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SUSTAINABLE PRODUCT-SERVICE DESIGN IN MANUFACTURING INDUSTRY

M. Peruzzini, E. Marilungo and M. Germani

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1. Introduction

The interest of manufacturing enterprises in Product-Service (P-S) is growing; indeed, the transition from selling traditional products to proposing product-service integrated solutions can bring a new strategic advantage and consequently greater earnings. It is particularly challenging for manufacturing companies. However, the majority of manufacturing enterprises is still far to propose P-S solutions ready for the market because they are strongly focusing on the product: as a consequence, they are not well organized for service design, they adopt product-centred design approaches, and finally they lack of structural methods and tools to guide P-S design. Furthermore, industrial research is more focused on the technological support instead of design strategies. Contrariwise, P-S design must be strongly user-centred to be successful, more than on technology, to acquire a new market and create new expectations in the customers. In fact, creating a P-S implies two important changes in company processes: firstly, traditional product lifecycle has to be enhanced by including also service management; secondly, the product-oriented company model must be extended to realize a service-oriented ecosystem [Peruzzini et al. 2012]. Indeed, interrelations between products and non-physical services are complex to model and they require managing new relationships between different stakeholders, which are organized in the so-called Virtual Manufacturing Enterprise (VME). In this context, the new relationships allow realizing the company's P-S idea thanks to the exploitation of the whole ecosystem capabilities.

In this context, the paper proposes a methodology to support the design of manufacturing P-S solutions from the earliest lifecycle stages and to guarantee the satisfaction of the customer needs. For this purpose, each company has to design in a collaborative way by creating the right ecosystem which combines the necessary knowledge and skills, and defining the reference P-S model to manage all information about key resources, key partners, and key activities in the VME. Furthermore, sustainable P-S solutions have to be designed according to the modern market trends and regulations. For this task, having a preliminary sustainable assessment during the early design stages is fundamental to support strategic decision-making, define the most appropriate target market and business model, and identify the best solution. The method validity is demonstrated by an industrial case study focusing on a mechatronic appliance extended with a tailored service: it combines a modern washing machine with service mobile applications and creates different business models addressing different target markets to exploit the P-S capabilities.

2. Research Background

2.1 Product-Service innovation in the VME

Numerous manufacturing companies are pushed to move from a product-oriented design to an innovative scenario based on services, when a new interpretation of the concept of product is adopted and design involved both product and services [Manzini and Vezzoli 2002]. A P-S consists of a mix of product and services designed coherently and combined in order to increase the value for customers, starting from the idea of the Extended Product [Thoben at al. 2001]. According to this new perspective, services can be used to differentiate and support the product by the creation of a new Product-Service Systems (PSS) able to integrate tangible assets (materials, technologies, processes and all staff related typically to the product) and intangible assets (skills, competencies, services and all information related to human factors). In literature some examples of P-S co-creation exist [Hosono et al. 2013], but they are focused on the development of methods and tools to apply in production phase while there is a lack on the design phase.

The design and implementation of a PSS necessarily requires the creation of a VME as an organized and structured network of partners and stakeholders; it allows exploiting the necessary tangible and intangible assets and creating valuable solutions with a competitive advantage to share among all partners. Furthermore, creating a VME entails moving from the traditional concept of manufacturing enterprise to the new idea of virtual networks [Thompson 2005]. Indeed, VME is a temporary aggregation of several business partners focuses on the realization of a specific PSS idea in order to propose it on the market, sharing knowledge, costs and resources among the companies and stakeholders involved. Temporary association because the P-S solution can change over the time in terms of functionalities exploited by the service, and for this reason it is necessary have in the ecosystem another partner able to satisfy the new extension of the P-S solution. This aspect is very different from a product-oriented solution, where each change remains within the company, which holds its development, because it has all the competences, knowledge, skills and experience needed.

However, the VME creation implies the definition of a proper business model in order to recognize the strategic factors for each partner as well as the key resources and activities to involve in the P-S scenario to develop [Ghaziani and Ventresca 2005]. It also allows identifying the PSS strategy. Indeed, Canvas model [Osterwalder and Pigneur 2009] gives a clear definition of how an organization creates, delivers, and captures value in a simple way and the model can be shared and easily understand by all the VME partners. In particular we refer to the concept of Business Model (BM) as define by Bieger et al. [2011]. According to them, there is a set of central issues that a good BM should be defined and support the PSS design, which can be summarized by the following questions:

1. Which tangible and intangible assets are needed?
2. How can the greatest value-added be achieved within a specific market?
3. What is the best way to address the target customer?
4. How are products and performance innovation designed?
5. How can these elements be combined to create a positive growth?
6. What are the relations between product and services?
7. How is the value-added design chain configured? What opportunities exist for teamwork between different members within the design chain?

