Designing ecofriendly Product-Service Systems (PSSs) through morphological reasoning

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Abstract

Product-Service Systems (PSSs) have emerged in the last years as a means of integrating products and services in a coordinated manner, to deliver functional results that increase customer value while achieving environmental sustainability. Nevertheless, the design and development of these systems is hindered by the absence of consistent and robust approaches that facilitate their implementation. The initial phases of the design of any solution, product or service oriented, are the vital stages where its key elements are determined. The research proposes a functional approach based on morphological reasoning to address the PSS design concerns. The approach enables the integration of products and services while capturing the values and costs of their respective providers and receivers. Life cycle modeling is then applied to evaluate the environmental impact of such a concept while a cost analysis portrays the economic benefits that can be achieved. A case study at an agricultural manufacturer demonstrates the use of the described approach and exhibits the advantages that can be achieved through a PSS application.

Keywords
Product-service systems; morphological thinking; functional analysis; life cycle assessment; life cycle costing

1. Introduction
Product-Service Systems (PSSs) have significantly expanded in recent years allowing manufacturers to achieve economic benefits through increased customer satisfaction while improving the environmental performance of their offerings (Lindahl et al., 2014; Meier et al., 2010; Fargnoli et al. 2018). To achieve these goals, PSSs consist of shifting from stand-alone product sales towards the provision of functional results (Tukker, 2004). As noted by Mont (2002) and Beuren et al. (2013) manufacturers integrate services in their offerings as a means of achieving these functional results which leads to innovative solutions and an improved market position. Alongside the "business" advantages that PSSs offer, several advantages also relate to the environment as the consumed resources are minimized, the product and its use are optimized, the life cycle of the solution is improved, and several End-of-Life (EoL) strategies can be put in place such as recycling, reconditioning and product recovery schemes (Tran and Park, 2015; Haber and Fargnoli 2017a). Nevertheless, caution is advised as PSSs can have detrimental "rebound" effects from an ecological standpoint if uncarefully implemented (Tukker and Tischner, 2006). A consequence would be the achievement of economic outcomes at the expense of unwanted environmental outcomes thus jeopardizing the feasibility and success of the PSS (Tukker, 2004; Bocken et al., 2014).
To achieve these benefits, suitable stakeholder networks and innovative thinking that allow an effective integration of products and services are required (Baines et al., 2007; Meier et al. 2010; Sakao and Fargnoli 2010; Durugbo, 2013; Vasantha et al. 2012; Vezzoli et al. 2015). Several studies were proposed as possible ways to successfully implement a PSS in practice (i.e. Baines et al., 2007; Sakao and Lindahl, 2009; Sakao et al., 2009; Haber, 2017).

While the extent of research carried out in this context (Morelli, 2006; Lee and Abu Ali, 2010; Masanell and Ricart, 2010; Geum et al., 2011; Barquet et al., 2013; Carreira et al., 2013; Marques et al., 2013; Touzi et al., 2013; Zine et al., 2014; Trevisan and Brissaud, 2016) reflects the popularity of integrated product-service solutions (i.e. PSSs), it also highlights the existing deficiencies for designing and developing these functional offerings (Maussang et al., 2009; Amaya et al., 2014; Exner et al., 2014).

In fact, Tran and Park (2014) argue that the main hindrance that occurs when developing PSSs resides in the integration process: combining product and services in a practical manner on one hand while creating value for manufacturers and customers alike on the other. The integration process for PSSs descends mainly from product development (Scheuing and Johnson, 1989; Oliva and Kallenberg 2003; Shekar, 2007; Haber and Fargnoli, 2017a) yet the adaptation of some product development and design approaches are impractical from a PSS point of view (Tran and Park, 2014). In addition, an inadequate adaptation (and implementation later) may result in a negative environmental impact which opposes one of the key objectives of a PSS, i.e. a lower environmental impact than traditional business models (Mont, 2004; Baines et al., 2007; Tischner et al., 2009; Reim et al., 2014)

As pointed out by Aurich et al. (2010) and Vasantha et al. (2012), while implementing a PSS approach, the main difficulties arise in the conceptual design stage, when a decision has to be taken as to which solution better accomplishes both customer needs as well as environmental concerns.

