Increased Raw Material Efficiency through Product-Service Systems in Resource-Intensive Production Processes? Barriers, Chances and an Assessment Approach

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Abstract. Product service systems (PSS) are a strategic option to increase raw material efficiency by intensifying product use or decoupling volume from profitability. To increase their market share in resource-intensive industries, this paper discusses an assessment approach based on the multi-criteria method PROMETHEE, which considers the benefits and perceived risks in a transparent way. The necessary criteria covering all aspects of the decision to introduce a PSS focusing on raw material efficiency are identified and determined by expert interviews and a comprehensive literature research.

Keywords: PSS, raw material efficiency, multi-criteria decision making, PROMETHEE.

1 Introduction

Raw material efficiency is turning into a crucial topic for the German manufacturing industry, because Germany is a country with limited natural resources and because there is a growing global demand for certain scarce resources as well as increasingly volatile and rising material costs [1]. Thus, it is particularly important for German industries to use raw materials and resources more efficiently. Especially resource-intensive industries which have a large demand for raw materials such as, e. g. the chemical, non-ferrous metal and steel making industries, have to employ technologies, concepts and strategies which focus on raw material efficiency in order to remain competitive [2].

Besides technological developments, implementing product-service systems (PSS) is a strategic option to achieve this objective, e. g. by intensifying product use, or by applying the specific expertise of a provider to use the product more efficiently.

PSS create conditions which can improve the profitability situation of the companies involved, not only through the products as such, but largely, or even entirely, through certain services or functions performed by the provider. Among others, the benefit of using PSS in the industrial sector is revealed in an increased productivity

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and customer loyalty as well as competitive differentiation. This benefit is valid for both suppliers and customers [3]. Moreover, PSS enable the decoupling of volume (producing lots of goods) from profitability and – as a consequence – focus on the functionality, not on the material content. By this means they can reduce the environmental impact of production systems [4] [5].

A representative large-scale survey of German manufacturing industries conducted in 2009 [6] with a sample of 1,484 companies indicates the relevance of different motivational factors for offering and using PSS. Besides the ever-present aspect of cost-effectiveness, ecological aspects of sustainability are also crucial, e. g. in the case of energy-contracting [7]. The current use of different PSS concepts aiming to reduce material and energy consumption is plotted in Figure 1. Especially concepts such as chemical leasing (58 %), contracts for continuous optimization (36 %), pay on production and guaranteed life cycle costs (31 % each) seem to have an impact on the reduction of energy and material consumption. However, when considering the diffusion of PSS in resource-intensive industries[1], only 24 % of the companies use at least one of these five PSS [8].

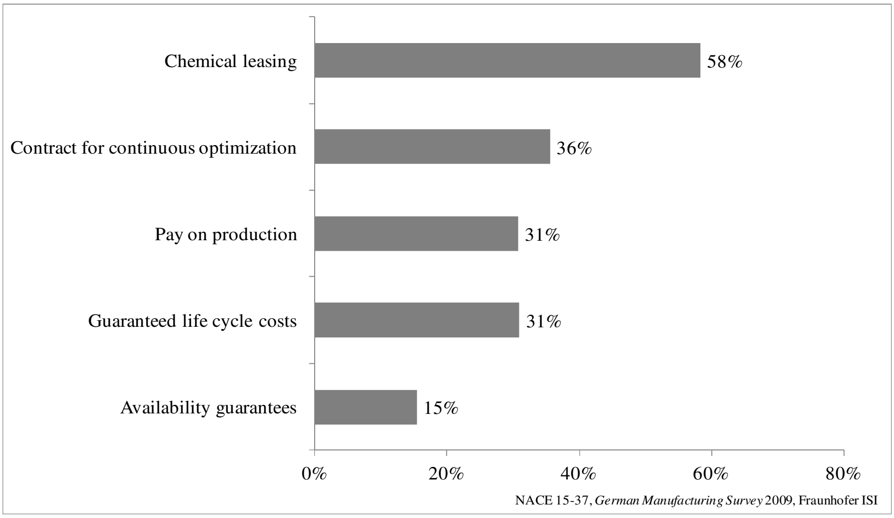

Fig. 1. Usage of different PSS concepts to reduce energy and material consumption

