INTERNATIONAL DESIGN CONFERENCE - DESIGN 2012
Dubrovnik - Croatia, May 21 - 24, 2012.

PRODUCT'S LIFE CYCLE MODELLING FOR ECO-DESIGNING PRODUCT-SERVICE SYSTEMS

M. Fargnoli, M. De Minicis and M. Tronci

Keywords: ecodesign, product-service systems, life cycle modelling, life cycle assessment

1. Introduction

In recent years sustainability issues assumed an increasing importance in industrial sector and ever more attention is now paid to environmental responsibility of organizations. Nowadays, green attributes are considered key aspects of the global competition. In this context, the possibility of assessing environmental performances of a product, before starting its production, is certainly significant. At the same time, shifting from product use to service use, represents one of the most powerful approaches for the achievement of a more sustainable society. On these considerations, the paper combines product's life-cycle simulation (Life Cycle Modelling, LCM) with industrial Product-Service Systems (PSS), underlining the beneficial effect of refurbishing/reconditioning operations. This integration enables the evaluation of product's environmental performances, helping designers in understanding the potential benefits of product servification. With this aim in mind, the integration of PSS strategies within ecodesign issues was carried out through the development of an industrial case.
The study was focused on the life cycle management of a household dishwasher, which is affected by a strict environmental legislation. The analysis of results brought to light that the PSS approach, supported by ecodesign tools, can have a sensible positive effect not only in terms of environmental performances, but also considering the customer satisfaction and the producer's bottom line. More in details, the paper is structured as follows: in section 2 motivations are presented; then, in section 3 and 4 the general background is discussed. The proposed approach is presented in section 5 and examined its application to an industrial case is illustrated in section 6. Results and conclusions are discussed in the further sections.

2. Motivations

Sustainability and sustainable manufacturing ideas have changed in recent years playing more and more a key role in the global market. As a matter of fact, looking at its evolution, sustainability has been initially associated to the environmental dimension, even though a more complex concept was further developed along with the shift from the numerous interventions made by international organizations on these themes (such as the well-known WCSD, OECD, UNEP, EEA).
Then, it is important to underline that a more comprehensive approach in product development, which be able to better balance the importance of the different requisites that a product has to fulfil, is put forward by the ever increasing number of rules provided by the environmental legislation. In particular, in the European Union, several directives, based on the Integrated Product Policy (IPP), set rules and requisites that product developers and manufactures should follow to put on the market their products. The CE mark, which demonstrate the conformity with environmental legislation, is now mandatory in accordance with both the ErP and the RoHS directive. Probably, this mark will be

included also in the recast of the WEEE directive. A large number of industrial products fall into the scope of these acts, especially (but not only) electric and electronic equipment, so they need to be designed and developed in accordance with the "life cycle thinking" and "eco-efficiency" principles (e.g. in [Aoe 2007]).
As many authors underlined, the attention paid to the sustainable development of products has forced engineers to consider environmental aspects in concurrency with other traditional aspects, i.e. technical and economic requisites. In this ambit, ecodesign has been considered the approach capable to lead to the most effective results in product development activities. Among the numerous definitions given in recent years, the newest and more holistic is the one provided by the standard ISO 14006:2011, which describes ecodesign as the activity aimed at the "integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycle". This novel standard is aimed at taking into account the design and development of a product, intended as a good or a service, or a combination of them, stressing the effectiveness of planning the management of all the phases of product's life cycle. From this perspective, i.e. the management point of view, product's usage is a service provided to the user with the goal to increase his/her satisfaction.
The importance given to services interwoven with the product's life cycle, and in particular with its use phase. Some activities, such as maintenance and after-sale service, play a key role in both customers satisfaction and the optimization of the environmental performances of a product along with its whole life cycle. Then, also the role of design and development activities has to change, considering the product along with its whole life cycle. In Figure 1 such a change is represented by the shift from the scheme based on the well known "over the wall" approach proposed by [Lindhal and Tingström 2001] to the holistic approach proposed by recent ecodesign issues, where all the following aspects should be taken into account and managed by the ecodesign strategies:

- product design, development and life-cycle planning (a);
- social and legislation requisites (b);
- customer needs and wants at the purchase stage (c);
- product usage, maintenance and disposal (d).