Based on the considerations and to address the issues mentioned above, this paper seeks to answer the following Research Questions (RQ):

RQ. How to select a suitable PSS solution that satisfies both the customers' and company's expectations?

To address the RQ, we utilize a functional decomposition approach to develop PSSs using morphological thinking as a means of generating and developing PSSs at a conceptual level since it is at this stage the focal components of the solution are defined (Haber and Fargnoli, 2017b). The proposed approach is then applied at an agricultural equipment. Its feasibility is verified through the Screening Life Cycle Modeling (SLCM) method (Fargnoli and Kimura, 2006), while also a cost analysis was performed to evaluate the benefits achieved. This contributes in extending current PSS studies when it comes to comprehensively addressing the elements of a PSS to achieve environmentally friendly results. The rest of the paper is articulated as follows: Section 2 illustrates the proposed approach, which is carried out at a case study in section 3. Section 4 discusses the achieved results while section 5 concludes the article and reflects on future work.

2. Proposed approach

The following section addresses the incentives and description of the proposed approach for PSS design. The first section (2.1) briefly describes the function-oriented morphological matrix and exposes its proposed adaptation to a PSS context. The second section (2.2) defines the PSS assessment model while section 3 schematizes the framework for PSS concept development.

2.1 PSS design

The motivations towards adopting a functional approach to developing PSS concepts lie within their predecessor's (i.e. stand-alone products) approach to generating solutions. As argued by Andreasen (1992), a system is represented by a main function consisting of sub and elementary functions that meet the customers' requirements when effectively combined. Furthermore, a functional approach facilitates the design and development of a solution as its decomposition into modular tasks (i.e. sub-functions) reduces business risks and facilitates the product-service integration process (Cavalieri and Pezzotta, 2012; Tukker, 2013). Morphological thinking is an effective form of functional reasoning as it decomposes multi-dimensional tasks and activities into sub-tasks and sub-activities, notably useful in engineering design (Zwicky, 1948). Furthermore, in such a context, it facilitates the representation and exploration of the design activities by listing the functions and their derivatives against their respective actuators (Table 1) (Pahl and Beitz, 2007; Ulrich and Eppinger, 2008).

Table 1. Scheme of the morphological matrix (adapted from George, 2012)

Function	Actuators to realize each function			
F_1	$AC_{1,1}$	$AC_{1,2}$	…	$AC_{1,m}$
F_2	$AC_{2,1}$	$AC_{2,2}$	…	$AC_{2,m}$
⋮	⋮	⋮	⋮	⋮
F_n	$AC_{n,m}$	$AC_{n,m}$		$AC_{n,m}$

PSS conceptualization and design differ from conventional product design by the insertion of services to achieve the required overall function. The latter requires integrating human actors such as providers and receivers who play a pivotal role regarding service quality and interactions. Once the main function is outlined and well defined, it can be divided into sub-functions. Moreover, the providers and receivers are also fragmented: each sub-function will require its own PSS Provider (SP) and Receiver (SR). To clarify the service actors and their respective activities, Kim et al. (2010) suggest the use of the Service Blueprint (SB) illustrating the providers and receivers' involvement (Figure 1). On the one hand, the internal interactions are invisible to the PSS receiver (s) and comprise of actions and activities within the manufacturer's environment. On the other hand, external interactions represent the activities visible to the PSS receiver (s). In our context, these activities, both visible and invisible will be treated as functions that comprise of their respective actors and measures to fulfill them (e.g. actuators) (Haber, 2017).