Recently, the actual heavy competition among companies pushes toward new business ideas; in this context designing a PSS can create an increase value perceived by the customer and a more flexible and personalized offer. On the other hand, it requires an organized VME and a successful business model. Another open issue refers to the PSS design validation: indeed, it is not easy understanding the performances of such new service-based solutions in respect with the product performance for both designers and customers. Sometimes they seem very promising but they cannot be easily tested and validated.

In past years, some studies focused on the optimization of sustainability impacts and visualization of the achieved benefits to the customers [Otto et al. 2003]; but they are mainly focused on LCA of products. As a consequence, they are not useful to guide the product or service design phase and they focuses on understanding sustainability performance without deepening how the results are obtained. To solve this issue, assessing sustainability of PSS can be a good way to understand also both the performances and analyses the results' composition [Peruzzini and Germani 2013]. Indeed, such an analysis considers all the partners' contributions within the collaborative network and allows designing the most promising solutions on the market and the most performing design alternatives.

2.2 Sustainability for PSS

It has been proven that service-enhanced products can provide not only a higher customer satisfaction [Garetti et al. 2012], but also a great advantage on the sustainability [McAloone et al. 2010]. In particular, sustainability is assuming a relevant role in both customer choices as the people attention to energy saving and environmental issues are increasing on the markets [Xing et al. 2013]. The modern sustainability thinking considers three dimensions: environment, economics and social wellbeing [Adams 2006]. From the economic viewpoint, services create new market potentials and higher profit margins, and can contribute to higher productivity by means of reduced investment costs along the lifetime as well as reduced operating costs for the final users. From an ecological viewpoint, P-S can be more efficient thanks to a more conscious product usage, an increased resource productivity and a close loop-chain manufacturing as reported by some examples [Favi et al. 2012]. Finally, services are able to support the building up and securing of knowledge intensive jobs, and can contribute to a more geographically balanced wellbeing distribution [Tukker and Tischner 2006].

In the manufacturing industry, product sustainability can be achieved by adopting lifecycle design approaches: they allow quantifying product impacts and providing tangible commercial values in terms of efficiency and costs [Jeswiet 2003]. They are based on the definition of several indicators to assess the lifecycle performance and support comparative analysis. Some techniques to support this described lifecycle design approach are the LifeCycle Assessment (LCA) [ISO 14040:2006], in order to evaluate the environmental impacts, and the LifeCycle Cost Assessment (LCCA) [Woodward 1997], in order to recognize all the economic impact during the product lifecycle. Recently, also the social impacts have been included in the lifecycle design approach by the so-called Social LifeCycle Assessment (SLCA) [Weidema 2006].

Recently some researches faced the sustainability issue for PSS [Mont 2002], [Young 2010], but they do not adopt lifecycle approaches. Recently some researches propose to translate a lifecycle design (LCD) approach to PSS [Peruzzini et al. 2013], [Kwak et al. 2013]: the demonstrate how to assess the sustainability impacts of an integrated P-S lifecycle system by considering not only the impacts related to the product realization, usage and dismissing, but involving also the ecosystem actors. In fact, PSS design implies the development of a new set of relationships among the stakeholders involved in the PSS network [SUSPRONET]. It means to involve organizations, public bodies, tertiary service providers and also the customers to create a new business framework that is organized to support both product and service lifecycles [Wiesner et al. 2013].

Furthermore, we found that VME organization and related business models have never been considered yet in sustainability assessment or the related partners' impact investigated separately taking into account the business model.

3. Methodology for Sustainable Product-Service Design

In order to design sustainable P-S solutions, this research aims to carry out a complete and reliable PSS sustainability assessment considering both the VME and the business models during the design stages. In particular, it proposes a structured methodology to investigate the three sustainability dimensions (i.e. environment, economics and social wellbeing) according to an integrated P-S lifecycle, the PSS ecosystem network (i.e. VME) and the business models proposed.