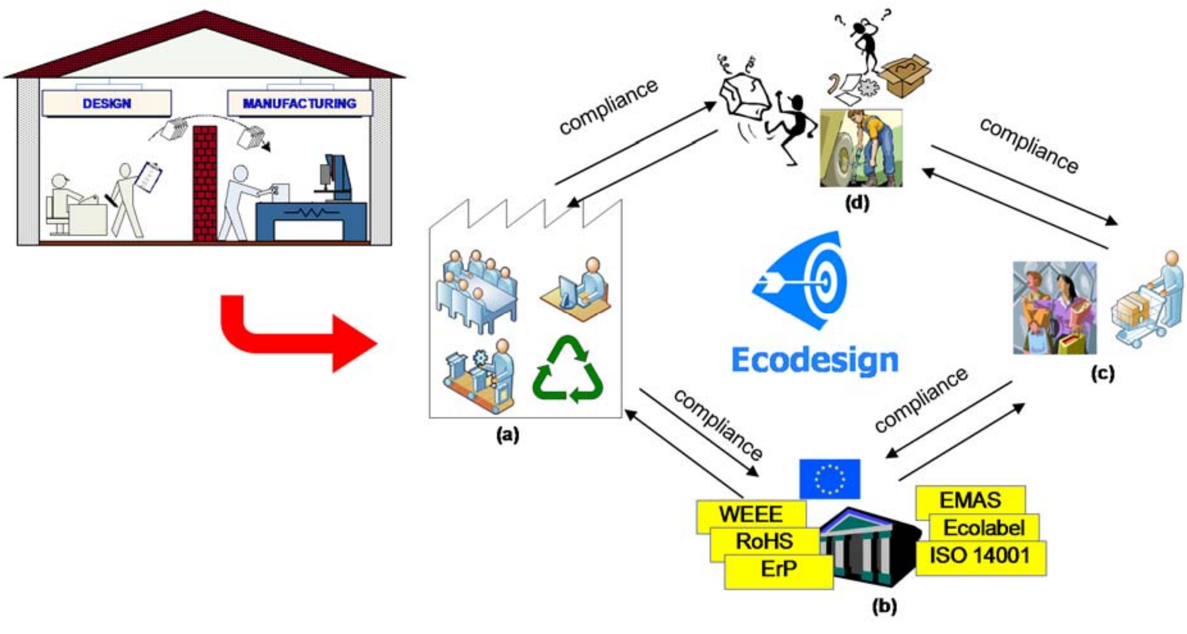

Figure 1. The evolution of ecodesign issues

Merging products and services into a complex system with the aim of providing a higher customer value represents the goal of the so-called "Product-Service System" (PSS) approach: developing a PSS requires specific planning and design activities, more complex than the ones carried out in traditional product development, where the OEM (original equipment manufacturer) has no contacts, or a very limited interaction, with the customer after the product is sold.
Actually most common cases of PSS concerns complex products, very advanced from technological point of view and/or expensive: in these cases, actually, the intervention of the OEM during the product's use phase (and sometimes also in the disposal stages) appears more convenient than the after-sales services operated by a different company. In recent years the ever increasing attention paid to environmental concerns has brought engineers to look at the PSS approach as a beneficial tool to enhance the sustainability of a product [McAloone and Andreasen 2004], [Sakao and Shimomura 2007].
Even latest environmental legislation foresees that manufacturer took care of a product throughout its life cycle, in particular for what concerns the disposal stages, in accordance with the well known "polluter pays principle". From this point of view, activities such as maintenance, repairing an re-collection after the usage, can be performed better by the OEM rather than a third party also in the case of common products (e.g. households), focusing on the customer demands and needs.
Nevertheless, the integration of PSS strategies within ecodesign issues is not sufficiently investigated, leaving aside a large number of opportunities to extend mutual benefits of these approaches. The proposed research work represents an attempt to achieve this goal, i.e. shows a possible combination of ecodesign issues and PSS strategies with the aim of optimizing the environmental performances of an industrial product. More in details, in the following sections the theoretical background on which the research is based, is summarized, analyzing both the Life Cycle Design issues and the PSS approach.

3. Life cycle design

A literature review in the field of sustainable design shows that many tools have been proposed to consider environmental aspects of product's life-cycle. But only few of these methods can be used at an early stage of design, which is certainly the phase in which ecodesign provides most benefits both by a technical and environmental point of view. During this phase it is possible to make conscious decision which affects product's life cycle such as end of life strategies (reuse, recycle, etc.). It is also true that at a conceptual phase there is a lack of important information about materials and production processes, so it becomes particularly important to select the most appropriate design tool.
One of the most used tool to analyze and improve product's environmental performance is the Life Cycle Design, which tries to identify and measure environmental impacts during all the lifecycle of a product in order to help designers in the definition of its environmental requisites [Kimura 2007]. An interesting development of this method is the Life Cycle Modelling, which develops simulations of product's lifecycle in order to evaluate the environmental performances of different design solutions.

