Continuous improvement planning through sustainability assessment of Product-Service Systems

Elisa Negri*, Maria Holgado*, Dirk Wagner, Christian Grefrath**, Marco Macchi*, Gerhard Gudergan****

*Department of Management, Economics and Industrial Engineering, Politecnico di Milano, via Lambruschini, 4, 20156 Milano – Italy (elisa.negri@polimi.it, maria.holgado@polimi.it – corresponding author-, marco.macchi@polimi.it)

** FIR at RWTH University, Pontdriesch 14/16, 52062, Aachen – Germany (wg@fir.rwth-aachen.de, gr@fir.rwth-aachen.de, Gerhard.Gudergan@fir.rwth-aachen.de)

Abstract: The paper presents a methodology for the integrated sustainability assessment of a Product-Service System (PSS) lifecycle, with the purpose to overcome limitations of current sustainability models in literature. The methodology envisions a decision support for companies during New Product/Service Development. Its eight steps are an extension of ISO 14040 Life Cycle Assessment. It considers all three sustainability dimensions – economic, environmental and social – and a service perspective, through the use of the Service Unit. A set of indicators for the three dimensions, aligned to the Service Unit concept, is proposed based on literature suggestions, and principles of completeness, consistency and avoidance of double counting of effects. The methodology can be adopted to apply continuous improvement to a Product-Service System from both the sides of developer and user. As such, it suggests links between sustainability and Total Quality Management concepts through the PSS lifecycle.

Keywords: Product Service Systems; sustainability assessment; life cycle; service unit; sustainability dimensions; environmental assessment; ISO 14040; economic assessment; social assessment; impact categories; sustainability indicators; total quality management; TQM; continuous improvement.

1 Introduction

In 1987 the concept of "sustainable development" was defined by the Brundtland Commission as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations General Assembly, 1987). The United Nations General Assembly (2005) then categorized it into three relevant dimensions, which are economics, environment and society. Since its first definition, sustainability has represented the core topic of a research front. The research community is growingly interested in investigating synergies between Total Quality Management (TQM) and Sustainable Development (SD), in its three domains – economic, environmental and social - (e.g., De Burgos Jimenez and Cespedes Lorente, 2001; Daily and Huang, 2001; Isaksson, 2006; McAdam and Leonard, 2003; Post and Altman, 1994; Tsai and Chou, 2009; Wilkinson et al, 2001). The synergies between TQM and SD can be seen from different perspectives. From organizational and strategic viewpoints, they have mainly two streams of interaction. Firstly, TQM and SD share the same core values. Typically, a successful TQM needs to be based on organizational culture and staff participation, commitment of leadership and management, customer orientation, focus on business processes, measurement focus, ethical base, training, teamwork (in particular cross-functional teams) and, most of all, continuous improvement (Isaksson, 2006; McAdam and Leonard, 2003; Reed et al., 2000; Svensson, 2006; Tsai and Chou, 2009; Wilkinson et al., 2001). These core elements are also the basis of sustainability oriented management systems, such as Environmental Management Systems (EMS) (Daily and Huang, 2001) and Corporate Social Responsibility (McAdam and Leonard, 2003). Moreover, continuous improvement has a particular importance, since it permeates all levels of practical adoption of quality or sustainability principles: from the practical performance measurements to the human resources training (Daily and Huang, 2001). Secondly, the organizational changes lead by sustainability within a company have a strong affinity with the implementation of TQM (Post and Altman, 1994). In particular, EMSs need an organizational development that includes TQM, due to the relation between environmental capabilities and capabilities derived from TQM (De Burgos Jimenez and Cespedes Lorente, 2001). From a more operational perspective, TQM leads to better quality in products and processes, and in consequence less production of waste and scraps, directly connected to emissions in the environment and to resource and energy consumption. Rework and waste are aspects that have economic implications, i.e. "waste in the form of scrap, rework and failed products" (Isaksson, 2005) named as "costs of poor quality" (Isaksson, 2005; Isaksson, 2006; Reed et al., 2000). In addition to the lesser costs of poor quality, also higher customer satisfaction is obtainable through a better quality of products and processes (Reed et al., 2000).

Moreover, quality is considered by many authors as a key factor to reach economic business goals, that are sustainable in time, such as competitive advantage and higher profits (Svensson, 2006). Due to its close relationship to economic factors, quality can be included in a measurement system for sustainability to account for the economic dimension. For example, Tsai and Chou (2009) have proposed an integrated system, which considers quality, environment and society, as a measurement system for sustainability. A practical example of synergic performance measurement, covering both quality and environmental spheres, is the so called TQEM (Total Quality Environmental Management), which is made at operations function level (De Burgos Jimenez and Cespedes Lorente, 2001; Post and Altman, 1994). In fact, operations

management is the joining link between TQM and sustainable development, as it connects quality issues, such as resource efficiency, to environmentally sustainable processes and procedures (Wilkinson et al., 2001). On one side, programs for environmental performance improvement can be considered as enhancing traditional operations management activities, including those related to Total Quality Management and Total Quality Control (De Burgos Jimenez and Cespedes Lorente, 2001). On the other side, quality improvement is among the benefits stemming from environmental performance improvement (De Burgos Jimenez and Cespedes Lorente, 2001).