The considered lifecycle is an extension of the product lifecycle, that traditionally considers three macro-phases: manufacturing, use, and end-of-life. It extends product lifecycle by adding service activities concerning design, implementation, operation, and decommission, as well as PSS definition that consists of PSS creation, PSS commercialization, and PSS delivery). Such integrated lifecycle has been also used in a recent study [Peruzzini et al. 2013].

The present research focuses on the early lifecycle stages, from the idea generation to the end of design stages. Indeed, these phases are the most critical for manufacturing companies when they decide to move from product to P-S. Figure 1 shows the method structure and its main steps. The method interests the early lifecycle phases, from ideation to release to production / implementation, and for each phase it identifies a proper supporting tool, which identifies the specific requirements and defines an element of the PSS solution to be realized. There are four main steps:

1. Identification of concepts and ideas: it aims to find out several ideas related to the service-enhanced products by means of brainstorming and focus groups involving different departments (i.e. marketing, IT, service, R&D). Such stage usually takes place within the leading company who conceives the new P-S idea. At the end the most promising ideas are selected (usually 2-3) and for each of them a deep Requirement Analysis is conducted, in order to identify the main P-S solution requirements (e.g. technical, aesthetics, etc.) which need to be satisfy;
2. Definition of tangible and intangible assets: for each idea generated, the tangible and intangible assets necessary to its development are defined and analysed. It is conducted according to the requirements defined at the previous step to have an assets mapping able to represent the baseline to realize concretely the main product-service requirements. Indeed, assets selection is the preliminary step to start the design of both product and service: if assets are properly defined and relations among them are elicited, product design and service design can run as parallel activities;
3. VME creation and definition of the business model for the VME: for each P-S idea designed, the most suitable partners in the company ecosystem are firstly selected according to their ability to provide tangible and intangible assets as mapped. The selected partners will provide the requested knowledge, skills, technologies or services, and cooperate as a temporary association (i.e. VME) to develop the selected ideas, so that a VME can be identified. The next step is the definition of the most proper business, in order to have a complete business idea for each solution. Indeed, a large number of industrial company internal and external factors exist that have effect on the success of business and industrial models. For each business case, internal requirements are identified according to the Business Model Canvas, which is based on building blocks and is one of the most used in manufacturing, while external requirements are derived using STEEP analysis. The aim of the STEEP analysis is to map the environmental, political, economic, technological and sociological trends that the selected VME would follow during the future PSS development. Moreover, also a deep analysis about the current product offered on the market is involved in the STEEP analysis, in order to understand the strength and weakness of it, useful for the innovative P-S development;
4. Sustainability assessment of the designed ideas: during the design stage, the generated Product-Service solutions are assessed from a sustainability viewpoint considering also the different use scenarios described by the business models. Assessment consists of the definition of reliable measuring techniques to assess the sustainability of the business model and related VME: a combination of suitable lifecycle design techniques is defined to assess PSS sustainability. In particular, LCA focusing on environmental resources, LCCA estimating the lifecycle total costs, and SLCA estimating impacts on human resources and human health are applied to each BM defined. It allows going down in the analysis for each partner involved. Such an assessment provides for each designed PSS a set of objective indicators to compare their performances: *ENI* (ENvironmental Indicator) for environmental assessment, *ECI* (EConomic Indicator) for cost assessment, and SOI (SOcial Indicator) for assessing social wellbeing. The three indicators were evaluated firstly separately and then they were normalized and summed into a unique indicator *SI* (Sustainability Indicators).

In step 4, indicators are normalized to obtained a monetary value expressed in euro (€) so finally *SI* states the global expense due to global PSS impact related to the BM defined, expressed by Eq. (1). Furthermore, comparison between alternatives indicates the saving that can be achieved by improving sustainability.

$$ENI + ECI + SOI = SI \qquad (1)$$

In more details, for each selected PSS solution directly correlated to a specific business model defined, indicators (*ENI*, *ECI* and *SOI*) are separately calculated by well-known lifecycle analyses (i.e. LCA, SLCA and LCCA). The main novelty is the introduction and analysis of the use scenarios, which contemplates the VME and the BM.

ENI is measured by Eco-Indicator99 (EI-99) considering Ecosystem Quality impact and Resources consumption. The unit of measurement is EI-99 point (Pt).