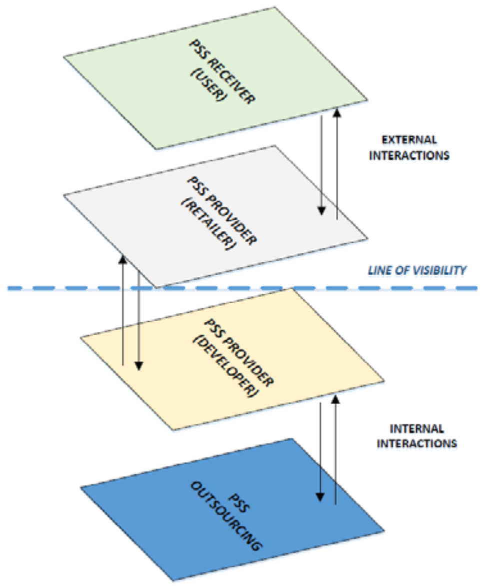

Figure 1. Adapted PSS blueprint

The functions, actuators, providers, and receivers have to be addressed comprehensively for a successful product-service integration that maximizes value for all the stakeholders involved (i.e. providers and receivers). Hence the morphological matrix is adapted to a PSS setting as can be seen in Table 2. Each sub-function requires its specific actuator(s), provider(s) and receiver(s) and is then evaluated to bring forward its associated costs and value at a preliminary level (Table 3).

Table 2. Morphological matrix in a PSS setting (adapted from Haber and Fargnoli, 2017)

Sub-Functions	**Elementary Functions**	**Product/Service Actuators**			**Actuator Provider**		**Actuator Receiver**	
PSS sub function A	A.1	$P/S_{A1.1}$	$P/S_{A1.2}$	$P/S_{A1.3}$	$SP_{A1.1}$	$SP_{A1.2}$	$SR_{A1.1}$	$SR_{A1.2}$
	A.2	$P/S_{A2.1}$	$P/S_{A2.2}$	$P/S_{A2.3}$	$SP_{A2.1}$	$SP_{A2.2}$	$SR_{A2.1}$	$SR_{A2.2}$
	A.3	$P/S_{A3.1}$	$P/S_{A3.2}$	$P/S_{A3.3}$	$SP_{A3.1}$	$SP_{A3.2}$	$SR_{A3.1}$	$SR_{A3.2}$
	A.4	$P/S_{A4.1}$	$P/S_{A4.2}$	$P/S_{A4.3}$	$SP_{A4.1}$	$SP_{A4.2}$	$SR_{A4.1}$	$SR_{A4.2}$
PSS sub function B	B.1	$P/S_{B1.1}$	$P/S_{B1.2}$	$P/S_{B1.3}$	$SP_{B1.1}$	$SP_{B1.2}$	$SR_{B1.1}$	$SR_{B1.2}$
	B.2	$P/S_{B2.1}$	$P/S_{B2.2}$	$P/S_{B2.3}$	$SP_{B2.1}$	$SP_{B2.2}$	$SR_{B2.1}$	$SR_{B2.2}$

Table 3. Descriptive evaluation of the PSS sub-functions

Elementary Function	**Product/Service Actuator**	**PSS Provider**	**PSS Receiver**	**Value for Provider**	**Cost for Provider**	**Value for Receiver**	**Cost for Receiver**
A.1	$P/S_{A1.2}$	$SP_{A1.2}$	$SR_{A1.1}$	Value-$P_{A1.2}$	Cost-$P_{A1.2}$	Value-$R_{A1.1}$	Cost-$R_{A1.1}$
A.2	$P/S_{A2.1}$	$SP_{A2.1}$	$SR_{A2.2}$	Value-$P_{A2.1}$	Cost-$P_{A2.1}$	Value-$R_{A2.2}$	Cost-$R_{A2.2}$
…	…		…	…	…	…	…
The matrix is continuously filled out until all functions (Table 2) have been described							

2.2 PSS modeling

Although numerous studies have addressed the sustainability assessment of PSSs (Morelli, 2006, Vezzoli et al., 2014; Shimomura et al., 2015; Chou et al., 2015), few research works have proposed tools for dealing with it in the early design stages of their development (Fargnoli et al., 2014; Sousa-Zomer and Miguel, 2017).