Sustainable development is realized in companies through different methods and techniques. Products themselves may represent an opportunity for sustainable businesses: an example are the "Product Service Systems" (PSS) (Baines et al., 2009). A PSS is defined as "a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling final customer's needs" (Tukker and Tischner, 2006, p. 1552). The sustainability potential springs from the possibility of decoupling environmental pressure from economic growth, because they focus on the use of a product, rather than on its ownership (Tukker, 2004). In fact, the PSS concept is based on the idea that consumers do not specifically require a product but the functionality that this product with its services offers. The offer of this functionality, if faced with a "green mindset" (Tukker and Tischner, 2006; Yoon et al., 2012), leads to higher degrees of freedom in the development of sustainable product-service solutions and of less impacting business models (Tukker and Tischner, 2006).

Adding services to products may result in many benefits, such as costs reduction, decrease of relevant emissions and resource consumption, and also changes in social impacts, even without any physical modification on the products (Baines et al., 2009). As such, PSS can then be considered as a promising approach to achieve the objectives "stated" in the SD and TQM agenda. In the SD's perspective, the current paper proposes a methodology to assess the sustainability impacts of a PSS solution, as a decision-making support to be used during New Product/Service Development in companies. This proposal aims at enhancing traditional operations management activities, by taking a specific perspective on the product-services lifecycles. In particular, the sustainability assessment methodology is envisioned as a decision support for companies willing to assess the sustainability impacts of their product-services lifecycles over the three sustainability dimensions. The methodology presents innovation elements with respect to the old assessment methodologies present in literature, such as the assessment of the three sustainability dimensions in parallel, the non-site- nor industry-specificity, the possibility to assess services (and not only physical products) and the new approach for setting system boundaries.

Considering the TQM's perspective, the adoption of the methodology has a particular potential usefulness for planning services, to be offered within product-service solutions, considering also the eventual scenarios that may occur during the product-service usage phases, leading to different performances than normal expectations. Doing so, it would be possible to introduce TQM at the beginning of the lifecycle, through the identification of potential improvement options for product-service solutions that may be adopted at an usage phase, whenever the encountered operating conditions would require performance improvements.

The paper presents a literature review in Section 2, focusing on the link between Product-Service Systems (PSS) and SD and on methods to assess sustainability. Section 3 introduces the methodology, its objectives, its steps, its innovative elements and its uses; a particular focus on the chosen indicators also appears in this Section. The MS™ Excel-based methodology implementation is discussed in Section 4. The case study demonstrating the methodology is illustrated in Section 5: the results of two use cases are herein shown, leading to a final discussion on the empirical evidences got from the case study. Section 6 eventually presents suggestions for future research.

2 Literature Review

Literature has shown that Product-Service Systems may positively influence the three sustainability axes (Baines et al., 2009): (i) economic benefits come from the potential in differentiation and competitiveness of PSSs (especially against low cost economies), because of the more customized, higher quality product-services offered; (ii) PSSs allow a more intensive usage of products and a smaller amount of total production, thanks to the promotion of alternative uses of products and to the manufacturers' responsibility over the final disposal of produced goods, leading to less impacting product design and uses; (iii) for society, governments can find inspiration from PSSs in releasing policies supporting sustainable goods consumption and added services may create new job positions.

PSSs are also considered effective enablers to sustainability thanks to renting-sharing services of environmentally sound products, that may result too expensive for consumers to buy: PSSs allow to overthrow high price entry barriers for sustainable product-services (Tukker, 2004).

2.1 Sustainability Assessment Methodologies

Sustainability assessment methodologies in literature are numerous. Some of them propose theoretical approaches, others specific industrial cases. The majority of them is focused on one specific sustainability dimension (economic, environmental or social), within which only few impact categories are addressed. It is rare that these methodologies reach complete integration over the triple bottom line, even if many authors express its desirability (Klöpffer, 2008, Rebitzer and Hunkeler, 2003, 2005).

The following paragraphs present the most relevant assessment methodologies in literature for the purpose of the paper: Life Cycle Assessment and Material Input per Service Unit (MIPS) methodologies are representing the environmental dimension; the two subsequent sections mention economic and social assessment approaches and, finally, examples of integration of the three dimensions are illustrated.

2.1.1 Environmental Assessment

The most common environmental assessment technique is the Life Cycle Assessment, described in the International ISO 14040 standard (international Organization for Standardization, 1997). Another very important methodology to measure environmental burdens is the MIPS method (Material Input per Service Unit), although this is not very used in literature, it is a valid technique to compute the resource consumption in the life cycle of product-services. For the purpose of the paper these are the two most powerful environmental assessments present in literature, for this reason they are described in the current section.

ISO 14040 is characterized by a lifecycle perspective, which considers cradle-to-grave phases (raw materials, manufacturing, assembly, distribution, use, end-of-life) and is necessary to avoid shifting of environmental burdens from one lifecycle step to another (Finkbeiner et al., 2006). It serves both as a decision support tool to compare impacts of different techno-economic alternatives and as quantifier for improvement potentials under many environmental respects: climate change, stratospheric ozone depletion, smog creation, euthrophication, acidification and similar. In order to compare different product solutions, data are normalized on the functional unit, which describes and quantifies properties of the product, such as: functionality, appearance, stability, durability, ease of maintenance etc. (Weidema et al., 2004). The four steps determined by the ISO 14040 are the following (International Organization for Standardization, 1997):

- **(i) definition of goal and scope**: it defines the intended application of the study, the functional unit, the product system, the system boundaries, the impact allocation procedure, assumptions and limitations;
- **(ii) inventory analysis**: it involves data collection and calculations to quantify relevant input and output of the system;
- **(iii) impact assessment**: it includes selection of impact categories, calculation of impact indicators and, if necessary, normalization of results;
- **(iv) interpretation of results**: it consists of presentations and recommendations to decision-makers and sensitivity analyses.