4. Product service-systems

Sustainable manufacturing issue has been mainly addressed considering cleaner production and technologies, waste minimisation and recycling practice, eco-design and design for sustainability . But from an environmental perspective, also product-services, such as maintenance, are important. Then, industrial Product-service system, which is defined as customer life cycle-oriented combinations of products and services, realized in an extended value creation network, comprising a manufacturer as well as suppliers and service partners, seems to be an interesting approach. The aim of PSS is to provide consumers with products and services characterized by the same level of performance, but lower environmental impact. This objective is obtained providing utility to consumers through the use of services rather than products. This innovative way of thinking provides sensible advantages by an environmental point of view, as it reduces the consumption of resources, meeting both costs and environmental performances. Economic targets for producers becomes linked to how efficiently the service is provided rather than the number of sold products. But the use of this approach must be coupled with a life cycle design of the product in order to provide good results. Unfortunately there exist numerous obstacles to PSS application, such as cultural reasons and resistance to change by organizations. The potential of PSS for more sustainable production and consumption can be addressed considering the influence of PSS on environmental performance. In particular, user and product oriented services frequently contribute to reduce environmental loads in terms of more conscious product usage as well as increased resource productivity. Concerning product oriented services, preventive maintenance is seen as a strong contributor to closed loop manufacturing. However, in addition to these positive environmental consequences, rebound effects must be considered due to their ability to make shorter product or component life times preferable. This is especially the case for products with high energy or material consumption based on technologies that frequently undergo significant efficiency advancements, such as household appliances.

4.1 LCA applied to PSS

Life cycle assessment can be effectively applied to evaluate environmental performance of a product-service system. In particular, in this case is of utmost importance is the concept of functional unit, as PSS comprise intangibles elements too. Moreover, consumers may vary their attitude as a consequence of PSS characteristics. For example, the introduction of a car-sharing service influence the use of cars, public transportation or bicycles. Since product-service systems are developed and put on the market to provide customers with a particular function (as observed by [Roy 2001]), with no regards to the possession of physical goods or not, their life cycle assessment needs to be applied taking into account life cycle scenarios, i.e. investigating the eco-efficiency of product's life cycle management. For these reasons, Main objective of the analysis is the comparison between different alternative scenarios of product-service systems, according to a limited number of factors regarded as particularly important.

4.2 Maintenance for environmental sustainability

Maintenance can play an important role for environmental performances of industrial products. A possible analysis of the beneficial effect of maintenance can be developed pointing out negative effects of poor maintenance. Considering a production plant, [Raouf 2009] pointed out consequences of poor maintenance which can have a negative impact on the environment: overproduction and over processing due to failures, extra-inventory indispensable to mitigate the effects of breakdowns, defects caused by malfunctioning, extra-transportation and maintenance delay.

Such a framework is focused on production process and its environment, without taking into consideration the extended environment and time horizon characteristic of system's life-cycle. To overcome this limitation, another interesting approach is the 6R one, which analyses the role that maintenance activities play in each phase of system's life, from design to disposal. According to this pattern, proper maintenance may reduce material and energy consumption, wastes and pollution by preventing breakdowns and maintaining equipment efficiency.

Adequate maintenance can also increase the quantity of material which can be recovered or recycled as components are replaced before catastrophic failures. Whether reuse of old equipment and components is increased by maintenance activities, the redesign and remanufacturing of new items is decreased by enlarging assets lifespan: by applying a 6R approach it is possible to analyse the role that maintenance activities play in each phase of product's lifecycle.

By preventing breakdowns and maintaining equipment efficiency, proper maintenance can:

- Reduce: pollution, consumption of raw materials and energy, production of waste;
- Reuse: products and components;
- Redesign and Remanufacturing: products and components;
- Recover and recycle: replaced components and materials.

In the case of product-service systems, the most beneficial effect of maintenance jobs, when adequately planned, is certainly the enlargement of product's lifespan. At the same time, as the production of new products and components can be reduced by providing customers with refurbished products instead of new ones, maintenance activities limit the use of raw materials and energy spent for their production.

Thus, considering the case of PSSs, maintenance operations should be considered not only as the traditional interventions (e.g. cleaning or repairing) used for physical goods, but also as intervention aimed at recovering, refurbishing or reconditioning the products so that it can be re-used by the same customer or by a different one.

5. Methodology

The study is focused on the integration of PSS strategy within an ecodesign framework, with the aim of providing criteria for deciding whether and how to develop a PSS, rather than a traditional product (i.e. a physical product). As a matter of fact, from the producer (the OEM) perspective, the difference between goods and services consists in taking into account two different systems:

- manufacturing and putting on the market the good;
- supplying the services related with the operation of the good.