ECI refers to all the lifecycle costs (from raw materials and their transformation to service implementation and PSS creation, until the EoF). It adopts the Equivalent Annual Cash Flow technique (EA) to transform a generic cash flow distribution into an equivalent annual distribution by cost actualization according to Eq. (2):

$$EA = P\frac{(i+1)^n * i}{(i+1)^n - 1} \tag{2}$$

where *n* is the lifetime years' number, *i* is the generic discount rate (e.g. 3 %), and *P* is the value during the entire lifetime. Finally, it is expressed into QALYs (Quality Adjusted Life Years).

SOI considers separately Human Health contributions according to EI-99 methodology as before. Such values can be calculated by LCA and LCCA software tools (i.e. SimaPro, Gabi). *ECI* is originally expressed in euro and doesn't need to be normalized. On the contrary, ENI and SOI must be converted into homogeneous values before summing into a unique indicator. In particular *ENI* (originally expressed in EI-99 Pt) can be translated into *PDFm2yr* (Potentially Disappeared Fraction of species per square meter per year) and *MJ* (Mega Joule), and normalized by Eq. (3) and Eq. (4); *SOI* (originally expressed in QALYs) can be multiplied for the estimate cost for year according to recent European data, be Eq. (5).

$$\text{Pt} = \text{PDFm2yr and } \ (PDFm^2yr) * 1{,}4 = euro \tag{3}$$

$$\text{Pt} = \text{MJ and } \ MJ * \frac{0{,}00411}{lifetime} = euro \tag{4}$$

$$1\ QALYs * 74.000 = euro \tag{5}$$

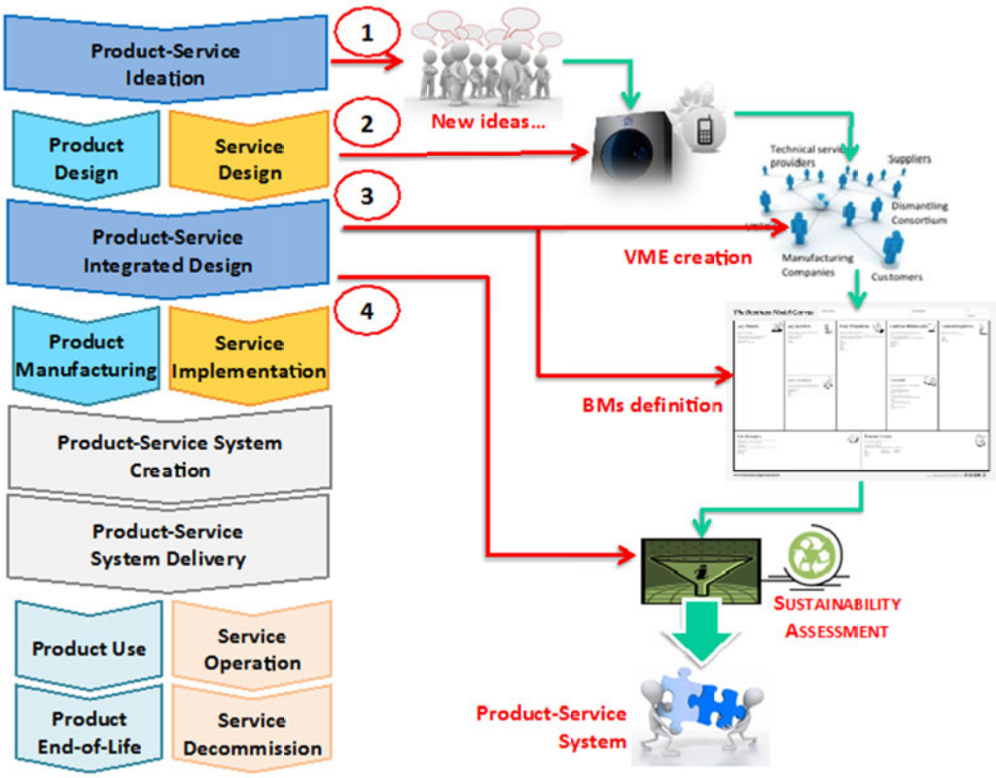

Figure 1. Methodology to support PSS design

Such a method has two main advantages: it can be adopted until the earliest design stages to support early decision-making, compare ideas at both business and technical levels, and validate the technicians' choices. According to the methodology described above, for each P-S idea is possible to identify a VME able to provide the tangible and intangible assets needed as well as a business model. In order to assess the sustainability of each business model to understand the goodness of the designed P-S, the indicators namely ENI, ECI and SOI were evaluated through the specific tools for each VME partners in each business model, as described on an industrial case study in the next paragraph.

