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# SAM: A PRODUCT-SERVICE SYSTEMS SPECIFIC FRAMEWORK FOR SUSTAINABILITY ASSESSMENT AND MONITORING

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**Abstract**: Product-ServiceSystem (PSS) solutions are characterized by intensive interaction among PSS-providers, suppliers, and customers, as well as an integration of physical and immaterial solution-components. These factors increase the complexity and interdisciplinary of such business-to-business offerings. Furthermore, these characteristics complicate thesustainability assessment and monitoring of PSS. This paper introduces an approach to anindicator-based framework to support managers and decision makers in dealing with this complex situation. The framework considers the most important sustainability aspects throughout the entire PSS-lifecycle and adheres tothe European-standard requirements. It has been validated in a case study in the field of industrial micro-production technology.
**Keywords**: Product-Service Systems (PSS), Sustainability assessment

## 1. INTRODUCTION

Sustainability, or more precisely sustainable development, aims at continuous improvement of the quality of life and well-being for present and future generations, i.e. finding short-, medium-, as well as long-term solutions [1,2]. In Europe, current governmental policies require companies to focus on new strategies for smart, sustainable, and inclusive growth [3]. This poses an enormous challenge to industrial companies as environmental, social, and economic concerns have to be integrated into a product by minimizing impacts of the product on these three axes throughout the lifecycle [4].In addition to this, modern business-to-business and business-to-customer markets tend to offer a solution bundle of goods and services to solve customer-specific issues. An example for such a solution is to provide ‘availability’ of specific equipment. In the traditional industrial economy, suppliers of micro-production, for instance, profit from selling equipment and parts (e.g. milling spindles) only. Through condition monitoring systems and analysis software, it is now possible to sell ‘availability’ of equipment and parts. In such solutions, suppliers benefit from improved customer operations. The value is no longer attributed to material goods but more closely related to the performance and real utilization of integrated goods and services in a manufacturing system [5]. Such solutions, i.e. bundles of goods and services, are called Product-Service Systems (PSS) [6,7]. Depending on the domain-specific perspective, PSS are also known as Industrial Product-Service Systems (IPS$^2$) [8], integrated solutions [9], customer solutions [10], and Hybrid Offering [11]. The proposed framework focuses on business-to-business PSS, which show the followings characteristics:

- Integrated planning, development, provision, and use of product and service [8]
- Intensive interaction, and co-production between provider and customer [6,12,13]
- Intensive co-operation between provider and supplier [6,13]

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- The provider becomes part of the customer's ongoing operations [12]
- Long-term relationship between provider and customer [8,12]
- Provider and suppliers extend their involvement and responsibility from planning and development to other phases in the lifecycle (e.g. reuse, remanufacturing, and recycling) [6]

These characteristics of PSS not only increase the complexity and the interdisciplinary of business-to-business offerings, they also complicate sustainability assessment and the monitoring of PSS solutions.

The goal of this paper is to introduce a new approach for an indicator-based framework to support managers and decision makers with sustainability assessment and the monitoring of the PSS solution. The approach considers all (i.e. social, economic, and ecological) sustainability dimensions throughout the entire PSS lifecycle in different domains such as electronic, mechatronic, and immaterial solution components. It takes into account the requirements of EU and German standards alike (DIN, VDI, etc.).

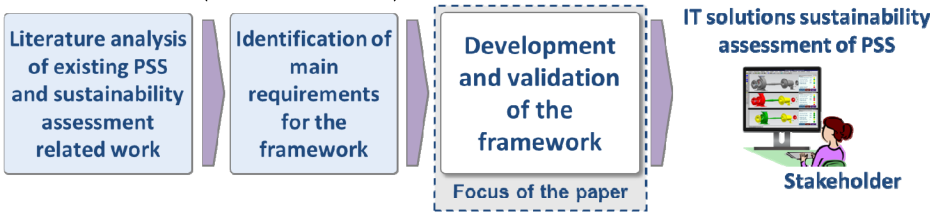


Figure 1 – Goals and methodical procedure

## 2. RELATED WORK

Today, there is a strongly increasing number of research works dealing with sustainability aspects in the industrial area. The work of Warhurst [14] focuses on the development and use of sustainability performance indicators in mining companies and takes into account the perspectives of internal and external stakeholders. It also provides an overview of different indicator types (e.g. descriptive, performance, efficiency, production), and describes the characteristics of different sustainable indicator systems by existing organizations (e.g. UN, World Bank). The framework proposed by Epstein and Roy [15] provides an approach to examine the drivers of corporate sustainability and the relations to stakeholder reactions and long-term financial performance. In [16], the balanced scorecard method has been extended to a sustainable balanced scorecard approach by including environmental and social performance indicators and aggregating all indicators into an overall sustainable performance index.