Another frequently mentioned methodology was developed by the Wuppertal Institute for Climate, Environment and Energy in order to support the calculation of the Material Input Per Service unit, abbreviated MIPS (Lettenmeier, 2009; Ritthoff et al., 2002). This aims at the quantification of materials and energy needed to provide a service, considering the complete lifecycle of the products that are the physical bases of the service and then expanding the evaluation to a wider service perspective through the concept of Service Unit. The latter is similar to the concept of Functional Unit, mentioned in LCA, but it is more focused on the service delivered than on the physical product offered.

The perspective of this methodology is different from the conventional ones, which strive for less emissions and waste: if less materials and energy are used as input to the system, also the emitted output will be lighter. This encourages existing products' and production processes' dematerialization, thanks also to the service perspective, which is consistent with the tendency of offering Product-Service Systems, instead of simply selling physical goods.

System boundaries firmly separate the eco-sphere (natural environment) and the techno-sphere (human activities): materials flow from the eco-sphere to the techno-sphere. Ideally, the system boundary should be unique and inclusive of all lifecycle phases.

Kilograms of materials are the measure units for the Material Input – MI - (representing the amount of moved natural resources during the product-service lifecycle). MI must be grouped and summed by category and then divided by the number of Service Units (S) provided in the lifecycle of the product-service under consideration. Measure units for Service Units cannot be determined in advance because they depend on the single case.

2.1.2 Economic Assessment

Economic sustainability is pursued since business was born: financial evaluations are popularly known for their importance in decision making in companies. Literature suggests the use of those economic indicators, that are typically performing economic calculations on projects, also in the economic evaluation of alternatives in New Product/Service Development. This is not surprising, since the lifecycle of a product can be considered as a project itself. In general, economic assessments, as the already mentioned environmental ones, consider the lifecycle of the product-service under consideration. The most popular indicators are the Life Cycle Cost (LCC - sum of all costs for a certain player related to the product-service), Net Present Value (NPV - algebraic sum of all discounted costs and revenues for a certain player), Profitability Index (value increase per investment) and Internal Rate of Return (the discount rate which makes the NPV of a project equal to zero). In addition to these, the Payback Period, time for a project to repay for itself, is also used; this does not have a lifecycle perspective and it is used as a complementary indicator with one of the others.

The lifecycle perspective is used to avoid selecting an alternative with lower initial costs but higher operations and maintenance costs. Usage costs may be equal to many times the initial purchase or investment costs (Woodward, 1997).

As Life Cycle Assessment is the environmental most common assessment methodology, Life Cycle Costing is the most popular economic measurement; its several uses span from support in the choice of alternatives (Cole and Sterner, 2000; Woodward, 1997) to selecting new approaches for maintenance and operations management (Frangopol et al., 1997; Karyagina et al., 1998; Utne et al., 2012), from optimization of new product-services design (Asiedu and Gu, 1997; Curran et al., 2007) to triggering changes in current configurations of existing systems (Wang and Sivazlian, 1997).

2.1.3 Social Assessment

Although products and services have social consequences at all stages of their lifecycles, social burdens are still not extensively considered. There is still no widely accepted assessment approach and social consequences are difficult to quantify and to put in relation to flows related to the product-services (as in the case of financial and physical flows); moreover, the needed information type is more complex to obtain and deal with: it has to do with the single company's conduct and its impact on stakeholders with very high site-specificity (Dreyer et al., 2006; Jørgensen et al., 2008). Unlike in environmental assessment, where areas must be protected from undesired emissions or resource consumption (the so called Areas of Protection), in social field the controlled areas are not strictly "under protection from damage" but are those where improvement is possible and desirable (Dreyer et al., 2006; Grießhammer et al., 2006; Hauschild et al., 2008; Jørgensen et al., 2008). Some authors suggest that LCA can be used as a conceptual basis for social assessment, since its it an already widely acknowledged methodology (Dreyer at al., 2006, 2010; Grießhammer et al., 2006; Hauschild et al., 2008; Jeswani et al., 2009; Klöpffer, 2008; Rebitzer and Hunkeler, 2005): the outcome of the adaptation of LCA is the SLCA, or Social Life Cycle Assessment. SLCA is not conflicting with the principles of profitability and competitiveness in business, it is just a decision support tool to do business in a socially responsible manner (Dreyer et al., 2006). SLCA could be developed following two distinct perspectives: a societal one and a company one: the resulting methodologies might be different. Since the most common use is the support in decision making in companies, in literature the second perspective is more common. However, if the aim is to perform a social assessment, regardless of the real possibilities for companies to change things, then the first perspective is the right one (Dreyer et al., 2006; Dreyer and Hauschild, 2006; Jørgensen et al., 2008). SLCA has a theoretical basis, following the four steps of the LCA methodology; but has not yet practical implementations. Social impact categories are usually referring to principles expressed in the Universal Declaration of Human Rights, in SA8000 (Social Accountability International, 2008), in the Tripartite Declaration of Principles concerning Multinational Enterprises and Social Policies and in International Labour Organization conventions (Dreyer at al., 2006, 2010; Hauschild et al., 2008). Considering all these sources, a list of possible examples of social impact categories can be the following: avoidance of discrimination, child labor, forced labor, freedom of association and collective bargaining, physical working conditions, training and education of employees health and safety of employees, job creation, development support for local community (Dreyer at al., 2006, 2010; Grießhammer et al., 2006; Hauschild et al., 2008).

