the companies involved in the project, to try to understand how much refurbishment and remanufacturing techniques are used and to tackle the issues of valuable materials and sales and after sales function.

In the first part of the following chapter, the questionnaire with its main feature is presented. The questionnaire was spread in the network of the partners participating in the RECLAIM project.

The second paragraph presents the main results of the questionnaire posing attention on the intention of companies to use in the future both remanufacturing and refurbishment techniques. On the contrary, if the company is already using those techniques, the focus is shifted on the main advantages and main characteristics of the two CE techniques.

5.1 Questionnaire framework and results

It has been chosen to develop a questionnaire, since it is one of the instruments that provides the highest amount of information that could be subsequently used for statistical purposes. The questionnaire is in fact a social research tool consisting of a rigidly formalised and standardised questionnaire grid, applicable to any object of investigation or social phenomenon to be analysed. It is a data collection tool that allows obtaining information of a purely quantitative nature, which can be analysed from a statistical point of view and easily generalised.

The logic underlying this research tool is that of measurement: by administering a questionnaire to a statistically significant sample, it is believed to be able to measure, in an objective and impersonal way, the demographic composition, opinions, attitudes, tastes, behaviours, etc.

The questionnaire has been developed using Google Forms and is composed of 18 sections. The collected data are completely anonymous and collected complying with European General Data Protection Regulation (GDPR). Data will not be used for commercial purposes and will only be available in aggregate form. Please note that we do not consider this questionnaire and its results representative for the entire sector considering that the outcome of the survey cannot be considered as a database – answers have been provided by companies/network of the project partners. There are no correct or wrong answers, we only ask respondents to help us understand what the main corporate remanufacturing strategies are.

In section 1 (of the questionnaire), a general introduction of RECLAIM projects is provided. In addition, information on data protection is provided. Furthermore, a checkbox is included that if checked personal data of the participant (name and surname, name of organisation, email and website) can be used and published if provided.

Section 2 simply asks whether the company has already used remanufacturing techniques. It also provides the shared consortium definition of what is meant for remanufacturing. In case the answer is positive, the respondents will be redirected to the subsequent module, otherwise they will be redirected to Table 36: Rlement is necessary in order to adopt a Refurbishment strategy

Section 14 (No Remanufacturing).

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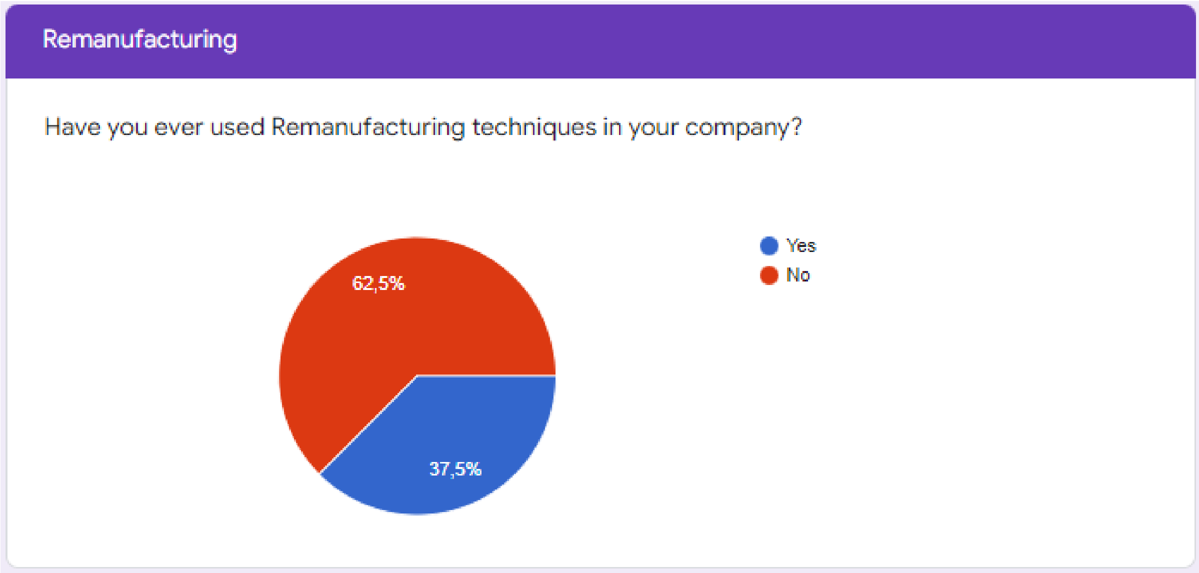

