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# INFLUENCE OF THE MULTIPLES LIFE CYCLES ON THE ENVIRONMENTAL IMPACT OF A PRODUCT

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## ABSTRACT

One of the design problems of B2C products results from their increasingly short lifespan. The technological changes, associated with the evolutions of use, lead the companies indeed to renew their ranges more and more early. This tendency generates waste more and more, while some components are thrown quickly they could be used in new generations of products; the remanufacturing appears of this fact as a promising solution.

However, the remanufacturing can be economically and environmentally beneficial only if the product and its life cycle are designed by taking account of the value, the nature and lifespan of the modules to be re-used, and the lifespan of the product.

This article proposes an approach of green design of reusable modules with environmental and economic evaluations covering Multiples Life Cycles (MLC). We introduce into this article the parameters of number of cycle, duration of cycle and the number of reusable modules. This approach was tested within the framework of a comparison of 3 espresso machines. This test made it possible to show that the product decomposition in module with MLC for reusable modules have a better environmental and economic performance.

*Keywords: LCA, Modularization, Remanufacturing, Multiples Life Cycles (MLC).*

## 1 INTRODUCTION

The introduction of environmental dimension in design became a priority in our modern societies. The prospect to see the mining and energy resources becoming exhausted in medium term associated with the environmental problems [1] must lead the great industrial nations to deeply reconsider the way of manufacturing and consuming in order to reach a new model of more sustainable development: The Brundtland report defines sustainability as: "The ability of current generations to meet their needs without compromising the ability of future generations to meet their own needs" [2]. This new kind of development is built on 3 fundamental pillars:

- Environmental protection.
- Economic growth.
- Social equity.

Today the need for setting up new strategies as regards sustainable development like the "precious" material recycling or the re-use of components at high added values is increasingly strong. Shown by the increasingly consumption of electronic goods. Under the pressure of the marketing and requirements of the customers who wish always more functions, the technological change generates an accelerated obsolescence of these products. These thrown products, although become "used", are however always mainly functional; thus the majority of their components could be re-used in the manufacture of new ranges of products. In addition to the economic aspects, the remanufacturing makes it possible to answer the WEEE directive which imposes to the manufacturer minimum rates of recycling, of re-use and energy valorization [3]. However, the methods suggested at the present time do not make it possible to answer in a satisfactory way the technical potentialities of the multiple remanufacturing; the aim of this article is to fill this lack by proposing a method which make it possible to meet the new requirements that imposes the definition of sustainable development i.e. to

decrease our consumption of resources and production of waste, to support the emergence of a new model of production associated with a new economy, without loss of quality of life.

In the first section of this paper, a state of the art of research undertaken in the field of the remanufacturing and the design of modular products (Design for Modularity) will be presented; it will make it possible to put forward the lacks of the methods suggested in the literature. In the second part, we will propose a methodological support allowing an evaluation of existing products, starting from modular groupings operated according to definite criteria (criteria of values, reliability, technical, technological stability...). The evaluation is based on an analysis of product life cycle alternatives (the number of reusable modules, product lifespan and the number of use cycles under consideration for each module).

In third part, this approach is tested within the framework of a comparison of 3 machines espresso (a traditional machine without doses, a machine with aluminum doses and a machine with plastic doses). In the last part the benefit and limits of this new approach will summarize.

## **2 LITERATURE REVIEW**

The review of literature shows that the interest for the remanufacturing is growing [4] [5]. By definition, the remanufacturing is “The process of returning a used product to at least Original Equipment Manufacturer performance specification and giving the resultant product a warranty that is at least equal to that of newly manufactured equivalent” [6]. It gathers several fields of the design: evaluation of the remanufacturability and Re-design of product to facilitate the remanufacturing [7] [8] [9], research on remanufacturing operation (disassembly, cleaning, inspection and sorting, reconditioning, reassembly) [4] [5], environmental analyzes [10] and economic analyzes [11] [12]. In spite of that, various works treats often only one part of the problem.

At the same time as the optimization of the product disassembling for its valorization became a very dense subject of research [13] [14] [15]. In order to allow the separation of sub-assembly (reusable, which can be recycled or not, dangerous) of many research was carried out in order to systematize and optimize the process of dismantling. The difficulty increases with the number of component and the time of dismantling varies according to several parameters (interconnection of the components between them, joint types, direction of dismantling...). Gungor proposed since 1997 an algorithmic method making it possible to approach an optimal sequence of disassembling [13]. But this method does not take yet counts of them the economic and environmental aspects: the complete dismantling of a product in the shortest possible time would have a cost not justified. In fact, the justification of the remanufacturing must take into account of many criteria, as underlined by Kara [16]: “Full disassembly of a product tends to be unproductive due to technical and cost constraint...”.For Zuidwijk “A product recovery strategy determines the degree of disassembly of a product and the assignment of recovery options”[17].

According to [17] four options of valorization can coexist:

- Remanufacturing on a component level which implies a complete dismantling.
- Recycling of materials after a complete dismantling.
- Recycling of materials after a partial dismantling to respect quotas.
- Setting in discharge.