In product design, the most common approach to analyze and improve environmental performance is the Life Cycle Design (LCD), which is aimed at the identification and evaluation of the environmental performances of a product through all the phases of its lifecycle (Kobayashi, 2006; Kimura 2007; Umeda et al., 2012; Fargnoli et al., 2013; Cluzel et al., 2014).

Accordingly, a life-cycle design approach can be effectively applied to evaluate the environmental performances of a PSS (Aurich et al., 2006), where the focus of the analysis is represented by the functional units, since a PSS includes both tangible and intangible elements.

In such a context, the development of a product life cycle simulation (Life Cycle Modelling, LCM) allows the integration of the PSS technical issues and its management, enabling engineers to evaluate the environmental performances of the system along with the duration of the PSS contract. With this goal in mind, the SLCM method can be used, as means to make a comparison between different PSS scenarios, according to a limited number of factors regarded as particularly important (Fargnoli et al., 2012). Such a tool consists of a streamlined life cycle simulation aimed at evaluating the main environmental impacts related to a system life cycle where the assessment criteria are based on the ones which characterize the traditional LCA. The main phases of the method can be summarized as follows (Haber and Fargnoli, 2017a):

- Base Scenario (BS) definition, where the life cycle model of the existing system is defined;
- Alternative Scenario/s (AS) definition, where one or more models are developed based on the design requirements provided in the earlier stages of the design process.
- Simulation, where the life cycle analysis of both the BS and the AS is carried out.
- Analysis of results, where the results of the simulation are compared and critically analyzed in order to deploy a feasibility study

In order to obtain more efficacious results, the design requirements based on which the scenarios' development is based should be defined by means of techniques that allow engineers to capture the customers needs, such as questionnaires and interviews, as well as the Quality Function Deployment (QFD) based tools (Kim and Yoon, 2012; Fargnoli and Sakao, 2017).

2.3 General framework for PSS conceptual design

Based on the above considerations a general framework for the development of PSS can be drawn up, focusing the conceptual design stage in order to provide a feasible functional solution that can meet both the company and the customers' needs. A scheme of such a framework is represented in Figure 2, where only the conceptual phase of the PSS development process is represented.

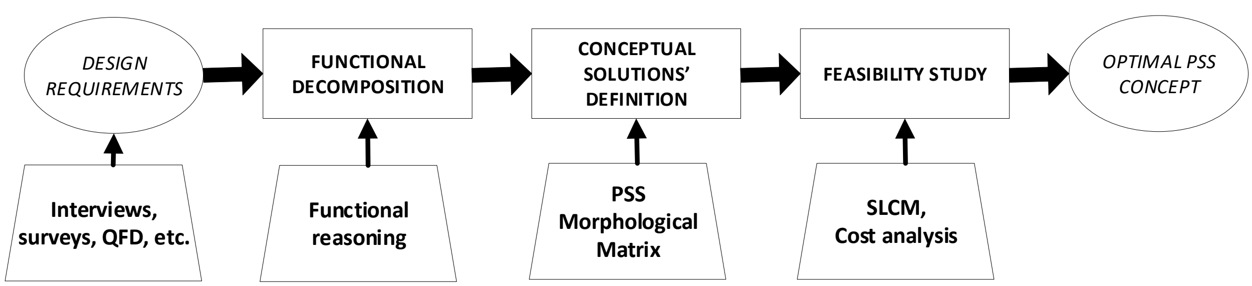

Figure 2. Scheme of the proposed approach

3. Case study

3.1 Overview

To verify the practicality of the PSS conceptual design framework, it was tested through the following case study, which took place at a manufacturer operating in the agricultural sector. In detail, the manufacturer produces Lawn Mowers (LMs) which are used in gardening applications. The LM weighs 48kg and consists of 4 main components: a 2.4 kW engine (displacement 150 cubic centimeters), a self-propelled single-gear advancement system, an aluminum mower deck and an endowment system.