Figure 17 - have you ever used remanufacturing techniques?

In section 3, the aim is to capture the satisfaction of the company using a remanufacturing strategy. The section is composed of 3 similar questions with the aim of checking the consistency of results. In all the questions the respondents are asked to evaluate the sentence on a scale from 1 to 7 in which 1 means "strongly disagree" and 7 "strongly agree".

How much do you agree with the following observations?	The choice to use Remanufacturing has been wise	• 33,3% voted 5 • 66,7% voted 6
	I think that I have done the right choice when I decided to approach Remanufacturing	• 66,7% voted 5 • 33,3% voted 6
	Remanufacturing is exactly what I was looking for	• 66,7% voted 5 • 33,3% voted 6

Table 27: Satisfaction of the company using a remanufacturing

Section 4 is focused on evaluating the company perceived quality of the remanufactured product. As in the previous section, there are 3 similar questions that are necessary in order to assess results consistency. In all the questions respondents are asked to evaluate the sentence on a scale from 1 to 7 in which 1 means "strongly disagree" and 7 "strongly agree".

	I think that the overall quality of Remanufacturing products is low	• 33,3% voted 2 • 33,3% voted 3 • 33,3% voted 5

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How much do you agree with the following observations?	Overall I consider the Remanufacturing products excellent	• 33,3% voted 2 • 33,3% voted 5 • 33,3% voted 6
	Quality of Remanufacturing products is on average	• 33,3% voted 4 • 66,7% voted 5

Table 28: Company evaluation on quality of the remanufactured

Section 5 presents a list of KPIs that could be used to access the opportunity to start applying a remanufacturing strategy. The KPIs are: maintenance costs, overall efficiency, technical upgrading, machine useful life, mean time to repair the machine, mean time between failures and product quality. In case there are other KPIs used, respondents are given the possibility to add them in the last part. In all cases it is asked to evaluate the KPI on a scale from 1 to 7 in which 1 means “strongly disagree” and 7 “strongly agree”.

Which information do you rely on to assess the opportunity of adopting Remanufacturing?	Maintenance costs	• 33,3% voted 5 • 33,3% voted 6 • 33,3% voted 7
	Overall efficiency	• 66,7% voted 5 • 33,3% voted 6
	Technical upgrading	• 100% voted 6
	Machine useful life	• 33,3% voted 6 • 66,7% voted 7
	Mean time between failures	• 33,3% voted 3 • 66,7% voted 6
	Mean time to repair the machine	• 33,3% voted 5 • 66,7% voted 6
	Product quality	• 100% voted 6

Table 29: KPIs

Section 6 presents a list of reasons that the company could have to invest in remanufacturing. The reasons are: offer more competitive price, embodied value retained, significantly lower input cost, assured warranty, multiple product life cycle, improved profitability, upgrade of the used product beyond the original specification, life expectancy as good as new and high-quality products. Also in this case the possibility at the end of the

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section to add other reasons is given. In all cases, it is asked to evaluate the reason on a scale from 1 to 7 in which 1 means “strongly disagree” and 7 “strongly agree”.