Among these four options it misses an important option, that which privileges the remanufacturing with an optimal dismantling corresponding to the extraction at the lower cost of the modules with strong added value.

In 2002 Lambert introduced the concept of “incomplete disassembly” [14] justified by certain technical constraints: irreversible connections and economic constraints since the costs of dismantling are inversely proportional to the profits obtained by the re-use of the disassembled components. Using software CAD it is possible to determine if the dismantling of one part is blocked by another part always present. This necessary profitability of dismantling made emerge a new research field in design: “Design For Modularity”. The modularization of products is indeed the first step for a sustainable design [18]. The modular products make it possible to improve valorization of materials by differentiating the modules which can be recycled from the modules which cannot be recycled [19]. In this direction, the design of the future products must take into account in the definition of the modules and architecture. But the majority of the products on the market do not have clearly defined modules; this largely complicates the evaluation of the end-of-life scenarios. In the products comprising a great

number of components, those can be gathered in sub-unit, corresponding to functional groups of the product (washing machine case study [16]).

In spite of that, various works treat often only part of the problem. The modular decomposition is a means of optimizing dismantling and making environmental and financial gains.

The remanufacturing is a strategy which makes it possible to re-use products or modules on several use phases according to the requirements of the customers or the market evolution (e.g. computers system updating) [18].

Tomiyama proposes a concept “Post Mass Paradigm Production” [20] which aims at reducing the consumption of the natural resources as well as the production of waste all while maintaining the standard of living current or higher.

The satisfaction of this new model passes by an increase in the products lifespan, posing the problem of functional obsolescence. The increase in the period of utilization and thus the limitation of obsolescence pass by a specific strategy according to the value of the component (repair, update, re-use...) “longer-life products should have functional upgradability besides reliability and fault-tolerance” [21] [22].

One of the aspects little developed consists in integrating this modular aspect in the product life cycle in order to evaluate either the product on only one life cycle but to extend the evaluation (economic and environmental) on several use cycles of the modules. The product is not then any more seen like a material assembly and manufacturing process but as a sum of modules interconnected which will become central units of the model construction. This vision is in particular approached in work of Alexis Gehin [10]. He proposed a concept (brick of life cycle) making it possible to develop a product model taking into account the strategies of revalorization of the components on several use cycles. The approach suggested by A. Gehin allows an environmental evaluation of a product according to these modules, the fact of considering several use cycles imposes operational costs (Supply chain, refurbishing...).

However few works gives a report on the performance of systems whose components are re-used beyond two use cycles: environmental impact and economic costs according to strategies of modules life cycle. Although the remanufacturing is a sustainable strategy of end-of-life, there must be a link between the current products and the future products.

The problematic of this article is to define the optimal life cycle of a product for Re-design from a modular point of view and Multiples Life Cycles (MLC) by respecting the 3 pillars of sustainable development.

### **3 EVALUATION METHOD FOR THE END-OF-LIFE OF REMANUFACTURABLE PRODUCTS**

The originality of this article is to consider the impact of the product either through its life cycle but to extend this one to the life cycle of the modules which compose it and this by considering their re-use. For consumer goods, the re-use of modules presents a theoretical environmental profit; however, its application in the industrial world must take into account many constraints: technically better, functional and economic.

#### **3.1 Optimization of product architecture.**

Majority of the consumer goods designed is based on architectures which marginally take into account the environmental problems. Electronic products for example, have many components manufactured with great material diversity (ferrous materials or not, plastic materials, glasses...), connected by varied joint types (clip, screw of various diameters, sticks, spring retaining ring, rivet...). With the installation of WEEE directive, the disassembly process became an important requirement that it is for recycling (separation of the materials mixtures) or for the remanufacturing of components. The current and future rates of valorization stipulated in this directive generate and will generate additional financial costs. These new requirements in terms of design made emerge new tools in engineering of the life cycle. Among these tools, software (like ProdTect<sup>®</sup> [23] or EIME adapted to the study of the electronic print board [24]) enables according to certain parameters of design (joint types, direction of dismantling, materials, manufacturing processes...) to know the dismantling times (or the costs) and the rates of recycling. To use these tools the knowledge of the product structure is a major requirement; this limits the use of this kind of tool in downstream stage of design. The designers input the properties of components (materials, shape, dimension, orientation, etc), the connections between

components and the priorities (the relations of anteriority between two components make it possible to define the sequence of dismantling). The software determines the level of dismantling corresponding either at a minimal cost, or optimal rate of valorization. The product is evaluated according to a specified scenario.

The time of disassembling is an important criterion in the construction of end-of-life scenario. A component with high value added can require the integral disassembling of the product: the environmental benefit can then be counterbalanced by crippling economic costs.

The tools for optimization of product architecture like ProdTect<sup>®</sup> and LCA tools are very complementary. The first one makes it possible to design a dismountable product. And the second one makes it possible to legitimate the manufacture of the product but especially to design an optimal end-of-life scenario by taking into account recycling rates to satisfy the regulation and to optimize the costs.