Despite the growth of this market, the manufacturer noted a revenue-decrease due to decreased sales of the product. Accordingly, he wants to address this topic by implementing a PSS rather than keeping his conventional sales-based business model.

The LM is destined for non-professional and semi-professional users owning small and medium sized gardens. Its lifespan is of 10 years and the engine is warrantied for 500 operational hours.

Market surveys performed by the manufacturer's marketing and customer care personnel underlined the customers' complaints regarding the reliability of the LM and its maintenance. The main findings of this analysis can be summarized as follows:

- although the LM is designed for 10 years, its average lifespan is approximately 7 years due to the negative effects of incorrect maintenance (often carried out by the users themselves);
- since the cost of a new engine represents 60% of the price of a new product, customers opt for a new equipment instead.

In addition, the surveys revealed the customers' interest in environmentally friendly solutions when purchasing a LM.

Considering the above information, the study opted for a business model focusing on a life cycle perspective as the correct management of the product's (i.e LM) life cycle can improve its environmental impact and reliability. Accordingly, this would lead to better customer satisfaction as well.

To address the maintenance concerns, which are the basis of the customers' current dissatisfaction, the manufacturer is seeking to keep the ownership of the LM as a means of ensuring its correct maintenance and thus reliability and performance. To do so, the manufacturer wishes to develop a leasing scheme, which falls under the category of Use-Oriented PSSs (Tukker, 2004). Following this scheme, the manufacturer is responsible for the production, maintenance and disposal of the LM while the customer pays a fee for its use for a specific period of time. Accordingly, we carried out an additional analysis in collaboration with the experts from the Italian Ministry of Agriculture and from the National Union of Agricultural Machinery Dealers (UNACMA): 10 different dealers of gardening equipment were interviewed by means of a semi-structured questionnaire concerning the main maintenance activities carried out in the last 5 years on this type of LMs, the type of operations, and the costs. The results of this analysis allowed us to define a set of PSS design requirements that accomplish the new business model.

3.2 Application of the PSS morphological approach

The development of the leasing scheme takes place according to the suggested design approach exposed in section 2.1. The main function to fulfill is "grass cutting" and it is decomposed into sub-functions where the fulfillment of each contributes to the holistic solution (Table 4).

Table 4. Functional decomposition of "grass cutting"

<table>
<tr><td>Main Function</td><td colspan="4">Grass cutting</td></tr>
<tr><td>Sub-functions</td><td>1. Gathering customer information</td><td>2. Providing cutting</td><td>3. Providing maintenance</td><td>4. Providing End of Life (EoL) service</td></tr>
<tr><td rowspan="4">Elementary functions</td><td rowspan="4">N/A</td><td>2.1 Providing cutting equipment</td><td rowspan="2">3.1 Providing ordinary maintenance</td><td rowspan="2">4.1 Providing recovery of the LM</td></tr>
<tr><td>2.2 Delivering cutting equipment</td></tr>
<tr><td>2.3 Providing cutting settings</td><td rowspan="2">3.2 Providing extraordinary maintenance</td><td rowspan="2">4.2 Providing EoL treatment of the LM</td></tr>
<tr><td>2.4 Providing cutting activity</td></tr>
</table>

Then, the morphological matrix adapted to PSSs was applied to identify the actuators, providers and receivers of each function.

The evaluation of each function is then carried out to provide feasible solutions that meet the design requirements aimed at implementing a leasing offering. The results of this analysis are represented by the definition of a conceptual PSS scheme (shaded parts in Table 5), whose preliminary assessment is summarized in Table 6.