Which of the following characteristics push a company to invest in Remanufacturing?	Offer more competitive price	• 33,3% voted 5 • 66,7% voted 6
	Embodied value retained	• 100% voted 4
	Significantly lower input cost	• 33,3% voted 4 • 33,3% voted 5 • 33,3% voted 6
	Multiple product life cycle	• 33,3% voted 4 • 33,3% voted 5 • 33,3% voted 6
	Assured warranty	• 66,7% voted 4 • 33,3% voted 6
	Improve profitability	• 100% voted 6
	Upgrade of the used product beyond the original Specification	• 100% voted 6
	Life expectancy as good as new	• 100% voted 6
	High quality products	• 33,3% voted 5 • 66,7% voted 6

Table 30: Reasons for remanufacturing

Section 7 is the last section for companies using a Remanufacturing strategy. The goal of this part is to assess which element is necessary in order to adopt a Remanufacturing strategy on the product; the possible elements provided are timely disposal of the product that needs to be Remanufactured, product design for disassembling, additional value added from new material and availability of technical upgradation. As in the previous two sections, also in this one the possibility to add more elements is given. In all the cases it is asked to evaluate the element on a scale from 1 to 7 in which 1 means “strongly disagree” and 7 “strongly agree”.

	Product design for disassembling	• 33,3% voted 1 • 66,7% voted 5

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Which of the following characteristics are necessary in order to adopt a Remanufacturing strategy on the product:	Timely disposal of the product that need to be Refurbished	• 33,3% voted 2 • 33,3% voted 4 • 33,3% voted 6
	Additional value added from new material	• 33,3% voted 4 • 66,7% voted 5
	Availability of technical upgradation	• 66,7% voted 5 • 33,3% voted 7

Table 31: Remanufacturing strategis

Section 8 is the section with which the part related to the Refurbishment strategy begins. The structure will be the same as in the Remanufacturing strategy, so in section 8 the shared consortium definition of Refurbishment is presented, and it is simply asked whether the company has already used a refurbishment strategy. In case the answer is positive, the respondents are redirected to the subsequent module, otherwise they are redirected to section 16 (No Refurbishment).

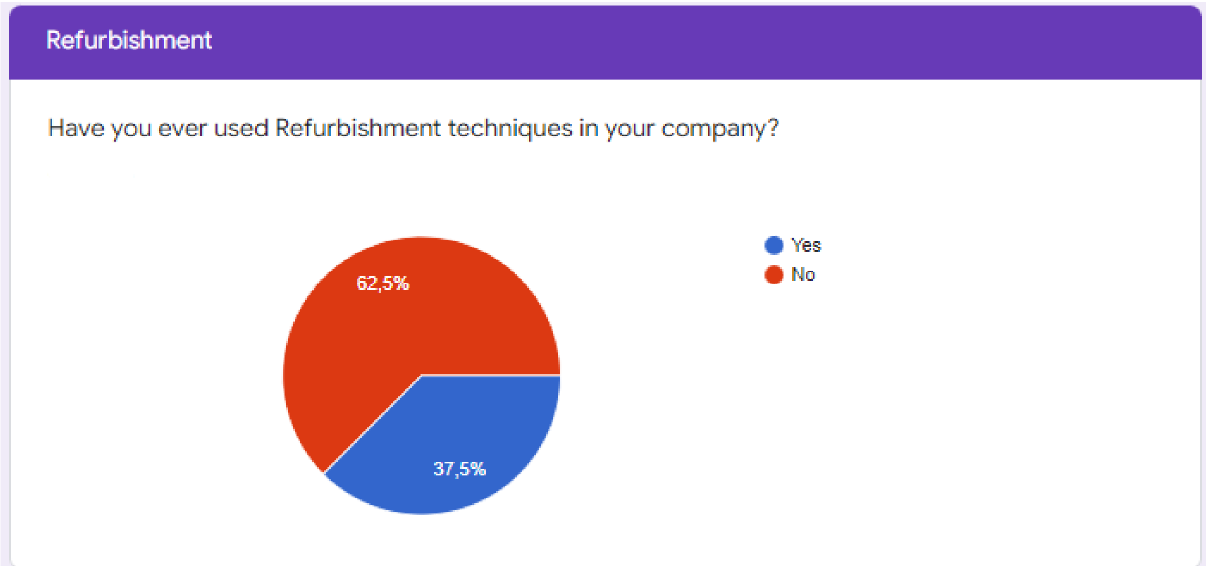

Figure 18 - Refurbishment

Section 9 tries to identify company satisfaction in using a refurbishment strategy. As for remanufacturing, corresponding section respondents find 3 similar questions and they answer using a Likert scale in which 1 stands for “strongly disagree” and 7 “strongly agree”.