In such a context, environmental legislation requirements have to be taken into account, since they oblige the manufacturer to take care of the good even after its purchase.
PSS approach can certainly help manufacturers in dealing with such a task, but for this purpose it needs to be included in design and development activities. With this idea in mind, the scheme of the proposed approach is summarized in Figure 2.
More in details, operating in the ambit of the design and development process proposed by the report ISO/TR 14062:2002, the use of the Quality and Environmental Function Deployment (QEFD) method [Olesen 1997] was foreseen, with the aim of bringing to light customer expectations of the product use, as well as to determine the so called Voices of Environment (VoEs), which include environmental requisites and performances the product has to satisfy.
Results obtained by the QEFD (generally the development of first phase of the QEFD, i.e. the "product planning" stage, is sufficient to provide useful information for the further steps of the procedure shown in Figure 2) are used to set the optimized the product's profile that should be achieved by the manufacturer, taking into account the whole product life cycle: this includes also the operation of the servicing activities requested by the customer and/or by mandatory requisites.

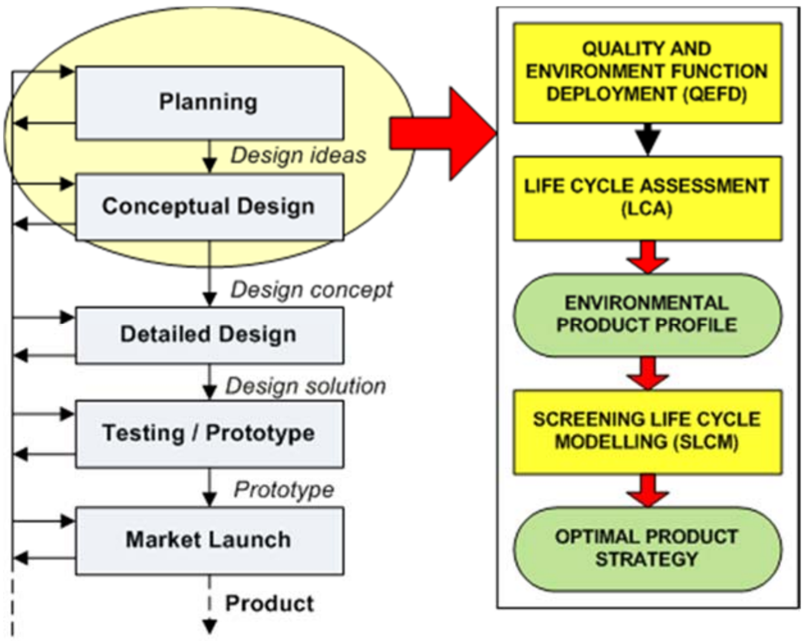

Figure 2. Scheme of the ecodesign framework proposed

The further step consists in analyzing the product life cycle following the Life Cycle Assessment (LCA) approach [Wenzel et al. 1997]: the evaluation of environmental burdens and performances allows engineers to bring to light the gap between performances of the already existing product and the expected ones. Thus, in order to optimize operations related with the product's usage and disposal, the Screening Life Cycle Modelling (SLCM) method [Fargnoli and Kimura 2006] can be applied. Results can allow engineers to decide by means of the development of several different scenarios the most convenient “environmental product profile”, identifying critical design and servicing options, optimizing at the same time the marketing strategies and adapting the traditional design concepts to the manufacturer’s bottom line.

6. Case study

The research approach was developed throughout an industrial case study, carried out in collaboration with a household manufacturer. In particular, the study was focused on the design and development of dishwashers because of the recent issue of Regulation (EU) n. 1016/2010, which implements directive 2009/125/EC (i.e. the so-called ErP directive) with regard to ecodesign requirements for household dishwashers. The model selected is a medium range dishwasher, which can be used in domestic context. Main characteristics of the model selected are the following:

- dimensions: 85x60x60 cm;
- lifetime: 12 years;
- place settings: 12;
- cycles per year: 270;
- water consumption (200 cycles): 15 litres;
- energy consumption (200 cycles): 214 kWh/year;
- energy efficiency class (Directive 2010/30/EU): AAA.