### 3.2 Criteria of modular concept

The modularity is an important aspect to optimize the remanufacturing. In the field of the B2B, there are many examples of success in literature like Xerox [25], baby prams [12] or Velo'v [26], being inspired in particular by the concept of Product Service System (PSS). However in small household appliances (B2C market) it is difficult to follow these examples without falling into the second-hand market. The small household appliances put on the market currently are not optimized for the remanufacturing processes; certain parts can be technically re-used but the installation of reverse logistic and the associated costs constitute a major issue. To cure it, it is necessary to call upon the concept of modularity: Design for Modularity consists to design elements of the product (The modules) which carry out some function satisfying a whole of need and being removable [27].

In other words a modular concept makes it possible to reduce the number of interactions between modules.

With this intention, it is necessary to determine, a priori, the modules which must respect certain criteria (price of the components, functionality, lifespan, etc.). The difficulty is to define the borders of a module, knowing that the preexistent modularity in the product is only the reflection of the aptitude for the assembly or maintenance. In the continuation of this paper we will regard a module as an assembly of components achieving a specific function.

To define a module, it is necessary to gather components of the product according to criteria. These criteria are more or less well defined: in literature we find many works treating of these criteria (Table 1). The idea of these various concepts is to gather the components having close characteristics (e.g. Ease to repair [19] [28]) in order to simplify the process of end-of-life [29].

*Table 1. Modules characterization*

End of Life Strategy [29]	Modules properties [28]	Modules properties [19]
RECYCLING	Pollutive materials Easy recyclable	
MAINTENANCE	Quality: Separate testing Maintenance: Service and repair	Ease of quality insurance Ease of cleaning - to repair - testing
REUSE	Carry over Technology evolution	Long life Technology Stability
UPGRADING	Upgrading planned	Functional upgradability

One of the blocking points of the remanufacturing is the economic aspect. Indeed we must take into account additional costs related to a requirement of essential quality (according to the definition of the remanufacturing) but also costs of reverse supply chain (RSC). This cost of logistics associated with the product returns and the transport of the modules can be optimized in the design of modules: the components of the same supplier can be gathered in order to reduce the distances of RSC.

### 3.3 Modular vision of life cycle.

In most of the case the electronic products have one value lifespan much less important than their physical lifespan, the main cause being the obsolescence of a component or a module including the components whose technology develops quickly (for example the computer material). This report shows that it is difficult to remanufacture a machine completely because its lifespan will depend on the most fragile components, on the components whose obsolescence is fastest or on the "housing"

components which most strongly deteriorate. Excepted this non reusable modules, some modules (less sensitive to the technical, more reliable or less visual evolutions) can be re-used for the manufacture of new machines (identical or more advanced).

In a traditional outline when a product is not functional any more it is either put in discharge, or recovered by manufacturing which must manage its end-of-life in accordance with the legislation. According to these directives it is either incinerated (energy recovery), or recycled, or re-used. With the last process, the functional components are not destroyed any more but reused as many cycles as its lifespan allows it. Thus, if a product become nonfunctional or obsolete beyond 5 years but it has a component which can resist 20 years, this component could be re-used 3 times. We talk about modular life cycle because in this vision the module is an individual product. It is independent of the product in which it is inserted (they can be in particular inserted on different product ranges). The characteristic of their life cycle is to integrate additional stages of refurbishing: disassembling, cleaning, repair, test, reassembly [5]. These additional stages generate always additional economic costs and environmental loads. In order to determine the best compromise it is necessary to simulate various scenarios while varying the lifespan of the modules as well as the number of cycle and the lifespan of the product. This approach is built on a judicious parameter setting of the system product-modules and their life cycles.

### 3.4 Design parameters for the end-of-life of reusable products

Today the majority of the consumer goods are designed according to constraints on the respect of the environmental standards imposed by the institutions. LCA methods make it possible to evaluate the products in the last phases of products design, reducing the designer's degree of freedom. Within the framework of the products remanufacturing, many factors are concerned, the lifespan of the product, the lifespan of the components, the number of reusable component and the "remanufacturing process" [8]:

Inspection - Cleaning - Disassembly - Storage - Repair - Reassembly - Testing.

Each one of these operations produce new constraints of designs: ease of Identification, ease of Checking, ease of Handling, ease of Access, ease of Stacking, ease of Separation...

We make assumptions on the composition of reusable modules to evaluate the performance of existing products. Also we define virtual modules (modules gathering of the components checking the criteria of classification section 2.2) in order to carry out the environmental evaluation of end-of-life for remanufacturing scenario. According to these criteria the modules could be recycled, re-used or upgraded (figure. 1).

The upgrade can be regarded as re-use on modules whose technology evolved slightly; it makes it possible to add value to the product by changing only one component. It is what often occurs in B2B market where the obsolete components are replaced by more powerful or more functional ones. The objective is to privilege maximum of remanufacturing.