	The choice to use Refurbishment has been wisdom	• 33,3% voted 5 • 33,3% voted 6 • 33,3% voted 7

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How much do you agree with the following observations?	I think that I have done the right choice when I decided to approach Refurbishment	• 33,3% voted 4 • 33,3% voted 6 • 33,3% voted 7
	Refurbishment is exactly what I was looking for	• 33,3% voted 5 • 66,7% voted 6

Table 32: Company satisfaction using a refurbishment strategy

Section 10, as well as section 4 for the remanufacturing, is focused on evaluating the company perceived quality of the refurbished product. As in the previous section, there are 3 similar questions that are necessary in order to assess results consistency. In all the questions respondents are asked to evaluate the sentence on a scale from 1 to 7 in which 1 means “strongly disagree” and 7 “strongly agree”.

How much do you agree with the following observations?	I think that the overall quality of Refurbishment products is low	• 66,7% voted 2 • 33,3% voted 5
	Overall I consider the Refurbishment products excellent	• 33,3% voted 4 • 66,7% voted 6
	Quality of Refurbishment products is on average	• 33,3% voted 4 • 66,7% voted 5

Table 33: Company evaluation

Section 11 presents a list of KPIs that could be used to assess the opportunity to start applying a refurbishing strategy. The KPIs are the same as remanufacturing (Section 5), in this way it is possible to compare them with the ones which are most important for the remanufacturing. In all cases, it is asked to evaluate the KPI on a scale from 1 to 7 in which 1 means “strongly disagree” and 7 “strongly agree”.

	Maintenance costs	• 33,3% voted 4 • 33,3% voted 6 • 33,3% voted 7
	Overall efficiency	• 33,3% voted 5 • 66,7% voted 6
	Technical upgrading	• 33,3% voted 5 • 33,3% voted 6

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Which information do you rely on to assess the opportunity of adopting Refurbishment?		• 33,3% voted 7
	Machine useful life	• 100% voted 6
	Mean time between failures	• 33,3% voted 6 • 66,7% voted 7
	Mean time to repair the machine	• 33,3% voted 6 • 66,7% voted 7
	Product quality	• 100% voted 6

Table 34: KPIs

Section 12 presents a list of reasons that the company investing in refurbishment could have. Also in this case, the reasons are the same as for remanufacturing (section 6) in order to be able to do a comparison between the two strategies. In all the cases it is asked to evaluate the reasons on a scale from 1 to 7 in which 1 means "strongly disagree" and 7 "strongly agree".

Which of the following characteristics push a company to invest in Refurbishment?	Offer more competitive price	• 33,3% voted 5 • 33,3% voted 6 • 33,3% voted 7
	Embodied value retained	• 33,3% voted 4 • 66,7% voted 6
	Significantly lower input cost	• 33,3% voted 2 • 33,3% voted 6 • 33,3% voted 7
	Multiple product life cycle	• 66,7% voted 4 • 33,3% voted 6
	Assured warranty	• 33,3% voted 4 • 33,3% voted 5 • 33,3% voted 6
	Improve profitability	• 66,7% voted 6

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		• 33,3% voted 7
	Upgrade of the used product beyond the original Specification	• 66,7% voted 6 • 33,3% voted 7
	Life expectancy as good as new	• 33,3% voted 5 • 66,7% voted 6
	High quality products	• 33,3% voted 5 • 66,7% voted 6

Table 35: Reasons for investing in refurbishment

Section 13 is the last section for companies using a Refurbishment strategy. The goal of this part is to assess which element is necessary in order to adopt a Refurbishment strategy on the product. Also in this case, the reasons are the same as for Remanufacturing (section 7) in order to be able to do a comparison between the two strategies. In all the cases it is asked to evaluate the reasons on a scale from 1 to 7 in which 1 means “strongly disagree” and 7 “strongly agree”.