2.1.4 Integration of Three Dimensions

Integration of the three dimensions into a unique assessment allows to have a complete sustainability overview. In fact, changes in environmental impacts of a company cannot be applied if they do not result profitable for the company; moreover, any environmental and economic development cannot be stable in the long run without a basis of social fairness. For this reason, it is important to assess the three aspects of sustainability at the same time (Klöpffer, 2008). To reach a consistent approach it is essential that overlapping areas shared by more than one dimension are not counted twice (i.e. human health issues may be considered both social and environmental or local economy development may be both belonging to the economic and the social spheres).

The integration of environmental and economic evaluation is relatively easy and already adopted by many examples in literature (Cooper et al., 2012; Edkunge and Råberg, 1998; Fesanghary et al., 2012; Hong et al., 2011); this is due to the fact that they both use quantitative indicators and often the same data in input (such as the used materials and energy) (Grefrath et al., 2012; Rebitzer et al., 2003; Shapiro, 2001); moreover they can both be drastically reduced with a proper design of product-services (Alting and Brøbeh Legart, 1995; Hunkeler and Rebitzer, 2003; Rebitzer et al., 2003; Züst and Caduff, 1997).

The inclusion of the social dimension into the integration of environmental and economic assessments leads to a Sustainability Life Cycle Assessment (Sustainability LCA) (Grießhammer et al., 2006). The biggest challenge to this aim is the qualitative nature of most social indicators which makes the assessment much dependent on decision makers' personal opinions.

Examples of integration of the three sustainability dimensions are techniques of Full Cost Accounting (Klöpffer, 2003; Cole et al., 2000), which consist in the economic quantification of social and environmental impacts to be included into the economic assessment, resulting in one only indicator for a complete sustainability assessment. Similar approaches are the Cost-Benefit Analysis and the Cost Effectiveness Analysis (Weidema, 2006; Cellini and Kee, 2010). Both of the analyses weigh the total expected economic-environmental-social costs against the total benefits; the first by subtracting their monetized values, the latter by calculating the ratio of a cost over a non-monetary benefit.

These techniques have a limited application in companies for two main reasons (Klöpffer, 2003): on one side, the assignment of a monetary value to social and environmental damages and benefits is not easy (and sometimes even repulsive); on the other side, since companies do not actually bear these costs directly (the society as a whole pays for them), these costs do not receive the necessary consideration.

3 Sustainability Impact Calculation Methodology

The methodology envisions a decision-support tool for New Product/Service Development. The idea is that real improvements in the whole lifecycle sustainability impacts of a PSS can be reached at this stage, while only marginal changes can be realized later (Rebitzer at al., 2004). In order to successfully apply the proposed methodology, the core elements that are necessary also for a quality management are necessary: continuous improvement approach to continuously improve the

sustainability impacts of the offers; leadership commitment is necessary to perform the assessment with consistent data and to implement actions as response to the found impacts; organizational culture is essential for a real sustainability committed company.

The literature presents some gaps in the existing methodologies: the integrated assessment reaches only a partial degree of integration, the assessed impact categories within each assessed dimension are only few, they do not offer a wide and complete assessment, and the applicability is usually confined to a specific geographic area and to a specific industrial context.

Thus, the Sustainability Impact Calculation Methodology pursue the following objectives:

Firstly, integration of the three sustainability dimensions must be reached; whenever possible, same data should be used for more than one dimension; this objective also includes the goal of achieving completeness in the assessment within each category and consistency of results. Secondly, comparability between different PSS solution must be ensured. Thirdly, double counting of effects must be avoided. Lastly, no sustainability dimension should be considered more important than the others.

The proposed methodology is based on the environmental International Standard ISO 14040, and represents an extension of it. It has been necessary to redefine some concepts in order to assess the three sustainability dimensions in parallel and to have a service perspective, rather than a more "physical" one. Figure 1 shows the eight steps of the methodology. Follows a brief introduction of each step:

I. *Definition of goal and scope*. Including the definition of the PSS under assessment, of what must be compared with it and of assumptions and criticalities of the analysis.

II. *Definition of system boundaries*. In this moment, it is decided which in- and out-flows to be considered and to be neglected. Traditionally, system boundaries define which flows are accounted for; in fact, those energy, material or financial flows which cross the system boundaries will be considered, while the others will be neglected. In the proposed methodology, system boundaries do not have this characteristics: they are different, according to the different sustainability dimensions:
   - The environmental one has the "traditional" system boundaries, considering only those material and energy flows that cut them, as inputs (resource consumption) or as outputs (emissions).
   - The economic analysis deals with financial flows. These can be either cutting the system boundaries, or completely internal to the system (those flows that are costs for a player and revenues for another). In traditional assessments, internal flows would not be considered; here they are considered because economic sustainability must be ensured for each player and not for the system as a whole.
   - The social dimension is not limited by system boundaries: it considers PSS lifecycle impacts on people, both internal (employee, customers, suppliers) and external (local community).

III. *Definition of processes to be assessed and of the lifecycle phases.* The assessment is performed separately for each lifecycle phase, in order to keep traceability of the critical results and to be able to implement direct improvement actions. At last contributions from different lifecycle phases will be aggregated into the complete lifecycle evaluation.

IV. *Definition of Service Unit*. Its definition is at the very basis of the whole assessment, representing its real "key" concept. The number of Service Units provided by the lifecycle of a PSS is the normalization basis of many of the indicators, it is therefore important to compute it carefully, since almost all results will be directly affected by it. It is not a new concept, since it was introduced in MIPS methodology by Ritthoff et al. (2002) and Lettenmeier (2009). To identify the proper Service Unit, it must be understood which is the service that must be guaranteed to the customer. Starting from this service, it is important to define a proper allocation procedure of data input. This is in line with the idea that, by adding more services to the same physical product, the total number of Service Units offered by the product may increase, reducing the impacts per single Service Unit delivered to the customer. In this perspective the methodology is suitable to analyze the impacts of different Product-Service System solutions, even if based on the same physical product.