Quantitative (cf. Figure 1) as well as qualitative results [9] have shown the potential of PSS to reduce resource consumption in raw material-intensive production systems. And yet the market share of PSS is still relatively low. In order to enhance the awareness of the benefits of PSS regarding their potential to increase material efficiency and to overcome existing barriers which impede the usage of such PSS, this paper describes a decision support model. Decisions for implementing PSS are strategic and complex due to the scope of their impacts such as changes in the ownership structure and property rights as well as the level of customer involvement. Hence,

[1] Resource-intensive industries: NACE 17, 19, 20, 21, 23, 24, 26, 27.

various objectives should be considered: Besides the competitiveness of the PSS, they have to comply with ecological and technical requirements. The influencing criteria can be qualitative or quantitative in nature. Additionally, conflicting target parameters should be taken into account. Consequently, a multi-criteria decision support model is developed in this paper, which helps companies decide in favor of PSS focusing on material efficiency, if the value creation architecture is economically and ecologically attractive.

The paper is structured as follows. Section 2 gives an overview of the methodology applied. Section 3 focuses on a literature review regarding PSS and material efficiency and describes the barriers impeding the usage of PSS and their potential to increase material efficiency. Section 4 develops a multi-criteria approach for evaluating PSS. Different criteria are identified based on the literature review and expert interviews which cover the different aspects of PSS such as material efficiency as well as the economic and organizational perspectives. The last section concludes the paper.

2 Methodology

The aim of this paper is to develop an assessment approach for PSS which compares different PSS in a transparent way, assesses their benefits and barriers and, as a consequence, facilitates the decision to introduce them and/or increase their utilization. A multi-criteria decision approach seems to be suitable for selecting appropriate PSS which fit the corporate strategy as it considers the different objectives and preferences of decision-makers using e. g. economic, ecological and technical criteria. Where there are competing objectives, the attributes of the criteria might even be contradictory [10]. Moreover, applying a multi-criteria decision approach should make the potentials of certain PSS, the perceived risks and benefits of implementing PSS to improve material efficiency, as well as economic savings on the company level more transparent for decision-makers. Such an approach structures and simplifies the process of finding the most appropriate PSS [11] [12].

To fulfill the aforementioned requirements of assessing the different PSS in an objective and transparent way, the outranking method PROMETHEE was chosen. This ranks the different alternatives according to the criteria and preferences of the decision-maker. One of the advantages of PROMETHEE is the simultaneous consideration of quantitative and qualitative criteria. Moreover, PROMETHEE allows the decision-maker to take vague, incomplete, incomparable or even contradictory information and thus preferences into consideration due to the possibility to define threshold values, strict preferences, indefinite preferences and indifferences. This is especially useful if the decision-maker does not possess exact information about the alternatives. Another benefit of applying PROMETHEE is the avoidance of compensation effects. Accordingly, the advantages of one item do not compensate the disadvantages of another, and important information remains visible. This may result in different alternatives being incomparable and – as a consequence – lead to only a partial ranking of the alternatives. However, the aim of PROMETHEE is not to identify the optimal alternative, but rather any suitable alternative which matches the decision criteria and preferences of the decision-makers. Thus, the method delivers a transparently described ranking of the alternatives based on a well-structured decision process.

PROMETHEE is a multi-criteria decision aid method, one of the so-called outranking methods, and is one of the multi attribute decision making tools (MADM). Hence, each of the finite number of alternatives is evaluated regarding the different decision criteria and preferences of the decision-maker. Based on this assessment, the different alternatives – in this case of PSS – are (partially) ranked to choose the most appropriate alternative [13] [14]. This is achieved by a pair-wise comparison of the alternatives concerning the different criteria [15] [16].