6.1 Use of the QEFD

The study is focused on a specific model which is commonly used in the accommodation facilities sector and information were provided by both producer and customer service. Additional data were drawn by interviewing a certain number of dishwasher's users. After realizing a work breakdown structure of the considered dishwasher and collecting essential information (dimensions, performance, noise level, consumptions, etc.) the QEFD was applied. This method is based on the traditional QFD scheme and rules: the difference between QFD and QEFD consists in providing a specific section for environmentally oriented customer specifications (VoEs), which should be treated separately from traditional VoCs. It has to be noted that, as far as "whats" is concerned, some inputs could not be distinguished in VoCs or VoEs easily, since some aspects (e.g. "water consumption" or "reliability" or "energy consumption") are both related to customer needs and requests, as well as to environmental requirements. In these cases, environmental part of the "whats" list was chosen. At the same time, as target performances values and indications provided by the MEEuP Reports (VHK for European commission, 2005) about ecodesign of dishwashers and the above mentioned Regulation (UE) n. 1016/2010 were used. Very high values of relative importance were obtained by characteristics concerning the usage stages, such as functionality, reliability, low consumptions (water, detergent, energy, salt), involving also some services provided to customer as the activities related to maintenance and repairing, and information on the use of the household. Looking at these activities from a PSS approach perspective, they concern:

- the supply of a tangible product (repairing and maintenance operations);
- the supply of an intangible product (information and training).

6.2 Life cycle assessment

Starting from the product's profile emerged from the previous step, its life cycle was evaluated applying the LCA method. The analysis were carried out using the Simapro software and the Ecoindicator 99 criteria, which provide an environmental impact assessment in terms of eco-points (Pt). According to ISO 14040:2006 standard, dishwasher’s life-cycle was divided in the following phases:

- production (raw materials, components, assemblies);
- distribution (average distance and transports);
- packaging (type and weight of product packaging);

- use (mean lifespan, energy and water consumption, maintenance and repairs);
- end of life (disassembly, incineration, reuse, disposal, recycle).

The general scheme of this evaluation is shown in Figure 3.

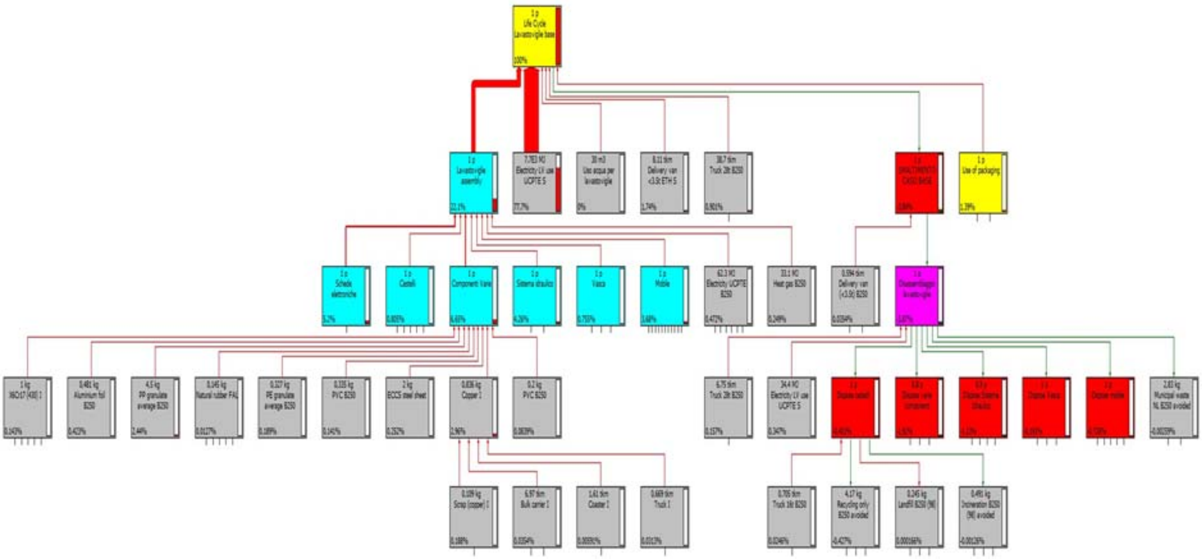

Figure 3. Tree diagram of the product's life cycle phases and sub-phases (obtained using the software SimaPro)

Results of the analysis are shown in Figure 4: reasonably, the most critical phase from an environmental point of view is the use one. It has to be noted that as far as the end of life is concerned, the option "municipal waste" was selected in accordance with the technicians of the company. As for maintenance, usually main activities are performed by the customers, cleaning the filters.