V. *Selection of indicators*. Impact categories and indicators must be selected, according to the focus of the analysis. Some indicators may not be relevant for the specific case or the needed data may not be collected. Depending on the chosen indicators, allocation procedure, data and data quality requirements must be made clear in this moment because it will affect data collection and results of the assessment. Pursuing the objective of completeness the methodology provides an indication of which impact categories and indicators to be studied. This is different from ISO 14040 methodology, which does not enter into a detailed description of impact categories and indicators, leaving them to the sensibility of the performer of the assessment. The detailed presentation of the indicators follows in Section 3.1.

VI. *Collection of data*. Bases for the integration of the three sustainability dimensions are built in this phase. The structure of the data collection itself allows for the same input data to be used for more dimensions, if this is reasonable. Using the suggested structure, risks of double counting are avoided. Ideal sources are internal to the company. If internal information is not available, external data from trustful sources can be taken (from

certified databases, statistical bureaus, governments and university research studies). It is important to get data in the needed units of measure.

VII. *Calculation of indicators values*. For each lifecycle phase, all indicators in each dimension are computed. Traceability must be ensured, to identify which impacts and lifecycle phases are most critical. Final values will be presented both in an aggregated form (to have an general overview of the PSS) and disaggregated (to identify the single criticalities to be improved). Unlike in LCA, where the impact categories and the indicators are defined in the third step (which is the one corresponding to this one), the proposed methodology has already identified them in the first step of the procedure, in order to give a direction in the collection of data.

VIII. *Analysis and reporting of results*. It includes different activities such as (i) interpretation of aggregated / disaggregate results, (ii) identification of criticalities and (iii) sensitivity analyses. Moreover, reporting consists in presentations to decision makers in the company and ideation of improvement actions.

The possible uses of the methodology are four: (i) assessment of the triple bottom line impacts of a PSS solution; (ii) identification of the most critical phases in the lifecycle and impacts of a PSS solution; (iii) comparison of different of PSS alternatives fulfilling the same need; (iv) monitoring of the long term changes of a PSS solution and its following versions. All uses must be seen in the light of continuous improvement, since assessing sustainability must be followed by the effort to improve the triple bottom line performances.

3.1 Classification of impact categories and indicators

The proposed impact categories and indicators can be adapted or removed according to the specific case of assessment. Suggested indicators have been selected pursuing also other requirements such as easiness in computation, relatedness to provision of the service in question, consistency with the approach philosophy (i.e. used as part of a decision making tool) and wide applicability in different industries and geographic areas.

3.1.1 Environmental Indicators

Literature offers a wide set of different environmental indicators: either assessing resource depletion, emissions or improvement potentials for the design phase. In the methodology some of them have been chosen, following the above criteria. In Table 1, the chosen indicators are reported, grouped by perspective, with their measure units and sources from which they were taken. (S.U. stands for Service Unit.)
Two additional indicators are included in the methodology, to satisfy the need for companies to have easily understandable indicators to be communicated to the market and employees, to be exploited for green marketing initiatives and to face stricter regulations from governmental norms. These are a detailed analysis of the energy consumption and CO_2 emissions, divided by energetic resources categories, as it is shown in Table 2.

3.1.2 Economic Indicators

Traditional indicators for costs and profits of a project are used for the economic assessment. They are presented in Table 3. Two perspectives are monitored, that of the company offering the product-service and that of the user. With the double perspective, it is possible to obtain a first estimate of the cost-saving for the user and cost-rise for the company offering the product-services due to the addition of services to the products. This helps having an idea of the right pricing of services, in order to ensure profitability for the company and cost-saving for the user. Economic sustainability is then granted for both players.

3.1.3 Social Indicators

Social impact categories have been categorized with an innovative classification scheme. Three classes of categories are identified, which differ from each other for the type of indicators that they contain.

(i) In the first class, fundamental issues are collected. These are characterized by Boolean indicators: acceptable or non-acceptable. Categories in this class are: child labor, forced labor, health and safety of employees, corruption, respect for law, degrading treatments, religion and opinion freedom.

(ii) The second class includes those impact categories that may influence economic and environmental impacts. The indicators are quantitative or semi-quantitative, this puts the basis for the potential of being expressed per the Service Unit. Examples of impact categories in this class are: allocation of profits, physical work conditions, psychological and organizational work conditions, job satisfaction.

(iii) Social categories belonging to the third class are issues which do not have a widely recognized optimal value, but they differ according to the single case and cultural context. These are assessed through an audit system and include: gender discrimination, minorities discrimination, age discrimination, job creation for disabled, choice of sustainability committed partners, users' health and safety, intellectual property rights, ethical guidelines for advertisement, local economy support, local community acceptance, freedom of expression.

4. Tool Development

The methodology has been implemented on MS™ Excel, chosen for its flexibility and popularity in use. Its deployment required many Excel files, used in parallel: one for the results, to be shown in a structured way ("output file"), and others for

data input and calculation ("processing file"), as many files as the number of lifecycle phases to be considered during the assessment.
More in detail, the output file comprises several sheets showing different results: one for the aggregated lifecycle results, one for each lifecycle phase, one comparing the single phases results and highlighting the most critical values (as "hotspots and criticalities"), and one which is dedicated to the energy and CO_2 detailed analysis. Last but not least, the same file also includes a sheet for the calculation of the Payback Period. Each processing file also presents a number of sheets for each lifecycle phase: a sheet for the calculation of Service Unit; four sheets dedicated to the inputs (materials, social, parameters and others); four sheets for calculations (material intensities, other environmental impacts, economic impacts, energy and CO_2, and social impacts). The Excel files structure is presented in Figure 2.