Which of the following characteristics are necessary in order to adopt a Refurbishment strategy on the product:	Product design for disassembling	• 33,3% voted 2 • 33,3% voted 4 • 33,3% voted 5
	Timely disposal of the product that needs to be Refurbished	• 33,3% voted 2 • 66,7% voted 5
	Additional value added from new material	• 33,3% voted 3 • 33,3% voted 4 • 33,3% voted 6
	Availability of technical upgradation	• 33,3% voted 3 • 66,7% voted 6

Table 36: Rlement is necessary in order to adopt a Refurbishment strategy

Section 14 is the part of the questionnaire to which respondents that do not use a remanufacturing strategy are redirected, otherwise this and the following section are skipped. In this section, the aim is to evaluate the intention to use in the future a remanufacturing strategy. The section is composed of 3 similar questions in order to assess results consistency. Respondents answered on the base of a Likert scale in which 1 means “strongly disagree” and 7 “strongly agree”.

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NO Remanufacturing. How much do you agree with the following observations?	I want to use Remanufacturing techniques in near future	• 40% voted 1 • 20% voted 5 • 20% voted 6 • 20% voted 7
	If I get any chance, I will use Remanufacturing techniques in the manufacturing process	• 40% voted 1 • 20% voted 6 • 40% voted 7
	If I get any chance, I predict that I shall use Remanufacturing techniques in the near future	• 40% voted 1 • 20% voted 6 • 40% voted 7

Table 37: Opinions when no remanufacturing strategies are apllied

Section 15 is the second question for companies that are not already using a remanufacturing strategy. In this case, it has been chosen to propose again the question regarding the elements that push a company to invest in remanufacturing. In this way, it can be possible to compare the situation with Section 6. Section 6 could be seen as the past, while 15 showed the actual trends.

Which of the following characteristics push a company to invest in Remanufacturing?	Offer more competitive price	• 20% voted 1 • 60% voted 4 • 20% voted 7
	Embodied value retained	• 20% voted 1 • 20% voted 4 • 20% voted 5 • 20% voted 6 • 20% voted 7
	Significantly lower input cost	• 20% voted 1 • 20% voted 4 • 40% voted 5 • 20% voted 7

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	Multiple product life cycle	• 20% voted 1 • 20% voted 5 • 40% voted 6 • 20% voted 7
	Assured warranty	• 20% voted 1 • 20% voted 2 • 40% voted 3 • 20% voted 7
	Improve profitability	• 20% voted 1 • 40% voted 5 • 20% voted 6 • 20% voted 7
	Upgrade of the used product beyond the original Specification	• 20% voted 1 • 20% voted 3 • 20% voted 5 • 40% voted 6
	Life expectancy as good as new	• 20% voted 1 • 20% voted 4 • 40% voted 5 • 20% voted 7
	High quality products	• 20% voted 1 • 20% voted 2 • 40% voted 5 • 20% voted 6

Table 38: No remanufacturing - elements that push a company to invest in remanufacturing

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Section 16 is the part of the questionnaire to which respondents that do not use a refurbishment strategy are redirected, otherwise this and the following section are skipped. In this section, the aim is to evaluate the intention to use in the future a refurbishment strategy. The section is composed of 3 similar questions in order to assess results consistency. Respondents answered on the basis of a Likert scale in which 1 means “strongly disagree” and 7 “strongly agree”.