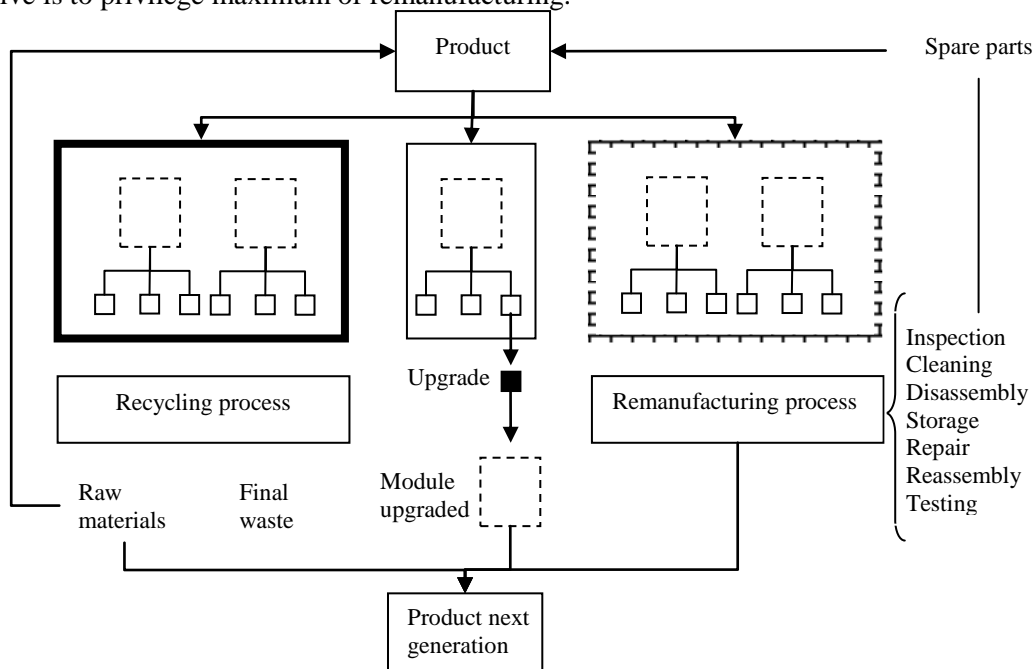


Figure 1. End of Life for closed loop manufacturing

To define the parameters well, the first step is to evaluate the various scenarios. One of this parameters must be the lifespan of the product (or value time), it's important because it influences the functional unit. Then we decompose the product in modules according to the criteria defined into section 2.2. Each module is defined by a parameter. Finally the last parameter is the number of life cycle feasible by a particular module. The number of life cycle corresponds to the number of times where a module could be re-used in the manufacture of another product or a higher range.

Table 2. End of Life for closed loop manufacturing

Parameters	Input dated
N	Value time (years)
$M_n$	Module n remanufactured
$Z_n$	Number of life cycle of module n (X times)

With these three parameters input (table. 2) and also the data of usage (electricity consumption, consumable...) we obtains a number of products according to  $Z_n$ , a logistic scenario, end-of-life scenario (with various recycling rates, re-use, incineration, landfill)

### 3.5 Methodology: Multiples life cycle analyzes

The construction of the model can be realized directly with LCA software like Simapro<sup>®</sup>. In order to improve comprehension of the method it will be supposed that  $Z_1 = \dots = Z_n = \text{constant}$ .

#### 3.5.1 Construction of the model

We look at the life cycle either from product point of view but of these constitutive modules. In this case it is not any more one product which we must model but a succession of products depending on the number of modules life cycle. Product modelization is carried out as if it were about an "Empty box" in which we would add the modules according to their lifespan. Either Z the number of reusable modules life cycle, in order to evaluate the impact of the remanufacturing of the module we will have to analyze Z machines. Among these machines, the first corresponds to completely new product without use of materials recycled or used modules. Z-1 remaining machines will be "Empty box" in which would come to be added the remanufactured modules (Figure. 2).