Unfortunately, most articles related to sustainability are either located in specific branches or take a broad, abstract perspective. Therefore, aspects relevant to PSS (such as customer-related processes and organization) are usually not considered.

The integration of sustainability into international standards is nowadays limited to policies and frameworks on a governmental level [17, 18]. Life Cycle Assessment (LCA) is the most standardized framework dealing with sustainability aspects. Unfortunately, it is focused on environmental aspects [4]. Even if the solution bundle of goods and services is considered, this framework is not specific to the development of PSS.

In the area of PSS, most existing papers discuss the impacts of PSS on sustainability [19, 20], dealing with the question of whether PSS are really sustainable [21], or with the sustainability benefits of PSS [22, 23, 24]. Different strategies of maximizing the social and environmental performance in offering PSS are also described [22]. Although this research takes into account all sustainability dimensions, the question of how the sustainability of PSS can be measured and controlled has not been addressed yet.

## 3. REQUIREMENTS

Based on the information in chapter 1 and 2, a sustainability assessment framework for PSS must meet the following main requirements:

- Products involved in a PSS have different, parallel lifecycles (see Figure 2) depending on the perspective of the involved party (providers, suppliers, or customers). From a PSS supplier's perspective, for instance, the use phase corresponds to the production phase of the customer. The results provided by the framework must consider the lifecycle of all products involved in the PSS. This also requires the consideration of the different perspectives of the involved parties by selecting appropriate indicators. Furthermore, the integrated aspects of goods and service in different phases should be taken into account during the identification and definition of sustainability indicators.

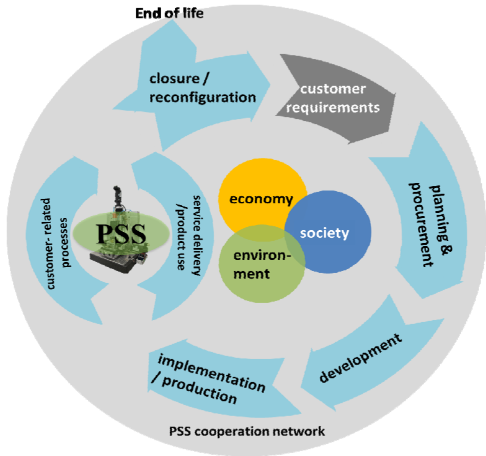

Figure 2 – PSS lifecycle and sustainability aspects

- Since the quality (more precisely: reliability) of data defines the reliability of the assessment results, the framework must propose solutions for the classification as well as the evaluation of the quality of data and results. Furthermore, solutions for the collection of specific virtual and real data have to be found. Therefore, the framework must allow the integration of data from different sources, i.e. from different domain-specific systems in particular IT systems. This also concerns the integration of data with different disciplinary backgrounds and from different hierarchical levels, as well as different network partners.
- The sustainability concept is based on a long-term vision. The framework, however, must also help to define short- and medium-term measures for the improvement of PSS sustainability.
- The framework must allow the monitoring of the sustainability measures defined upon assessment.
- The framework must allow and promote the involvement of all PSS parties (providers, suppliers, and customers).
- The environmental, social, technical, and economic aspects should be considered in an integrated manner. Thus, the dependencies among these aspects must also be considered.
- The framework must be compatible with both European and German standards.

## 4. SAM: ANINDICATOR-BASED SUSTAINABILITY FRAMEWORK

### 4.1General description

The proposed Sustainability Assessment and Monitoring (SAM) framework is based on a robust control systems approach. Figure 3provides an overview of its main stages. The structure and indications of the proposed framework have many aspects in common with standardized assessment frameworks such as Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). However, due to the characteristics of PSS, the framework shows important differences. First, in order to ensure the monitoring of PSS solutions, the framework follows a control loop. Input information is permanently derived from various sources and transformed into PSS Lifecycle Indicators (LI). The goals and scope of the assessment are permanently updated based on the specific choice of LIs. According to company-specific targets, an individual rating is defined for each LI. A suitable combination of LIs and their respective rating define the Key Sustainability Indicators (KSI) (cf. chapter 4.2).