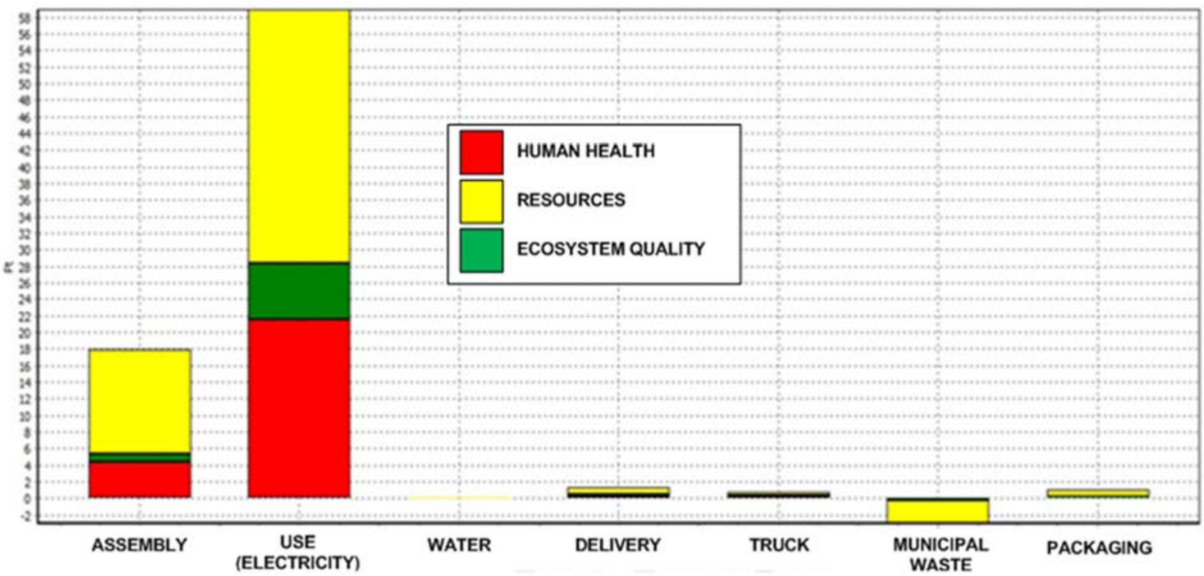

Figure 4. Results of LCA (SimaPro, Ecoindicator 99)

6.3 Life cycle modelling

Since from LCA analysis it emerged that the use phase is the most influential on the product's environmental performances, the method SLCM was used (in Figure 5 a scheme of the method phases and of related inputs/outputs is represented) in order to evaluate the possibility to improve the product's life cycle. The first step of the application of SLCM is to define the base scenario model, whose estimated lifetime is 10 years, on the basis of data collected by interviews with users and taking into account the fact that the consumption of water after 12 years of usage is three times higher and the energy consumption is at least two times (MEEuP Cases Report).

For the “base scenario” 20 years of production (corresponding to 2 life cycles) and a number of sold dishwasher per year of 10.000 were considered. Moreover, no maintenance activities provided by the company are planned and, after 10 years, the product undergoes disposal activities which characterize the municipal waste treatments for household appliances.

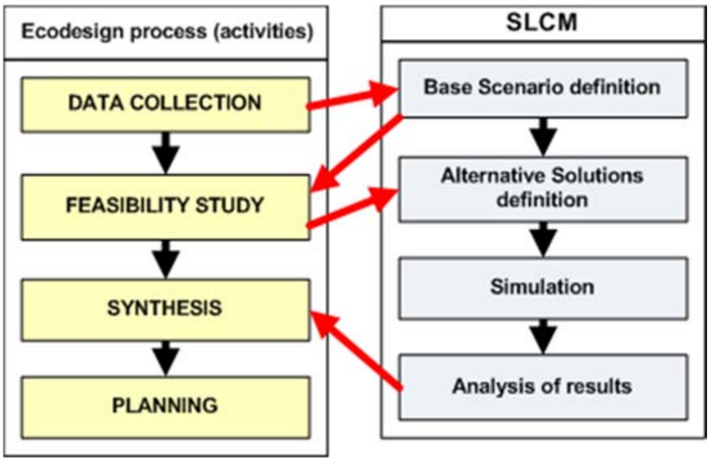

Figure 5. Use of the SLCM method: phases and inputs/outputs

Beside this, two alternative scenarios were developed mainly focusing the attention on: the usage of the product and its disposal. Regarding the first aspect, different options for maintenance and repairing were foreseen, reducing the mean time between maintenance operations. In this case, interventions by technicians are foreseen with the aim of reconditioning the machine. Also the disposal phase was modified by reducing the time the customer uses the same product and foreseeing different options of end of life treatments. These modifications were decided because the simple re-use of the dishwasher with no reconditioning operations is not convenient due to the significant increase of consumptions as time passes. To allow such operations (carried out by the manufacturer's technicians), it is necessary to collect the dishwashers and bring them to a special plant: as replacement the customer receives a new/reconditioned product.