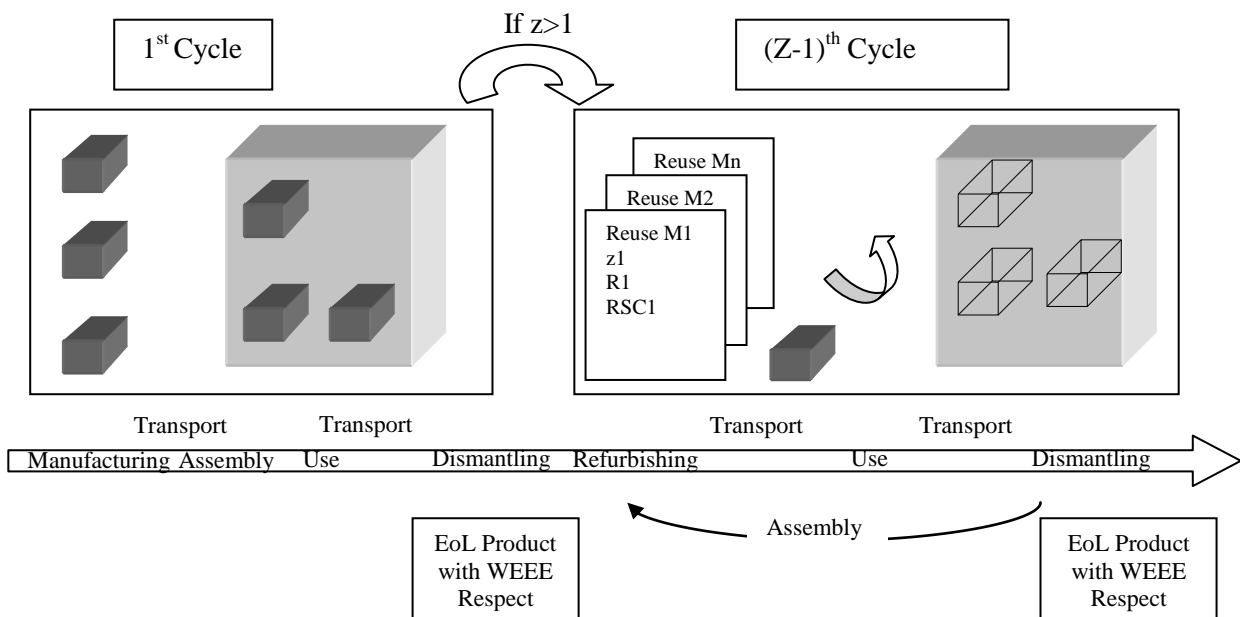


Figure 2. Construction of Multiple Life Cycles (MLC)

According to the composition of the machines in recoverable modules the end-of-life scenario will be different (for example material rate which can be recycled, refurbishing of the modules). The choice of

the remanufacturing imposes other constraints which we must integrate using new parameters. Product disassembly outside assembly center brings additional distances as well as transport to collect them when the product is thrown at the end of life. These Modules must then be repaired (refurbished). By using the parameters RSC (Reverse Supply Chain) and R (Refurbishing) we can extend simulation in order to have a more realistic vision of the life cycle.

**3.5.2 Functional unit for multiple life cycles.**

The definition of the functional unit [9] is a fundamental aspect, especially in this parametric modeling. Indeed while varying N and Z we modify the Functional Unit (FU), but to compare the various life cycle scenarios resulting from a choice of different parameters it is necessary to define an adequate functional unit in this type of evaluation. The idea would be to bring back FU to a functional constant (FC) calculus. To obtain an Environmental Score for a MLC scenario (EnS<sub>MLC</sub>) we propose to convert the environmental impact (EI) of each stage in annual impact.

Environmental score calculation

$$EnS_{MLC} = \frac{\sum_i EI_{stage\ i}(t)}{N \times Z} \tag{1}$$

i: manufacturing stage, transport stage, use stage, EoL stage...

**3.5.3 Framework.**

The performance evaluation of a product on several cycles of use requires a coordinated use of several tools (LCA, ProdTect, Economic assessment).

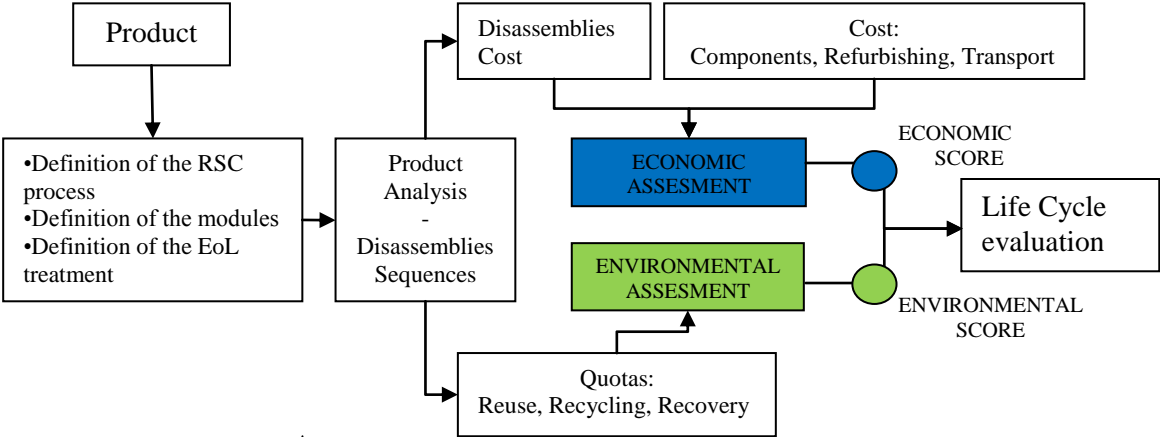


Figure 3. Framework overview

We must initially know the components of the product: their failure rate, their price, their lifespan, the technical stability of the component in time. Then according to the definite criteria of modularity (section 3.2) we establish modular groupings. The description of the product must make it possible to define realistic scenarios, particularly for the choice of reusable modules and process of refurbishing. The choice of these modules (potentially reusable) will make it possible to simulate several disassembling sequences according to various scenarios. Product analysis software will model these disassembling sequences, thus we will be able to determine time and the cost necessary to the recovery of all modules for one scenario. In addition to disassembly costs, the software makes it possible to validate the coherence of the scenarios. The second part of the approach, being based on the parameter setting of the life cycle (section 3.4), allows systematically to evaluate the life cycle of a product according to the number of modules life cycle Z and the product lifespan N. The designer builds initially his product using the Bills Of Materials (BOM) in the following way: Part-process, component-process, module-process and finally Product-process, for that it must use a database (Ecoinvent, Buwal, Idemat). It must then build its life cycle by taking into account all parameters which will make it possible to simulate several cycles of use: usage (energy consumption: Cx), lifespan of the product N, the modules which designer chooses to reuse in the following cycle M<sub>n</sub>, the number's cycles of reused modules: Z, the scenario of refurbishing (according to the modules) R, logistic scenario: RSC...