Analogous to the "inventory analysis" and "impact assessment" LCA stages, information is analyzed and aggregated in the "sustainability assessment" stage. First KSIs are assessed and controlled. The overall sustainability performance of a PSS-solution is obtained as output information. This considers the relations and mutual dependencies among different KSIs (cf. chapter 4.2).

Finally, in the last stage of the framework "controlling", assessment results are provided to the stakeholders. KSI are compared to Key Goal Indicators (KGI) to check whether they are within the acceptable margins. If that is the case, the stakeholder is not expected to take action. In contrast, if PSS sustainability is out of marge, stakeholders have to take appropriate action. In addition to this, the system can be disturbed by expected or unexpected noises. Unexpected noises are disturbances that have not been taken into account during the development phase of the PSS. Therefore, appropriate action has to be developed during the operating phase. If expected noise (e. g. a power failure) occurs, predefined actions are taken to resolve the problem. Both expected and unexpected noises affect PSS sustainability. In the case of the expected noise "power failure", a solution that applies a current generator consuming fossil fuels can increase $CO_2$ emissions. However, an increase in $CO_2$ emissions affects the "Environmental" KSI performance. If this value is out of marge(e.g. it no longer complies with emission control regulations), the stakeholder has to find a new, suitable solution (e.g. applying renewable energy technologies).This last stage of the framework is analogous to the LCA stage "interpretation". Furthermore, it includes the definition of measures, which influence the goals and scope of further assessments.

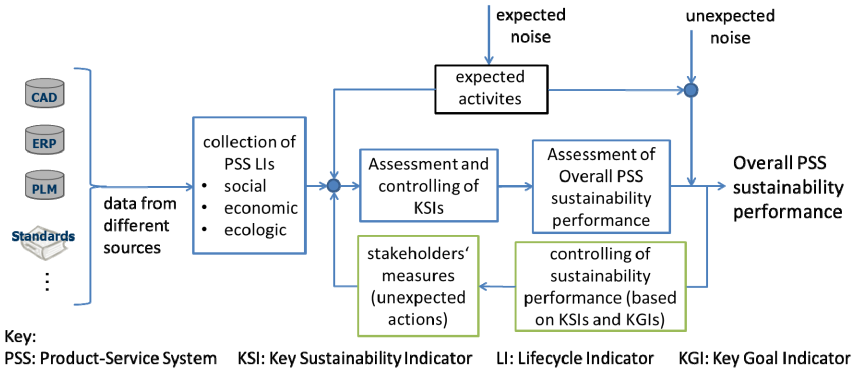


Figure 3 – Indicator-based framework for PSS sustainability

**4.2Sustainability assessment**

The goal of this stage of the framework is to assess the overall sustainability performance of PSS-solutions. According to the sustainability dimensions, this performance depends on environmental, social, and economic performances (c.f. Table 1). In some cases, it is suitable to analyze a fourth performance: PSS-specific performance. All these four performances depend, in turn, on single selected LIs. Some LIs can be considered for different KSIs e.g. energy consumption can be considered either for economic or environmental performance. Economic LIs can e.g. be used to assess environmental- and social-related costs and enable their controlling. The allocation of LIs does not influence the final result as soon as they are considered only once. Therefore, these indicators serve as a tool and are an important input for the lifecycle-based assessment of PSS product performance in economic, environmental, and social matters [14]. However, other projects have shown (cf. chapter 2) that there are still difficulties as regards the integration of social concerns due to undefined social indicators [4]. Prior to selecting any environmental, economic, or social LIs, companies need to develop clear business strategies and target definitions upon which an individual process of KSIs definition must be established. Hence, definitions provided in this framework are general and must be adjusted to each use case.

Due to the complex lifecycle of PSS products, indicators must fulfill several criteria, and they must be adapted to the developed framework. Thus, in order to implement indicators in corporate environments, they must show specific characteristics. An important criterion is that they must be simple and clear, i.e. they should be determinable in short time without much effort. They must be easy to understand not only by experts, but also by non-experts. Another important aspect is that indicators should require data, which is difficult to obtain. Hence, data acquisition must be feasible and simple. In order to support the assessment process, indicators must be trusted and useful, and rules must be established as to produce consistent results. To guarantee the integration of indicators in other assessments, they must also be reusable. Finally, they must be secure; information must be treated strictly confidentially and properly secured [25, 26].