Acting like this, equipment efficiency is preserved during its life and its reliability is sensibly improved. The idea is to provide the customer with a dishwasher service rather than a dishwasher machine, as regular maintenance and refurbishment is included in the contract between customer and provider. In such a contract, the first one has the advantage of using an efficient and reliable dishwasher, whereas the latter can obtain customer’s loyalty. Despite this, the already mentioned positive effects of maintenance with regards to environmental impact can be applied when the maintenance interval is adequately selected. According to data provided by the manufacturer’s customer service, after the first three years of installation, the percentage of dishwasher which can be refurbished with positive effects is around 99%, so this interval was selected as maintenance/reconditioning interval of one of the alternative scenarios, named “PSS 1”. Actually, considering product ageing, after 3 years it is still possible to reuse about 20% of replaced components and only 1% of dishwasher requires disposal. In this case it is reasonable to assume a product’s lifespan of 12 years instead of 10. Following these indications, the second alternative scenario, named “PSS 2”, was developed, considering the reconditioning intervention after 6 years. Since according to the manufacturer data, no relevant failures occur within the first 4 years, it can be foreseen that 90% of products can be reconditioned and re-used after 6 years. It has to be noted that an eco-efficiency factor for new products was used in accordance with [Aoe 2007]. In Figure 6 results of the application of the SLCM are shown: the comparison of different scenarios was carried out using the SimaPro data (Eco-Indicator 99 criteria).

7. Discussion of results

Results obtained from the simulation clearly show the benefits, in terms of environmental burdens, of switching to a product-service system. Both "PSS 1" and "PSS 2" scenarios allow the manufacturer to provide a product having better performances during the usage stage, especially taking into account the consumption of energy and water.

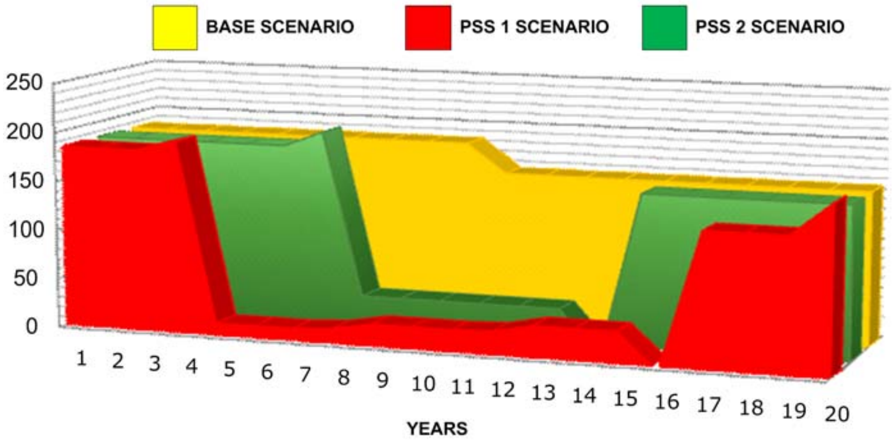

Figure 6. Comparison of the different scenarios (environmental impact is measured in 10^3 Pt)

Moreover, customers can always have at their disposal a product with high functionality. From the producer point of view, the these new scenarios allow them to be in compliance with environmental legislation easier, providing also indication for the product development which could further improve its environmental performances (e.g. a higher level of modularity, different materials, etc.). In fact, it has to be underlined that in all three scenarios the main structure of the machine was not changed. Taking into account the volume of production in the whole scenarios' period, a different behaviour can be noted. As shown in Figure 7, the number of products put on the market following the "PSS 1" scenario (reconditioning after 3 years), the amount of dishwashers provided to customers is after the first 3 years equal to 30.000 units per year. This brings to an environmental impact per customer equal to 52,1 Pt. Instead, considering the "PSS 2" scenario, the number of customers served per year becomes constant after first six years (60.000 customers), that allows a lower environmental impact per customer (ca. 43 Pt). Moreover, in this case, also the number of intervention for reconditioning of the product is inferior, allowing the company to reduce the costs for such activities.