The designer can be helped by a “graphic” interface directly connected to LCA software using Macro Excel.

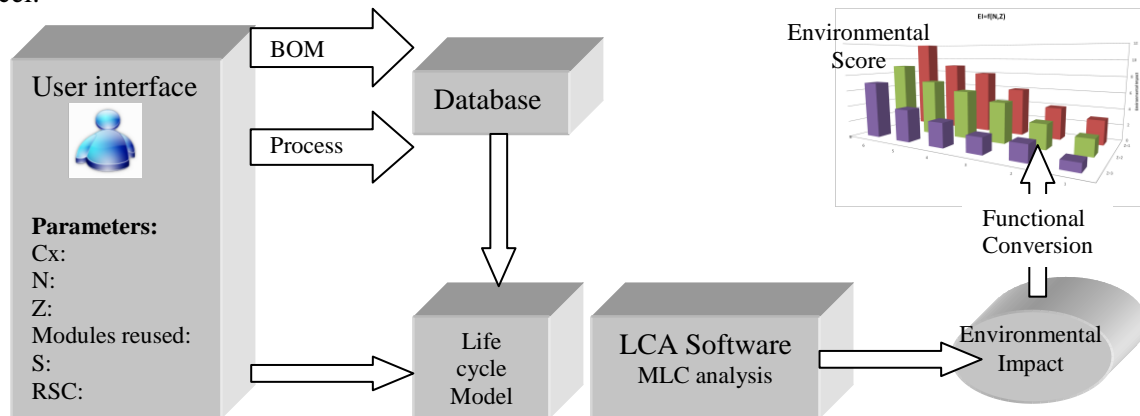


Figure 4. Framework analyzes environmental

In the same time we carry out an economic study (figure. 3). At the end, according to the choices of the designer, we will have a performance evaluation (environmental and economic). The results will be given in the form of 3D histograms allowing a quick analysis of the results.

#### 4 CASE STUDY: MACHINES EXPRESSO

In order to validate this approach, we propose to apply it on an industrial case study: the espresso machine. This last decade they have been an emergence of the machines with coffee doses revolutionizing the sector and with a strong competition. That's why we privileged the study of several machines with different technologies: A manual espresso machine and two concurrent machines with doses.

##### 4.1 Perimeter of study.

LCA study has been limited initially to the environmental impacts related to MLC in extraction-manufacture-distribution-use and end-of-life of the machines stages.

Then we have looked the influence of the MLC compared to different usage: doses or not, sleep mode or not...

Protocol:

1. MLC Evaluation: variation of the factors M,  $N_R$  and Z.
2. Evaluation Use 1: impact of the doses on the environmental performance.
3. Evaluation Use 2: Impact of electricity consumption on the environmental performance.

##### 4.2 Modular decomposition.

We applied our experimental approach on the three following Espresso machine:

- Product A ( $P_A$ ): manual machine without doses.
- Product B ( $P_B$ ): manual machine with doses.
- Product C ( $P_C$ ): automatic machine with doses.

Before to begin the evaluation for the 3 different machines, their modules must be defined:

The pumps and the boilers are very near technologically. On the other hand the 3 products are dissociated by a “quite different Infuser module” because their technology (patented) makes it possible to dissociate competitors. These 3 modules answer at the remanufacturability criteria (section 3.2):

- The vibrating pump have a great lifespan (because short cycles), a great technological stability (in 20 years the pumps of espresso machines evolved slowly).
- The boiler is a central element of the system which often determines the lifespan of the machine (its breakdown leads generally to a reject of the machine) because of its high value, descaling seems to be an environmentally and economically interesting option.
- The infuser answers at the criterion of fast dismantling with a simple cleaning.

The Espresso machine is a simple case of study because it gathers 3 modules potentially reusable according to the criteria determined above limiting the number of possible combinations for a first

experimentation. Our approach must make it possible to make arbitration on the choice of modular grouping economically and environmentally advantageous.

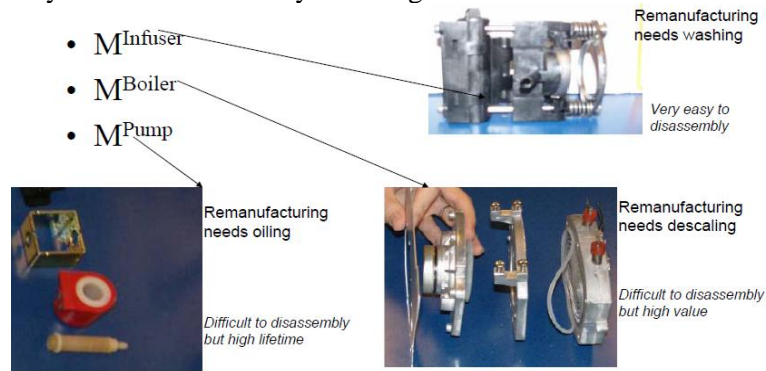


Figure 5. Modules characteristics

In order to simplify calculations we will limit ourselves to the analysis of 4 scenarios:

- WEEE Scenario: The current scenario recommended by WEEE directive.
- Re-use of the infuser
- Re-use of the infuser and the boiler.
- Re-use of the infuser, the boiler and the pump.