Another important impact on the results of an assessment is based on the quality of data, which has to be evaluated. Details usually calculated, measured, or gathered from external databases. Since data from these different sources can have different quality, a quality coefficient has to be introduced to measure and weigh the quality of each data source. This helps to establish potentials for improvement and increase data quality. The framework proposes a classification of data on three quality levels: Data from direct measurements and/or internal sources, as well as data specific to the PSS solution is categorized as ‘high quality level data’. PSS solution-specific data from external sources such as supplier databases is categorized as “medium quality level data”. Finally, data from open source databases and/or data not specific to the PSS solution is categorized as “low quality level data”.

Table 1 below lists selected performance indicators for the measurement of sustainability as regards PSS.

Table 1 - Key sustainability indicators

| | KSI | KSI Description | Examples of selected single LIs |
|---|---|---|---|
| Overall sustainability performance | PSS-specific performance | This indicator provides an assessment of PSS-specific values. | Order cycle time, reuse of goods, number of new customers. |
| | PSS Economic performance | This indicator helps to control the cumulated economic aspects throughout the whole lifecycle of a PSS product. | Added value, gross profit, sales growth, return on sales, return on equity, the cost of PSS development, the cost of service processes, as well as the costs of infrastructure and spare parts. |
| | PSS Environmental performance | This indicator describes the fulfillment of ecological criteria of PSS products throughout the whole lifecycle. | Demand of energy, water, materials, and the extent of emissions, as well as the percentage of recycled materials. |
| | PSS Social performance | This indicator describes the fulfillment of social aspects of a PSS product throughout the whole lifecycle. | Number of training activities, and the degree of satisfaction of employees, customers, suppliers, health and safety prevention, the percentage of accidents, as well as job creation. |

## 5. CONCEPTUAL CASE STUDY

The proposed framework has been validated and verified in a conceptual case study, which has been developed in the scope of a German research project (Collaborative Research Center Transregio 29) on $IPS^2$ Engineering. The case study simulates the business-to-business relationship between two industrial companies: MicroS+ is a PSS solution provider who manufactures micro-milling machines and provides related services. OMICHRON is the customer manufacturing wrist watches. OMICHRON needs a micro-manufacture cell to produce high-quality wristwatch movement plates for the medium-priced segment. To solve OMICHRON's problem, MicroS+ proposes an overall PSS solution for which the product and service have been developed together. The complete base scenario and related business models are described in more detail in [27].

The proposed framework has been validated for a PSS solution based on an availability-oriented business model. In this collaboration-intensive business model, the PSS provider MicroS+ is responsible for services ensuring availability, while the customer OMICHRON runs the production processes of wristwatch movement plates. One component of the PSS solution is to ensure the availability of the milling spindle. The micro-manufacture cell remains the property of MicroS+ although it is located at OMICHRON’s site. Sustainability assessment is done in monthly or phase-specific reports (cf. Figure 4). Phase-specific reports are aggregated in an overall assessment of PSS sustainability. The KSI representing the four different dimensions of sustainability are calculated from a set of relevant single indicators. The selection of single indicators depends on which PSS lifecycle phase is assessed. Relevant single indicators used in most of the lifecycle phases are introduced further below.

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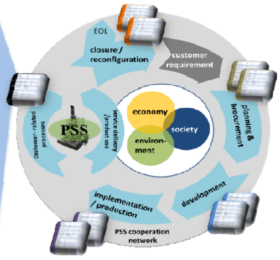
| PSS operating phase: KSIs | Selected Lifecycle Indicators (LIs) | Value | Individual rating * (0-5) | Partial average | Total |
|---|---|---|---|---|---|
| PSS-specific performance | Reuse of goods | 10% | 3 | 2,5 | 2,5 |
| | Order cycle time | 500 h | 2 | | |
| Economic performance | Sales growth | 1% | 3 | 4 | 3,8 |
| | Return on sales | 3% | 5 | | |
| Environmental performance | Energy consumtion | 4935 kWh prim. energy | 4 | 4,5 | |
| | CO2 emissions | 3554 kg CO2-eq. | 5 | | |
| Social performance | Employee satisfaction | 2.8 | 3 | 3 | |
| | Job creation | 786 h | 3 | | |
| Overall PSS-sustainability performance | | | | | 3,5 |




* The individual rating depends on company-specific targets

Figure 4 – Excerpt from sustainability report in operating phase

**Single Indicator 'Job creation'**

This indicator assesses the impact of PSS use on the creation of new jobs. The use of PSS usually requires qualified workers. Therefore, PSS providers often hire workers, train them, and provide them to the customer. As a result of this, additional jobs are created by implementing a PSS solution. For the calculation of the single indicator 'Job creation', the working hours of total PSS-related additional jobs are used as a unit.