5. Case study

The company in the case study (later referred to as "company") is an agricultural machine and tractor manufacturer with a deep concern for sustainability issues. It has been selected for the demonstration of the methodology, because of its trend to move to different Business Models than traditional production-sale ones. They span from simply adding services (such as maintenance, training and software), to Total Service Solutions. These new Business Models are ascribable to the concept of PSS, and the methodology evaluates them under the sustainability perspective. The possible benefits expected by the company are: reduction of emissions, waste and resource depletion; increase in farmers' life quality through a better management and automation on the field; increase in profits/reduction of cropping costs.
The company has visibility on three usage phases of its machines, therefore the lifecycle evaluation will comprise four lifecycle phases starting with production phase and including the subsequent 1st, 2nd and 3rd usage phases. The three usage phases are characterized by different performance levels, to keep into account the aging of machines. Since vehicles are made of good quality metals and materials, all components and materials are re-sold to developing countries and then recycled; from the company's perspective these cannot be further controlled and, according to the methodology, are out of the system boundaries.
The demonstration of the methodology aims at showing the utility of all uses presented in Section 3. Section 5.1 focuses on the first uses of the methodology, in the case of fixed OEE scenarios. It is helpful as background to understand the continuous improvement scenarios, successively shown in Section 5.2. With continuous improvement scenarios there are expectations of OEE variations, and a subsequent need to adapt the PSS solutions with the purpose to cope with such variations. This last use, with its strongest link to the concept of continuous improvement, envisions the relevant role of monitoring the PSS solution in time.

5.1 Fixed OEE scenarios

The demonstration initially consisted in the application of the methodology on an use case whose aim was the assessment of three different scenarios (S1, S2 and S3), which differed from one another for a specific Overall Equipment Effectiveness level (where OEE = Performance level * Availability * Quality (Muchiri and Pintelon, 2008)). In particular, in S1 the machine speed is the one obtainable with the current service offer; S2 is characterized by a 10% speed increase and S3 by a 20% increase from the basic S1 speed, being the OEE levels as follows: OEE_1=0.87; OEE_2=0.93; OEE_3=0.98. OEE levels 2 and 3 would be achievable thanks to additional service offers, enhancing the basic service offer.
OEE elements are computed as follows: performance level is equal to the ratio of the actual speed divided by the reference machine speed; availability is the machine running time divided by the total time; quality is assumed the same in all scenarios and equal to 1 (the reason is that the focus of the evaluation is the changing performance level and availability).
One Service Unit was fixed as 50 hectares of field harvested with a speed of 6.7 hectares per hour. An increase in the services added to the product, leads to increased availability and speed of the machine, thus rising performance level. As a consequence, the number of Service Units provided in the lifecycle of the PSS becomes also higher.
Results of the sustainability assessment have shown that, in the environmental sphere, each impact category reacts differently to the increase in OEE. An example of differently impacted categories is shown in Table 4, where biotic materials and water consumption, acidification and terrestrial euthrophication potentials are decreasing as a direct consequence of the increase in the number of provided Service Units, because the increased speed do not involve an addition in these emissions and the indicators are just affected by the growth in the number of Service Units, which are at the denominator of the computations. Soil depletion potential is not affected, because the lifecycle of the PSS does not need it; abiotic materials consumption is influenced to a limited extent, because the increase in number of Service Units balances the increase in materials needed for the increased speed (higher fuel consumption). Air consumption and global warming worsen their performances, because the increase in fuel consumption uses air for combustion and emits high quantities of CO_2 that cannot be balanced by the increase in the number of Service Units.
The economic dimension reports a steep decrease in lifecycle costs for the company (-9.1% in Scenario 2 and -16.7% in Scenario 3) and for the user (-7.4% and -13.4%).
The social dimension does not record any quantifiable change in impacts to stakeholders. This is aligned to the expectations, since only marginal modification (for consumers, employees and local community) are introduced due to the additional services in the various scenarios.
This example shows one of the main benefits of the integrated assessment methodology: changes that benefit some indicators and worsen other aspects may be avoided, because many sustainability issues are kept monitored at the same time.

5.2 Continuous improvement scenarios

The methodology is particularly intended for its adoption in a continuous improvement context: thanks to the methodology, it is possible to monitor the sustainability performances of the PSS during its lifecycle, and to add new services or modify the existing ones if the performances are worse than expected. This belongs to the fourth use suggested in Section 3. It was not possible to validate it extensively, because it would require to monitor the PSS for a long period of time and the research had time constraints, not comparable with the long life of a machine. However, in the current section a use case is also reported: it is limited to the New Product/Service Development stage, with the purpose to show how the methodology would work at this stage, preparing the ground for continuous improvement during the usage phases.

It is assumed first that the customer chooses the basic service offer, obtaining OEE_1 and S1 machine speeds that are, under ideal conditions, 3.4 ha/h during the first two usage phases, while in the third phase only a speed of 3.2 ha/h. However, it could be supposed that, due to bad operating conditions, the actual speed provided by the machines decreases 10% more in the transitions to the second usage phase and again 10% more than the expected 6% to the third usage phase. Resulting in speeds equal to 3.06 ha/h and 2.57 ha/h. In these conditions, OEE variations occur: as a reaction, the customer may be willing to increase the service going to the next level of service offer (i.e. from the service offered in S1 to that of S2 and from S2 to that of S3), in order to rise OEE levels and speeds. To verify these further options for the service offers, the computation of the resulting sustainability impacts is an exercise which can be performed, making assumptions at the New Product/Service Development stage. To this end, it is supposed that by shifting from one service to the other, the same percentage increase in speed is obtained as in the previous analysis presented in Section 5.1, respectively 10% and 20% by shifting from service offered in S1 to that of S2 and from S2 to that of S3.