4. Industrial application: smart washing service

The case study has been realized in collaboration with Indesit Company, a world leader company designing and producing household appliances. The company is actually product-centred and it leads a vertical supply-chain. The case study aims to support PSS design: the company defined a new P-S idea and compared different alternatives, considering also the VME and different BMs, on the basis of its sustainability. The Product+Service case study focuses on a washing machine prototype enhanced with some service-oriented features: it is connected to a domestic network and its data are elaborated to provide the so-called "Smart Washing Service", when the product is rented or given for free and the service consists of an annual supplying of machine use as well as energy and detergent consumed at an annual fee. Furthermore, a web/mobile application offers customers like suggestion about the product usage and dedicated training. This P-S idea requires the design and realization of product, service and infrastructure. The product is an evolution of a previous model by an embedded Zigbee module that allows data to be sent by a local gateway; the service is the application available at the advanced on-board display and any mobile interface (e.g. smart-phone); the system infrastructure exploits an Internet Wi-Fi router to make data available for the application. The main research questions to answer during the design stage are the followings:

a) Which is the total sustainability impact due to the implementation of the new PSS solution?
b) How do the impact change for different scenarios?
c) Which BM is more sustainable?
d) Which are the advantages for the VME?

4.1 Industrial case study

Three different VMEs and the related BMs have been identified for realizing the Smart Washing Service. The pillars of such service are the following items: it uses an advanced washing machine that is able to communicate with an external systems thanks to connectivity features, as defined in the previous paragraph; and a web/mobile application to provide the service to the final users, that is adapted for delivering different scenarios. The identified scenarios have been tested in order to understand which is the most sustainable solution to innovate the traditional product concept for the leading company. Hereafter the three tested scenarios are described.

The first PSS solution is called "PSS for students", which BM by Canvas is represented in Figure 2. Here, the identified target customers are students from Universities, who usually live in a rent house for several years (3 or 5 years usually); the business model provides the washing machine (WM) for free. About the usage, students are characterized by a non-regular frequency of use, as cycles highly depend on their habits and presence, so the number of cycles per week is very changeable. For this reason, the WM provided dedicated and cheap short-cycles and the users can see the cycle cost by a web/mobile application. The VME involves several actors: Indesit Company as leading company, IT partner that supports the development of the service architecture and provides the web/mobile application, a research centre as technologies developer, a designer who cares about the product redesign and the application design, the energy utility to have special rates, and the detergent producer supporting the company in the PSS delivery phase, house builders that can arrange special contracts with the energy utility to attract new customers, and finally the dismantling consortium managing the product end of life and service decommission.

The second PSS solution is called "PSS for company employees". Here, the target customers are employees of those companies which need to wash their clothes frequently, for instance during

working time before a meeting or after working time. In this case the BM considers that the specific company can sign a contract for having washing machines for free and cycles at a special rate, as they can guarantee a fix number of cycle per day. Indeed, such employees can't come back home for washing their clothes but they need fast cycles and not at full load. For this case, the leading company supposed to provide a customized washing cycle for any occurrences and a monitoring application to inform the users while they are working or waiting through a web and mobile application. Users can know how much the cycle will be in advanced and when the cycle will finish. The VME involves the same actors of the previous case, with differences in the involvement of other companies as end-users.
The third PSS solution is called "PSS for gaming" and it is oriented to high-tech customers who love convenience and smartness in the home appliances and aim to have a personalized home automation system. These target customers usually appreciate the aesthetic design of both product, and are very interested in monitoring the performances as well as optimize their cost in terms of energy and detergent consumptions. For these reasons, the leading company has designed a web/mobile application to monitor timing, costs, detergent use and other WM parameters in order to give real time information on washing cycles and potential faults by preventive maintenance messages. Moreover, the customer can enter a competition like a game with his/her friend and interact with his/her social networks to share the application, controlled the costs and compare energy performances. The VME is similar to the previous cases, but it differs in the connection to the smart grid that is necessary to implement the gaming, and the connection to social networks (i.e. Facebook, twitter, etc.) to be used to share data and results. The Canvas representations of the last two solutions are not reported due to the length constraints.