#### 4.3 Economic assessment.

For each scenario we calculated the cost caused by the modules end of use cycle, this cost takes into account the transport, the storage and the treatment of end-of-life.

Global cost calculations:

$$C_{\text{global}} = C_{\text{tps}} + C_w + C_t \quad (2)$$

$C_{\text{tps}}$ : Transport cost for ton/km: 0.4 € for one lorry of 20t.

$C_w$ : warehousing cost

- For 1m<sup>3</sup> in/2€;
- For 1m<sup>3</sup> off/2€;
- For 1m<sup>3</sup> stocked during one day, 0.6 €.

$C_t$ : treatment cost

According to the “Prodect<sup>®</sup>” report, we suppose that the treatment costs are:

- Cost of dismantling.
- Cost of recycling with resale of materials.

Because the machine is transported completely to the production center, the transport cost and the warehousing cost are not influenced by the number of modules to be remanufactured, only the treatment cost which will vary from a scenario to another.

Table 3. Remanufacturing cost for each scenario

Scenario	Transport cost	Warehousing cost	Treatment cost	Global cost
WEEE	0.412	0.19	4.84	5.442
1 module	0.43	0.27	3.99	4.69
2 modules	0.51	0.27	3.28	4.06
3 modules	0.56	0.27	3.71	4.54

- $C_{\text{infusion system}}$  : Supply cost of a new modules “Infusion system” = 3 €
- $C_{\text{boiler}}$  : Supply cost of a new module “boiler” = 5 €
- $C_{\text{pump}}$  : Supply cost of a new module “pump” = 4 €

Economic score calculation:

$$EcS_{MLC} = Z \times C_{global} - \sum_j (Z - 1) \times C_{modules_j} \quad (3)$$

j = Infusion system, boiler and pump.

#### 4.4 Environmental assessment.

At the same time as this economic assessment, we carry out a Life Cycle Assessment for each configuration (re-used modules, number of cycle of use, lifespan...) to define an Environmental Score according formula (1) section 3.5.2.

For each of 4 scenarios we vary the number of cycle Z for one lifespan and N constant, we make again the operation until N=5. Three cycles of use are enough because beyond the technological rupture would be too large for this type of products. The upgrade can prove to be an option to take some into account according to the compatibility of the module with the architecture of the new product.

Table 4. Environmental & economic assessment for product C with 3 modules reused

P=NxZ	N	Z	EI	EnS	EcS
1	1	1	3.49	3.49	4.54
2	1	2	3.8	1.90	-2.92
3	1	3	4.13	1.38	-10.38
2	2	1	3.9	1.95	4.54
4	2	2	4.63	1.16	-2.92
6	2	3	5.35	0.89	-10.38
3	3	1	4.32	1.44	4.54
6	3	2	5.46	0.91	-2.92
9	3	3	6.59	0.73	-10.38
4	4	1	7.73	1.93	4.54
8	4	2	6.29	0.79	-2.92
12	4	3	7.84	0.66	-10.38
5	5	1	8.86	1.77	4.54
10	5	2	7.13	0.71	-2.92
15	5	3	9.09	0.60	-10.38

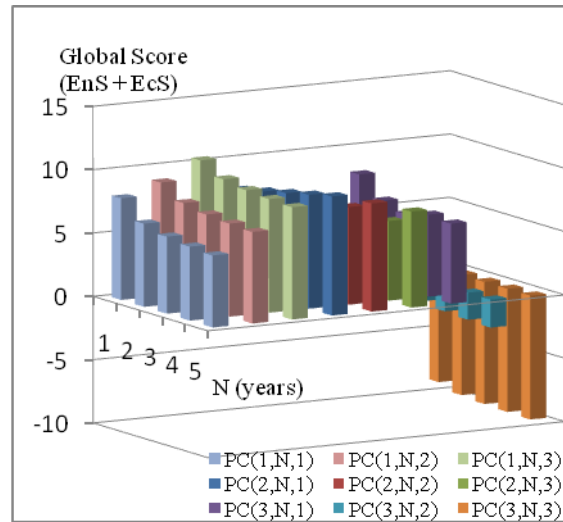


Figure 6. Simulation for one product

#### 4.5 Results and interpretation.

For each of the 3 machines we represented the results on 3 diagrams separately (Figure 6). Each section represents the aggregate environmental score and an economic score corresponding to the economic costs generated by the remanufacturing.

Each simulated configuration is represented by a point  $P_A(M, N, Z)$  positioned in a Cartesian chart according to its economic costs and its environmental impact (Figure 7). ( $P_A$  represents product 1, M the number of re-used module, N product lifespan and Z the number of cycle).