Figure 3 presents a tree of the possible paths that may be covered in a bad scenario, where "Service level x" indicates the service level of Scenario Sx. In the second usage phase, it can be chosen to keep Service level 1, regardless of the poorer performance in speed terms or to increase the service level to the next one, in a "continuous improvement" approach, in order to gain a 10% increase in speed. And again in the third usage phase, it is possible to keep the service level as in the second usage phase or to shift it to the next level, as a reaction to the worse performance achieved.

For each of the four possible paths, it is possible to compute the lifecycle sustainability impacts through the methodology. It is therefore possible, already at the New Product/Service Development stage to see what would be the best "reaction" to the worsened performance in terms of sustainability burdens.

In Table 5 an example of a comparison of the impacts of the possible paths. The outcome shows that lower impacts in all environmental impact categories are achieved by: (i) reacting with a higher service level, and therefore with higher OEE, to the worse performance, than with non-reacting; and (ii) reacting sooner.

The economic dimension also shows lower costs both for the company and for the customer, recording a percentage cost decrease per Service Unit between 2% and 4% both for the company and for the user, in each transition from one path to the following. The social dimension, as in the demonstration in Section 5.1, has only marginal changes that can be neglected for the use case under analysis.

5.3 Discussion

The methodology fulfils the initial objectives and through the demonstrations it is possible to identify its main benefits: (i) avoiding of local improvements of few impact categories that result in worsened performances in others, and the (ii) continuous improvement usage, that provides an idea of the best "reaction" to bad performances already at the design stage of a PSS.

From the industrial application it was possible to get also some lessons learnt, related to critical activities: (i) In the data collection phase, measure units must be clearly expressed and consistent with the "Service Unit" perspective; company representatives must be helped and guided in the definition of the proper Service Unit and in the collection of the appropriate data type; (ii) System boundaries setting is also a delicate matter, because they define which are the flows cutting them and those that are internal that must be accounted for; (iii) the implementation of the methodology, in order to be successful, must be characterized by all requirements that were previously mentioned with regards to TQM and sustainability driven organizational changes, such as management commitment, employee training, company culture. These are essential because: on one side to collect data which correspond to real performance of the PSS requires an explicit will from the company's top management; on the other side, the assessment has a meaning only if followed by direct actions in the continuous improvement perspective, which cannot be taken without a choral commitment of the whole company.

6. Further research

The methodology can be improved with further research work that may address the creation of analytical connections between the three sustainability dimensions: this would create an even more integrated sustainability assessment of PSS solutions. In particular, it would represent a great improvement, if the second class of social categories (which is the most quantitative among the social burdens and already shown factors impacting on the other two sustainability dimensions) is linked with mathematical expressions to the environmental and economic assessment.

Moreover, further research could work on the second class of social categories with the aim to express it "per Service Unit"; this would align it to the other dimensions of sustainability.

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Figures and Tables:

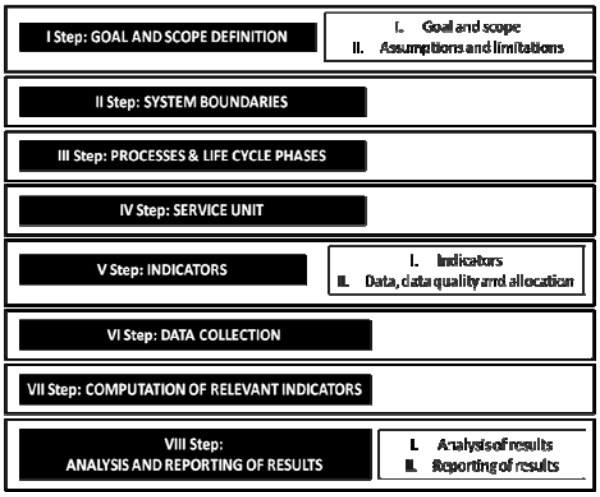

Figure 1 - Methodology Steps

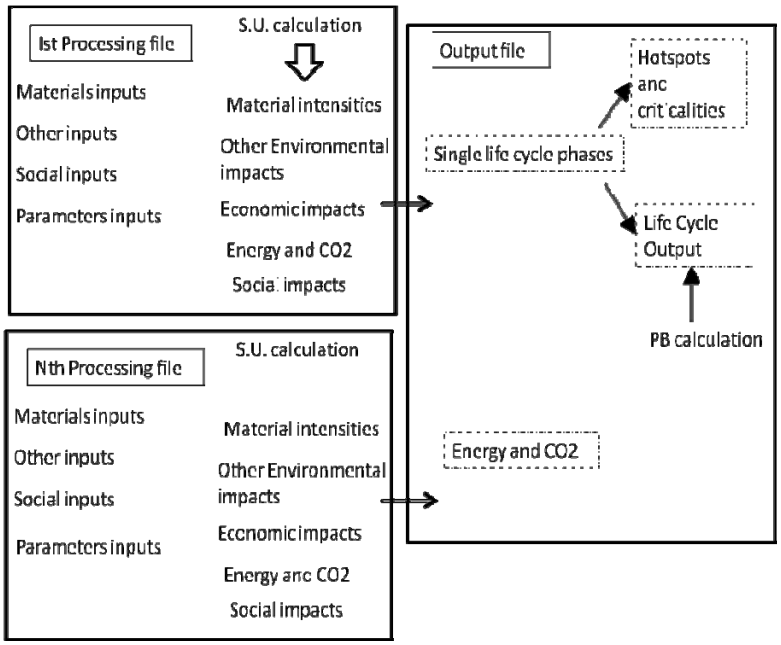

Figure 2- Structure of implementation files

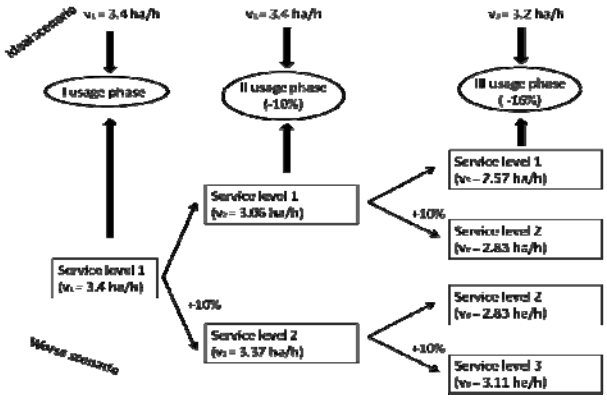

Figure 3- Possible paths of continuous improvement

Perspective	Impact category	Measure Unit	Source
Resource depletion	Abiotic Materials	Kg/S.U.	*Ritthoff et al. (2002)*; *Lettenmeier (2009)*
	Biotic Materials		
	Soil Erosion		
	Water		
	Air		
Emissions	Acidification	SO_2 eq. Kg/S.U.	*Pehnt (2006)*
	Global Warming	CO_2 eq. Kg/S.U.	*WMO (2006)*
	Euthrophication	$(PO_4)^{3-}$ eq. Kg/S.U.	*Seppälä et al. (2004); Pehnt (2006)*
	Ozone Depletion	CFC-11 eq. Kg/S.U.	*WMO (2006)*
	Eco-toxicity	1.4 DCB eq. Kg/S.U.	*Huijbregts et al. (2000)*
	Human Toxicity	DALY/mg absorbed/S.U.	*Crettaz et al. (2002); Pennington et al. (2002)*
	Photochemical Oxidant Formation	C_2H_4 eq. Kg/S.U.	*Derwent et al. (1998)*
	PAN Creation	C_3H_6 eq. Kg/S.U.	
	Waste	Kg waste/S.U.	*Saur et al. (2000)*
Design variables	Recyclability	Rating 1-6	*Coulter et al. (1998)*
	Disassemblability	Rating 1-5	

Table 1 – Environmental Impact categories and Sources

CO_2 sources	Measure Units
CO_2 for fuel combustion	kg CO_2/S.U.
CO_2 for internal energy production	kg CO_2/S.U.
CO_2 for electricity	kg CO_2/S.U.
Total CO_2	kg CO_2/S.U.
Energy sources	**Measure Units**
Energy from renewable sources	MWh/S.U.
Electric energy from non renewable sources	MWh/S.U.
Other energy resources	kg/S.U.

Table 2 – CO_2 and Energy sources

Indicator	Comments
Net Present Value for company	To have a general idea if it is profitable and how much.
Life Cycle Cost for company	It is a sum of all costs incurred by the company. Depending on the case, this sum can be discounted or not, according to the organization's preferences.
Total Cost of Ownership for the user	To understand the client's perspective and benchmark the company's offer to the competitors'. This can also be calculated both with discounted cash flows or non-discounted ones.
Payback Period	To evaluate the risks connected to the project.
Internal Rate of Return	To compare the return rate of the project to the desired one or to that of other products/services under development.

Table 3 – Economic indicators

	Impact category	S1	S2	ΔS1-S2	S3	Δ S1-S3	Unit of measure
Improving	**Biotic Materials**	0.5	0.5	-9.1%	0.4	-16.7%	kg/S.U.
	Water	13 802.7	13 076.2	-5.3%	12 516.8	-9.3%	kg/S.U.
	Acidification	8.5	7.7	-9.1%	7.1	-16.7%	SO_2 eq kg/S.U.
	Terrestrial Euthrophication	1.4	1.3	-9.1%	1.2	-16.7%	$(PO_4)^{3-}$ eq kg/S.U.
Not-affected	**Soil**	0	0		0		kg/S.U.
	Abiotic Materials	1 326.3	1 304.1	-1.7%	1 294.3	-2.4%	kg/S.U.
Worsening	**Air**	1 027.2	1 099.7	7.1%	1 174.7	14.4%	kg/S.U.
	Global Warming	860.5	937.1	8.9%	1 014.5	17.9%	CO_2 eq kg/S.U.

Table 4 - Differently impacted categories

	S1-S1-S1	S1-S1-S2	S1-S2-S2	S1-S2-S3	Unit of measure
Biotic Materials	0.55	0.53	0.51	0.50	kg/S.U.
Water	13 802.72	13 478.50	12 996.58	12 708.72	kg/S.U.
Acidification	8.52	8.32	8.02	7.84	SO_2 eq kg/S.U.
Terrestrial Eutrophication	1.44	1.40	1.35	1.32	$(PO_4)^{3-}$ eq kg/S.U.
Soil	0	0	0	0	kg/S.U.
Abiotic Materials	1 326.31	1 295.15	1 248.84	1 221.18	kg/S.U.
Air	1 027.17	1 003.04	967.18	945.75	kg/S.U.
Global Warming	860.53	840.31	810.27	792.32	CO_2 eq kg/S.U.

Table 5 - Impacts of different paths