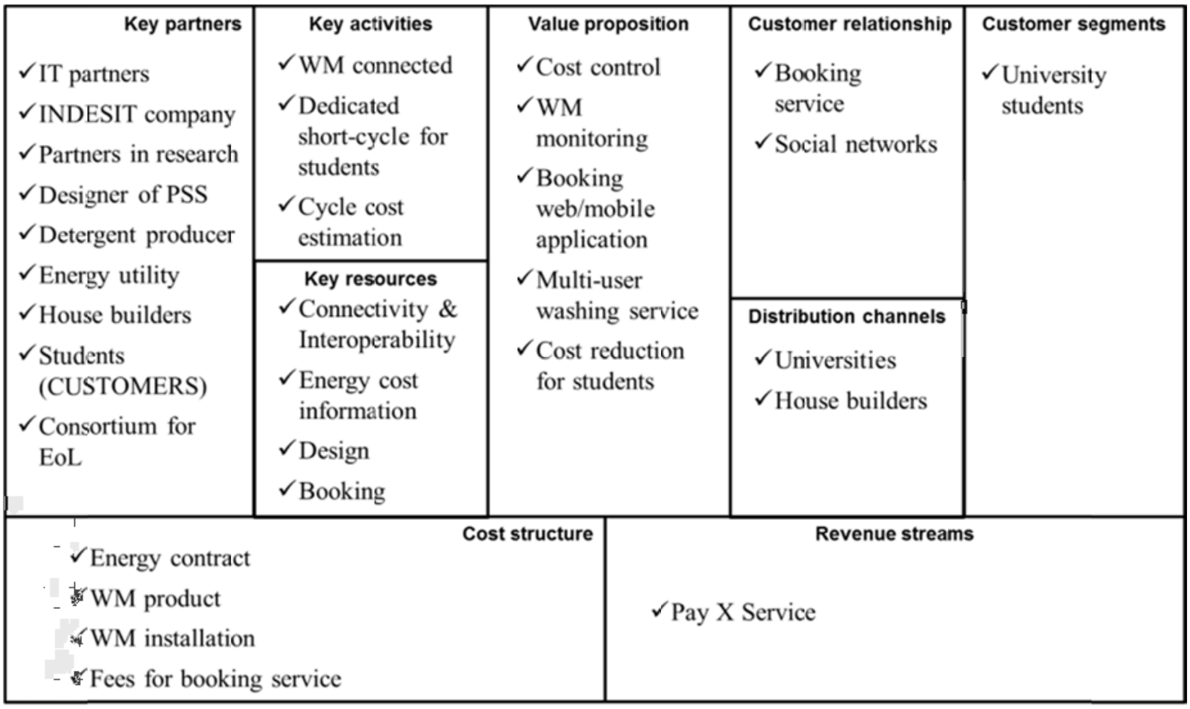

Figure 2. BM no.1 "PSS for students"

4.2 Sustainability assessment

The three PSS solutions identified in the case study have been fully designed and analysed in detail by the sustainability assessment method. The following tables collect the achieved results on different business models, in order to understand which the best is solution designed and which will be assessed through economic KPIs before to be delivered to the market. Indeed, the main companies focus is on the profits that a new solution can produce; however, before such economic stage, a reasonable product-service must be designed by a technical point of view.

Table 1 collects the results about the BM no.1 (i.e. PSS for students). Table 2 collects the results about the BM no.2 (i.e. PSS for company employees). Table 3 collects the results about BM no.3 (i.e. PSS for gaming).

Table 1. Sustainability assessment of BM no.1"PSS for students"

VME PARTNERS	SOI	ENI	ECI	TOTAL
	QALY	Pt	€	
IT partner	9,60E-05	58,10	€ 76,33	**€ 1.089,79**
INDESIT company	3,12E-03	206,60	€ 539,00	
Research partner	X	X	€ 120,00	
Design PSS	X	X	€ 100,00	
Detergent producer	2,74E-04	32,75	€ 774,39	**€ 1.285,03**
Energy utility	3,38E-04	40,02	€ 275,71	
House builder	X	X	€ 50,00	
Students (CUSTOMERS)	1,99E-05	1,89	€ 136,34	
Dismantling consortium	X	-73,47	€ 4,89	**-€ 1,12**
SI	**€ 284,64**	**€ 12,40**	**€ 2.076,66**	**€ 2.373,70**

Table 2. Sustainability assessment of BM no.2 "PSS for company employees"