Table 5. Application of the PSS-Morphological Matrix

Sub-functions	**Elementary functions**	**Product / service actuators**			**Actuator provider**			**Actuator receiver**		
1. Gathering customer information	N/A	Customer interaction	Online form		Cust.	Manu.	3rd Party	Cust.	Manu.	3rd Party
2. Providing cutting	2.1	Leasing	Rental	Purchase	Cust.	Manu.	3rd Party	Cust.	Manu.	3rd Party
	2.2	Customer pick-up	Home delivery		Cust.	Manu.	3rd Party	Cust.	Manu.	3rd Party
	2.3	Product manual	Training	None	Cust.	Manu.	3rd Party	Cust.	Manu.	3rd Party
	2.4	Lawn mower			Cust.	Manu.	3rd Party	Cust.	Manu.	3rd Party
3. Providing maintenance	3.1	Preventive maintenance	Predictive maintenance	Risk based maintenance	Cust.	Manu.	3rd Party	Cust.	Manu.	3rd Party
	3.2	Immediate corrective maintenance	Deferred corrective maintenance		Cust.	Manu.	3rd Party	Cust.	Manu.	3rd Party
4. Providing EoL service	4.1	Product return	Product take-back	None	Cust.	Manu.	3rd Party	Cust.	Manu.	3rd Party
	4.2	Recycling and reuse	Landfill		Cust.	Manu.	3rd Party	Cust.	Manu.	3rd Party

Table 6. Qualitative assessment of the proposed solution

Elementary Function	**Product/Service Actuator**	**PSS Provider**	**PSS Receiver**	**Value for Provider**	**Cost for Provider**	**Value for Receiver**	**Cost for Receiver**
1	Customer interaction	Cust.	Manu.	Information for improvement	Customer care resources	N/A	N/A
2.1	Leasing	Manu.	Cust.	Control over LM	Production and contract	LM	Cost for temporary use of LM
2.2	Home delivery	Manu.	Cust.	N/A	Distribution	LM at his location	N/A
2.3	Training	Manu.	Cust.	N/A	Training personnel	Instructions and knowledge for use of the LM	N/A
2.4	Lawn mower	Cust.	Cust.	Use of LM	Fuel cost	Use of LM	Fuel cost
3.1	Preventive maintenance	Manu.	Cust.	Correct maintenance using original parts and qualified personnel	Maintenance parts and service technicians	Performance and reliability of LM	N/A
3.2	Immediate corrective maintenance	Manu.	Cust.	Correct maintenance using original parts and qualified personnel	Maintenance parts and service technicians	Performance and reliability of LM	N/A
4.1	Product take-back	Manu.	Manu.	N/A	Transportation	LM recovery	N/A
4.2	Recycling and reuse	Manu.	Manu.	N/A	Disassembly and assembly	Reduced production	N/A

The defined PSS concept represents the leasing scheme (6+6) that the manufacturer seeks to implement. The leasing solution consists of the customer leasing the LM to carry out the cutting activities himself while the manufacturer handles the necessary maintenance activities and takes back the product at the end of the lease period (6 years). Furthermore, the manufacturer provides customer training to ensure the proper use of the LM and to help avoid breakdowns and reduced performance. When maintenance is due (i.e. ordinary), the customer brings the LM to the manufacturer's center following the schedule provided by the latter. Upon recovery of the LM at the end of the 6th year, the manufacturer provides the customer with a reconditioned LM for another lease period of 6 years. This takes place during winter months when gardening activities are minimal. Thus, the ownership of the LM remains with the manufacturer and the customer is charged a fee for its use for a defined period.