NO Refurbishment. How much do you agree with the following observations?	I want to use Refurbishment techniques in the near future	• 20% voted 1 • 20% voted 2 • 20% voted 5 • 20% voted 6 • 20% voted 7
	If I get any chance, I will use Refurbishment techniques in the manufacturing process	• 20% voted 1 • 20% voted 2 • 20% voted 5 • 40% voted 7
	If I get any chance, I predict that I shall use Refurbishment techniques in the near future	• 20% voted 1 • 20% voted 2 • 20% voted 5 • 40% voted 7

Table 39: Intention to use in the future a refurbishment strategy

Section 17 is the second question for companies that are not already using a refurbishment strategy. In this case, it has been chosen to propose again the question regarding the elements that push a company to invest in refurbishment. In this way, it can be possible to compare the situation with Section 12. Section 12 could be seen as the past, while 17 showed the actual trends.

	Offer more competitive price	• 20% voted 1 • 20% voted 4 • 20% voted 5 • 20% voted 6 • 20% voted 7
	Embodied value retained	• 20% voted 1

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Which of the following characteristics push a company to invest in Refurbishment?		• 40% voted 5 • 20% voted 6 • 20% voted 7
	Significantly lower input cost	• 20% voted 1 • 40% voted 5 • 20% voted 6 • 20% voted 7
	Multiple product life cycle	• 20% voted 1 • 20% voted 3 • 40% voted 6 • 20% voted 7
	Assured warranty	• 20% voted 1 • 40% voted 3 • 20% voted 4 • 20% voted 6
	Improve profitability	• 20% voted 1 • 60% voted 5 • 20% voted 7
	Upgrade of the used product beyond the original Specification	• 20% voted 1 • 20% voted 4 • 20% voted 5 • 40% voted 6
	Life expectancy as good as new	• 20% voted 1 • 20% voted 3 • 40% voted 5 • 20% voted 6

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	High quality products	• 20% voted 1 • 40% voted 4 • 20% voted 5 • 20% voted 6

Table 40: Characteristics push a company to invest in Refurbishment

In the last section some general information is asked, such as company name, company sector, for how long they have been applying remanufacturing/refurbishment strategies and if they are producers of electromechanical machinery.