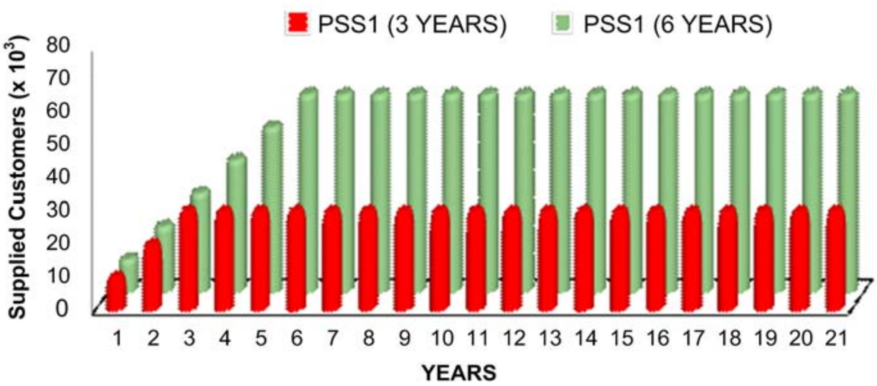

Figure 7. Cumulative number of customers served per each PSS scenario

An alternative approach could have been the product redesign which allowed the extension of its lifespan, initially estimated in 12-14 years, up to 20 years. Nevertheless, according to manufacturer's data, for this kind of products the technological breakthrough interval is short. Products containing high-technology components, such as modern dishwasher, cannot be designed for long life as they tend to quickly become obsolete [Hundal 2000]. Then for this sector is not advisable to foresee a long life. Such an approach lead engineers to foster the design of modules which can be assembled, disassembled and replaced more easily, dividing the product in sub-assemblies which have similar reliability and maintenance characteristics.

8. Conclusions

In conclusion, results of the simulation show that considering a shorter life cycle of the machine, can be very convenient both from the general environmental impact of the product point of view, and from the particular of the energy consumption. The limit of shortening the lifetime of the dishwasher can be set by considering the company bottom line (production, reconditioning and disposal costs), as well as the customer satisfaction for the product/service purchased. In this context, the latter aspect constitutes the bigger hindrance in implementing the PSS approach in the case of households, since not all customers might agree with using a refurbished product (on the contrary of what happens, for example, in the leasing of some equipment for office, such us copy machines of coffee machines). Nevertheless, this aspect needs to be further investigated, taking into account also the terms of possible purchase/leasing contracts between the company and the manufacturer. Such an aspect also positively characterizes the behaviour of the scenario “PSS 2”, in spite of the higher costs and impacts during the production phase. Although the study has shown the potential of the SLCM approach, it requires further studies because of the variety of options that could be employed (especially focusing on different alternatives of maintenance/reconditioning operations). Preliminary results confirmed the importance of considering the PSS approach during the design activity, and underlined its role in increasing the recycling and reuse opportunities with the aim of improving the environmental performances of industrial products.

References

Aoe, T., “Eco-efficiency and ecodesign in electrical and electronic products”, Journal of Cleaner Production, Vol. 15, Issue 15, 2007, pp. 1406-1414.

Fargnoli, M., Kimura, F., “The Screening Life Cycle Modelling in the Sustainable Product Design”, Innovation in Life Cycle Engineering and Sustainable Development, Springer, 2006, pp. 281-292.

Hundal, M., “Design for Recycling and Remanufacturing”, Proceedings of the 6th International Design Conference - DESIGN 2000, D. Marjanovic (Ed.), FMENA, Zagreb, 2000, pp. 165-170.

Kimura, F., “Modeling, Evaluation and Design of Product Quality under Disturbances throughout the Total ...”, The Future of Product Development, Ed. F.-L. Krause, Springer, 2007, pp. 675-684.

Lindahl, M., Tingström, J., “A small textbook on Environmental Effect Analysis”, Dept. of Technology, University of Kalmar, Kalmar, 2001.

McAloone, T.C., Andreasen, M.M., “Designing for Utility, Sustainability and Societal Virtues: Developing Product Service Systems”, Proceedings of the 8th International Design Conference - DESIGN 2004, D. Marjanovic (Ed.), FMENA, Zagreb, 2004, pp. 1545-1552.

Olesen, J. “Environmental QFD – The Creation of Project Focus”, Proceedings of ICED 1997, Volume 1, WDK 25, Tampere, 1997, pp. 323-328.

Raouf A., “Maintenance Quality and Environmental Performance Improvemment: An integrated Approach”, in Handbook of Maintenance Management and Engineering, M. Ben-Daya, S.O. Duffuaa, A. Raouf et al. Eds., Springer London Ltd., 2009,pp. 649-664.

Sakao, T., Shimomura, Y., "Service Engineering: A Novel Engineering Discipline for Producers to Increase Value Combining Service and Product", J. Cleaner Production, Vol.15, n. 6, 2007, pp. 590-604.

Wenzel, H., Hauschild, M., Alting L., “Environmental Assessment of Products - Vol. I: Methodology, tools and case studies in product development”, Chapman & Hall, London, 1997.

Mario Fargnoli, PhD
Technical Director
Ministry of Agriculture, Department of Rural Development
Via XX Settembre 20, Rome, Italy
Telephone: +39 06 4665 5168
Telefax: +39 06 4881 707
Email: m.fargnoli@mpaaf.gov.it