3.3 Feasibility analysis

To better evaluate the feasibility of the PSS concept (i.e. in quantitative terms) the SLCM method is used. It consists of comparing the current sales model (i.e. the Base Scenario (BS)) to the proposed leasing solution (i.e. the Alternative Scenario (AS)).
First of all, the BS is defined according to the following assumptions:

- Lifespan of the LM: 10 years
- Production: 30 LMs per year at a constant basis
- Distribution: the average distance is of 100 km as per the manufacturer's recommendations
- Maintenance: according to the manufacturer's recommendations and in collaboration with gardening machinery experts, the maintenance activities can be classified into two categories: ordinary and extraordinary. The schedule of each activity alongside its associated costs (in American dollars (USD)) and duration (in minutes (min)) is depicted as follows:
    - Ordinary Maintenance (OM): (determined per the manufacturer's recommendations)
        - Per 1 year (OM1): replacement of engine oil, cleaning of fuel and air filters (30 USD; 30 min)
        - Per 2 years (OM2): replacement of engine's spark plugs (24 USD; 10 min); replacement of the battery (60 USD; 30 min)
        - Per 3 years (OM3): replacement of distribution belt (72 USD; 50 min)
        - Per 5 years (OM5): sharpening of cutting blades (36 USD; 30 min); replacement of fuel and air filters (36 USD, 30 min); replacement of wheels (60 USD; 20 min)
    - Extra-ordinary Maintenance (EM): (determined in accordance with gardening machinery experts and the manufacturer's experts)
        - Per 2 years (EM2): sharpening of deteriorating blades (36 USD; 30 min)
        - Per 3 years (EM3): repair of malfunctioning engine (60 USD; 30 min); replacement of the throttle cable (24 USD; 20 min)
        - Per 5 years (EM5): replacement of deteriorating battery (60 USD; 30 min); replacement of blades (60 USD; 30 min)

Second, the AS envisages the following changes to the maintenance schedule as the lifecycle of the LM is extended to 12 years given the 6+6 leasing scheme (Table 7).

Table 7. Maintenance interventions in the BS and AS

	BS (10-year life cycle)											
Year	1	2	3	4	5	6	7	8	9	10	11	12
OM1	●	●	●	●	●	●	●	●	●	●		
OM2		●		●		●		●		●		
OM3			●			●			●			
OM5					●					●		
EM2		●		●		●		●		●		
EM3			●			●			●			
EM5					●					●		
	AS (12-year life cycle)											
OM1	●	●	●	●	●		●	●	●	●	●	●
OM2		●		●			●		●		●	
OM3			●					●			●	
OM5					●					●		
EM2		●		●			●		●	●		●
EM3			●					●				
EM5					●					●		

The changes to the maintenance schedule also leads to improved costs and time (i.e. intervention duration) which vary as shown in Table 8.

Table 8. Comparative results of maintenance cost and time

	Cost	Time
Base Scenario (10-year life cycle)	1872 USD	1230 min
Alternative Scenario (12-year life cycle)	1854 USD	1270 min
Base Scenario (yearly)	187 USD	123 min
Alternative Scenario (yearly)	155 USD	106 min

Additionally, the Life Cycle Assessment (LCA) method was carried out using SimaPro 7.3 software and the Eco-Indicator 99 (EI99) evaluation criteria (Goedkoop and Spriensma, 1999). Due to manufacturer's privacy concerns, the EoL values cannot be shown but were included to allow an accurate assessment (Figure 3). Then a simulation was run over 15-year period taking into consideration the BS an AS characteristics described earlier (Figure 4).