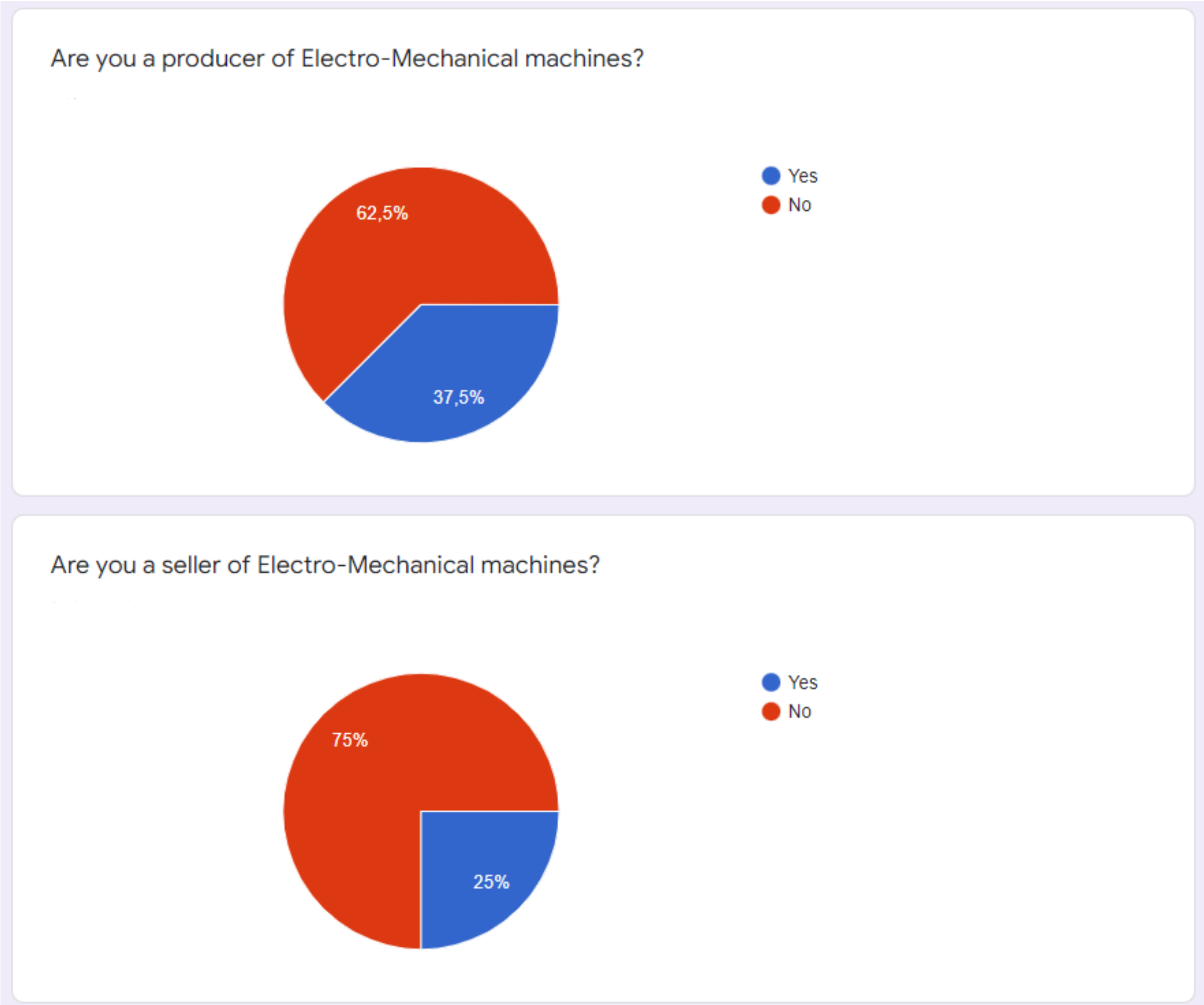

Table 41: Info on the companies that replied

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6 Conclusion

This deliverable has documented updated inputs of RECLAIM use cases and their strategies in the context of refurbishment and remanufacturing:

On one hand, looking at the answers of the companies involved we can assess in some cases such as Gorenje Pilot line B, Zorluteks and HWH are mainly lead by the objectives of proceed with remanufacturing of the large industrial equipment because:

(i) machine manufacturers no longer produces spare parts,

(ii) fear of unexpected layoffs that will have a financial and economic impact. In addition, the main reason for companies to evaluate the opportunities in the implementation of remanufacturing activities is not wanting to make new investments.

On the other hand, Gorenje A and B, Fluchos, HWH and Podium pilot industries are looking at refurbishment activities and strategies for the following reasons:

(i) lack of spare parts and

(ii) danger of stopping of the line and whole production for longer time; addressing these issues will lead industries to future economic profit.

Lastly, the analysis also considered companies not directly involved in the RECLAIM project to have a better understanding on how the manufacturing sector approaches the topic. The issues arose are related to the e-waste, valuable materials and sales and aftersales function. By analysing the answers of the survey we can assess that:

Looking at the Remanufacturing strategies, 62,5% of the companies have been applying those strategies. Even though the result represents a satisfactory and balanced outcome overall, we do not have the 100% satisfaction of the choice made still not the full majority is fully satisfied of the choice made (to the question “I think that I have done the right choice when I decided to approach Remanufacturing” only 33,3% gave the maximum). But it is important to underline that the main opportunity (and KPI) companies look to when deciding if to apply remanufacturing strategies is the “technical upgrading” and the “product quality”. Also, the companies agree that the push to invest in remanufacturing comes from the expectation of having a Life expectancy as good as a new product and improve its profitability.

Likewise, for the Refurbishment strategies, 62,5% of the companies have been applying them, meaning that if a company applies refurbishment also applies remanufacturing ones. Also in this case, the KPIs that companies take more into consideration are the extension of the machine useful life and the product quality.

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