**Single indicator 'Reuse of goods'**

As mentioned above, the value of offering a PSS solution is closely related to the performance and real utilization. To reduce the environmental impact and to increase economic efficiency, some items that have already been used but still meet the customer's requirements can be reused. This indicator specifies the amount of items deployed in a PSS that have been reused for the PSS solution.

**Single indicator 'Employee satisfaction'**

There are many ways to define the indicator 'employee satisfaction' depending on the company's goals. In this case study, 'employee satisfaction' has been calculated based on survey results that consider the following aspects: safety climate, work days missing, salary of full time employees, employee suggestions implemented, and satisfied employee ratio.

**Single Indicator 'Energy consumption'**

In order to calculate the energy consumption of PSS in the operating phase (product use, service delivery), different factors must be considered. Apart from the energy consumption of goods, the energy consumption in service delivery ($Q_{service}$) must be taken into account as well (e.g. tools used - $Q_{tools}$, light). The total energy consumption can be calculated as follows:

$$\sum Q_{electricity} = Q_{machine} + Q_{workplace} + Q_{service} [kWh]$$

The energy consumption of goods (e.g. machine, plant) can easily be measured by sensors. The energy consumption of tools that are used for service delivery can be calculated based on the power output ($L_{tools}$ ) and power efficiency ($LN_{tools}$) of these tools:

$$Q_{tools} = L_{tools} * LN_{tools} * T_{usage\_time} \ [kWh]$$

The Calculation of $Q_{service}$ depends on the amount of servicedelivery and energyconsumption of each delivery.Energy consumption ($Q_{workplace}$) of the surrounding area depends on the size of the site as well as the electric lighting and air conditioning facilities. The energy consumption of the electric lighting depends on the holding time and the required intensity of illumination. The intensity of illumination represents the incident light on a surface and is measured in lux. It can affect fatigue, performance, and accident rates of employees. For the workplace, an illumination of 1500 lux has been selected. If fluorescent lamps are used, an installed power of 0.03 kW per square meter workspace is scored. With regard to air conditioning, a power of 0.06 kWper square meter has been estimatedas the requirement.

$$\sum Q_{workplace} = Q_{light} + Q_{air\ condition} \ [kWh]$$

$$Q_{light} = L_{lamps} * T_{usage\_time} [kWh]$$

$$Q_{air\ condition} = L_{air\ condition} * T_{usage\_time} \ [kWh]$$

**Single Indicator '$CO_2$ emissions'**

A major cause for the emergence of $CO_2$ emissions is the use of fossil fuels for energy production. In the operating phase, energy is consumed by product use and service delivery (e.g. workers, tools). PSS usually consume and/or produce energy in the form of electric energy, thermal energy, cooling energy, and chemical energy. Considering service delivery, the energy needed for transportation must also be taken into account (i.e. usually chemical energy in the form of fuel).

CE = $CO_2$emissions; TC = thermal and cooling energy

$$CE_{total} = \sum CE_{electric} + \sum CE_{TC} + \sum CE_{fuel} \ [kg]$$

As thermal and cooling energy can be neglected in thecase study in hand, CE is calculated as follows:

$$CE_{total} = \sum Q_{electric} * E_{electric} + \sum M_{fuel} * E_{fuel} \ [kg]$$

$$E = \text{emission factor } (E_{electric} = 0{,}616 \ [kg/kWh];\ E_{fuel} = 2{,}854 \ [kg/l])$$

Finally, the lifecycle sustainability performance of PSS can provide information about the sustainability level of one PSS. It is calculated based on the overall sustainability performance in different lifecycle phases.

## 6. CONCLUSION AND OUTLOOK

The case study presented in this paper focuses on a single element of a PSS solution (milling spindle). It is limited to three sustainability indicators and to a single phase of the PSS lifecycle. The results have confirmed the usability of the proposed framework to assess the sustainability of PSS solutions. In the near future, the framework will be implemented and validated by an industrial transfer partner. It will comprise the assessment of a genuine PSS solution including further PSS sustainability indicators and take into account all PSS lifecycle phases. The most important challenge is the definition and assessment of social KPIs since they are often related to subjective input sources. As shown in Figure 1, the long term goal is to develop IT solutions that support the sustainability assessment of PSS.

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