Figure 3. Comparative LCA results

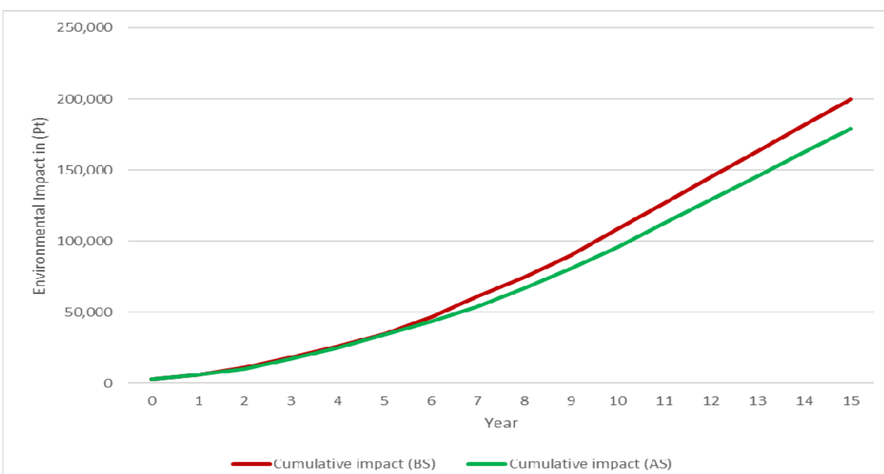

Figure 4. Comparative cumulative environmental impact results

4. Discussion of results

From the case study, it emerged that the proposed approach provided a conceptual solution that portrays benefits from an economic point of view as well as an environmental one. On the one hand, the AS shows a reduced maintenance time and cost when adopting the leasing option compared to the existing sales model where these factors are higher and confirm the resulting dissatisfaction expressed by the customer

On the other hand, the results of the LCA and the simulation show positive results from adopting a PSS (i.e. leasing) instead of the existing model (i.e. sales). In detail, the LCA shows an environmental impact of 381.6 Pt over 12 years (31.8 Pt/year) compared to 366.8 Pt over 10 years (36.7 Pt/year). In other terms a 13.4% improvement. Moreover, the simulation underlines this improvement as over the course of 15 years, the BS leads to 199,931 Pt while the AS achieves 178,932 Pt. Thus a 10.5% improvement in environmental terms. This is due to the more effective maintenance and EoL activities. In details, the AS, through the recovery of the product and its reconditioning reduce the production resources when manufacturing new LMs. The customer experience and satisfaction is increased as well since the maintenance activities take place at the manufacturer's thus ensuring the product's performances and better reliability given a reduced risk of failures and breakdowns. Accordingly, the manufacturer would benefit from a better reputation of its product, increased customer retention and lower production costs as the EoL measures (i.e. product take-back, recycling and re-use) lead to a reduced amount of resources for further production.

From a more general perspective, the proposed approach can represent an answer to the lack of tools for PSS conceptual design tools, which has been stressed by several authors (i.e. Doualle et al., 2016, Rondini et al., 2017).

In particular, the use of the PSS Morphological Matrix allowed us to provide a solution that matches the customers' requirements with the company needs, augmenting the value of the PSS offering. This result is in line with research findings provided by Kim et al. (2013). Moreover, its combination with other methods (e.g. SLCM) can prevent the occurrence of overdesigning, while augmenting the effectiveness of the conceptual design phase.

In conclusion, in line with Cavalieri et al. (2012), it has to be stressed that the use of a morphological approach can help PSS designers in providing solutions in a structured manner relying on the feasibility and combinability of modular results. Further research work should consider the latter aspect, given the benefits that modularization can have in PSS development (Sun et al., 2017; Sakao et al., 2017).

5. Conclusion

PSSs represent a feasible approach for providing customer value while enhancing environmental sustainability. The main hindrance resides in shifting from product development to PSS development through an effective integration of products and services. To address this topic, the research proposed a functional approach to developing PSSs through morphological reasoning and life cycle modeling. In detail, it showed how the elements of a PSS (products, services, providers and receivers) can be addressed simultaneously and comprehensively at a conceptual stage to ensure an effective design. The case study verified the proposed approach as it led to an improved maintenance schedule. The schedule of the PSS resulted in lower costs and intervention time on one hand, and a better environmental performance on the other.

Nevertheless, some limitations should be noted. For instance, a holistic feasibility analysis should be carried out to ensure the success the of the solution and its realizability from a manufacturer's point of view. Life Cycle Costing (LCC) methods can be applied to address the latter. Furthermore, a broader application of the approach to other fields can help refine it and provider further insight concerning its validity and applicability.

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