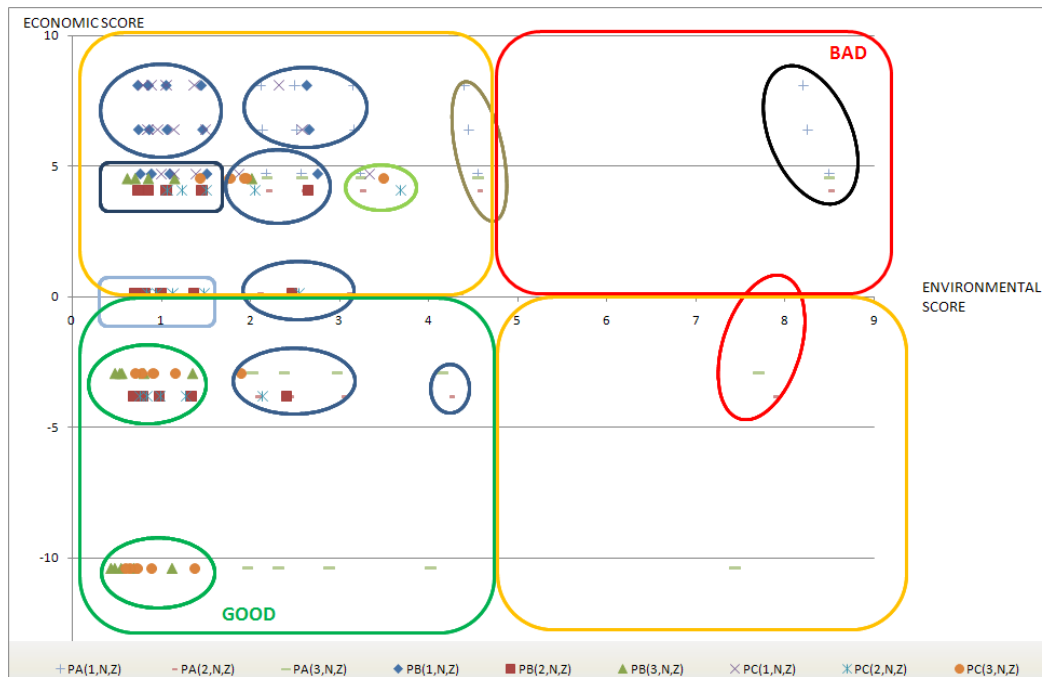


Figure 7. MLC selection chart for Espresso machine

This graph shows that some products are more impacting or more expensive than others but the remarkable point is the grouping of product configurations which we can make. By representing the results in this form a designer can qualitatively select a modular arrangement among a more or less large choice of configurations (choice of the reusable modules, modules life cycle, produced lifespan...). To carry out this case study we selected competing products but the goal is to use this approach in phase of design.

The impacts of the products are not only related to their Extraction-Manufacture and End-of-life phases (Phases which are influenced by the remanufacturing). In the case of the Coffee machine the use phase accounts for approximately 90% of the environmental impacts mainly due to the doses utilisation and the electric consumption of the machine in sleep mode.

Table 5. Distribution of Environmental impact: Produit C (3,5,3)

Manufacture & EoL	Use			
	Doses		Electric Consumption	
	Landfill	recycling	Sleep mode	No Sleep mode
Machine P <sub>C</sub> (3,5,3)				
5%	92,3%		5,3%	
7%		89,2%	7,4%	
6,3%		80,7%		16,3%
4,6%	85,5%			12,1%

Table 6. Distribution of Environmental impact: Produit C (3.WEEE)

Manufacture & EoL	Use			
	Doses		Electric Consumption	
	Landfill	Recycling	Sleep mode	No Sleep mode
Machine P <sub>C</sub> (3.WEEE)				
9,2%	87,8%		5%	
12,6%		83,5%	6,9%	
11,4%		76%		15,4%
8,6%	81,8%			11,5%

The comparison between MLC scenario and WEEE scenario shows that the share of the impacts due to the manufacture phase decreases by approximately 5% with the remanufacturing of 3 modules. On this type of products the use of consumable masks the performance.

## 5 CONCLUSION

The development of product life cycle is a big step aiming to design a sustainable product. The choice of this life cycle must intervene as soon as possible and must be responsibility for the designer or group of design. The approach suggested in this article is to allow an evaluation of several concepts (various arrangements of modules) on multiples life cycles. In the suggested study this evaluation takes into account two important factors, the environmental performance and the economic performance: This is two of the three pillars of sustainable development. The integration of this approach in design process makes it possible to technically isolate the most powerful systems taking

into consideration the constraints of treatment at the end of life (optimization of disassembly time, optimized modules recovery, refurbished modules and re-use them in new products) but also the level of the organizational constraints (logistic costs, environmental regulations...). The first results go in this direction, the product decomposition in module with several cycles of use for reusable modules have a better environmental and economic performance. For the continuation we plan to apply this method for a B2B product in an industrial sector. We also wish to answer a lack of the consideration of the customers' needs in products design.

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