VME PARTNERS	SOI	ENI	ECI	TOTAL
	QALY	Pt	€	
IT partner	9,60E-05	58,10	€ 76,33	**€ 1.069,79**
INDESIT company	3,12E-03	206,60	€ 539,00	
Technological consortium	X	X	€ 200,00	
Detergent producer	2,74E-04	32,75	€ 774,39	**€ 1.235,03**
Energy utility	3,38E-04	40,02	€ 275,71	
Employees (CUSTOMERS)	1,99E-05	1,89	€ 136,34	
Dismantling consortium	X	-73,47	€ 4,89	**-€ 1,12**
SI	**€ 284,64**	**€ 12,40**	**€ 2.006,66**	**€ 2.303,70**

Table 3. Sustainability assessment of BM no.3 "PSS for gaming"

VME PARTNERS	SOI	ENI	ECI	TOTAL
	QALY	Pt	€	
IT partner	9,60E-05	58,10	€ 76,33	**€ 1.189,79**
Research partner	X	X	€ 120,00	
INDESIT company	3,12E-03	206,60	€ 539,00	
Technological consortium	X	X	€ 200,00	
Detergent producer	2,24E-04	39,95	€ 633,00	**€ 1.433,12**
Smart grid partner	X	X	€ 300,00	
Energy utility	3,38E-04	45,25	€ 310,57	
Users (CUSTOMERS)	2,11E-05	2,79	€ 144,66	
Consortium	X	-73,47	€ 4,89	**-€ 1,12**
SI	**€ 281,06**	**€ 12,27**	**€ 2.328,45**	**€ 2.621,78**

The obtained results are very interesting and usefully support the PSS design. It is worth to notice that BM no.3 is the less sustainable solution, and as a consequence it is the most risky one. Indeed, in this case the final SI value is higher than other two BMs. Instead, BM no.1 and BM no.2 are very similar about sustainability. A more detailed analysis to evaluate the BM impact should be adopted in order to understand which scenario is more advantageous for the company. For instance, BM no. 2 is the less risky for Indesit Company as the impact during manufacturing stage is lower and it could be the most advantageous. Furthermore, it is possible to highlight if the impact of each single partners change for the different solutions. In particular, the dismantling consortium and the IT partner assume a similar role in the three scenarios and their impact on sustainability doesn't change. Finally, the highest impacts indicate the most critical contribution and suggest deepening those process stages in order to limit the impact on sustainability. The analysis of indicators (*ENI*, *ECI* and *SOI*) can also define the motivation of such low performances.

5. Conclusions

The present paper proposes a methodology to support design of P-S solutions in manufacturing industry by considering their impact on Sustainability. It proposes to adopt lifecycle design techniques and tools by a structured methodology, which supports companies in defining the idea and its requirements, selecting the tangible and intangible assets necessary to create the desired PSS, creating the Virtual Manufacturing Enterprise (VME) able to provide the P-S solution, and finally assessing the sustainability of the desired solution from the earliest design activities. In this way different alternatives can be easily analysed and compared, and sustainability impact elicited. In particular, the sustainability assessment considers three contributions: impact on the environment, on the costs, and on society. These aspects are investigated separately by LCA, LCCA and SLCA techniques and the related indicators are found (respectively *ENI*, *ECI* and *SOI*). A global impact is calculated as the sum of normalized indicators (*SI*).

The proposed method has been applied to a real Product+Service use case focusing on the "Smart Washing Service" and using an advanced washing machine. During the design stage three scenarios have been conceived: they differ in target customers, service typology and functionalities, and VME partners involved; as a consequence the derived business model differ too. The business model representation used in this paper represented how the leader company designs the solutions and the role of the selected partners, as well as the relations with the customers. The economic revenues by the P-S solution will are explained here, because they are beyond the scope of the present research, based on sustainability (so only costs are considered). However, they could be evaluated by proper business indicators and used to understand the goodness of each business model specifically. It will be included in future works.

The method application demonstrates its validity to assess the sustainability of complex PSS involving numerous partners and comparing different ideas and related business models. The case study demonstrates how to have a clear comparison between different designed solutions in terms of lifetime costs, environmental impacts, and social consequences. It also considers impacts for each partner involved in the ecosystem (VME). Finally, it can provide useful guidelines to revise and optimize the PSS design.

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Margherita Peruzzini, PhD., Post Doc. Fellow
Department of Industrial Engineering and Mathematical Science, Università Politecnica delle Marche
Via Brecce Bianche 12, 60131 Ancona (Italy)
Telephone: +39 0712204799
Telefax: +39 0712204801
Email: m.peruzzini@univpm.it