Figure 2 shows the conceptual approach of a decision support tool for PSS based on PROMETHEE. The development and definition of decision criteria is the first and one of the most crucial steps in constructing the assessment tool, as the quality of the final decision is significantly influenced by the determination of the decision criteria. Thus, it is essential to have carefully elaborated criteria that cover all the aspects of the decision to introduce a PSS [17]. The following requirements need to be met: The decision criteria need to be easily understandable, measurable, free of redundancies, and contribute significantly to the decision. Furthermore, the criteria need to be balanced regarding completeness and conciseness as well as simplicity and complexity [18] [19].

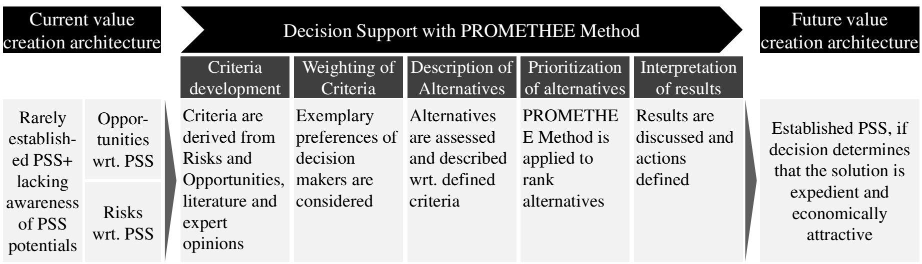

Fig. 2. Conceptual Approach of a Decision Support Tool based on PROMETHEE

Once the decision criteria have been selected, PROMETHEE allows the decision-makers to indicate their individual preferences by weighting them. Weights are assigned to each criterion, such that the overall sum is one or 100 percent.

This step is followed by the description and evaluation of the different PSS alternatives with respect to the defined criteria. The logic of the outranking method PROMETHEE then ranks the assessed alternatives according to the determined values and the weighting of the decision criteria.

PROMETHEE compares different alternatives with respect to the identified criteria. As this ranking does not yield an optimal solution, the results have to be discussed. A sensitivity analysis should be applied to test the stability of the results according to the weighting of the criteria and to demonstrate the consequences of any change in weighting.

To sum up, the structured approach simplifies the decision-making process of choosing an expedient PSS, which is economically and ecologically attractive.

In Section 4, the decision criteria are derived, which are a crucial prerequisite for applying this decision support tool based on PROMETHEE.

3 PSS and Raw Material Efficiency

3.1 PSS and Their Impact on Raw Material Efficiency

Raw materials are the basis for value creation in Germany's industrial society. Currently, there is an annual demand for 1.4 bn tons of abiotic raw materials in Germany[2] [20]. For a long time, this was not a major problem, but is now receiving more interest because of the international competition in purchasing raw materials [21]. Resource and especially raw material efficiency are therefore the object of multiple scientific projects focusing on resource-efficient production systems in the manufacturing industry. Implementing service-based business models is one strategic option to tackle the challenge of improving raw material efficiency.

The research into service-oriented business models is characterized by many different terms, e. g. servitization [22], functional sales [23] or performance-based contracting [24]. The business concepts underlying these terms describe a stand-alone solution which contains the combination of a minimum of one product and one service, is ready for the market and aims to fulfill specific customer needs [25] [26]. Within the research area dedicated to sustainability issues, these service-business relations between suppliers and their customers are predominantly referred to as PSS.

PSS concepts can be structured and designed in multiple ways [27]. Their key objective is to support customers in the daily use of the products (e. g. plant and machinery) by offering complementary services or – one step further – by assuming the risk for the production process (e. g. build-own-operate-model) and being paid for the production results. This frees the customer from tasks which are not related to the core business. The business model itself changes from a transaction-based concept to a relationship-based [28]. Unlike traditional business concepts, their added value consists of "providing functionality rather than products" [29]. Hockerts [30] claims that PSS are superior market solutions compared to the traditional selling of products.

The literature review showed that PSS reduce environmental impacts and positively influence sustainable development through the induced shift in incentives in the direction of dematerialization [31]. In traditional business concepts, the supplier wants to increase the volume of materials sold, whereas the customer wants to decrease the volume of materials used. In contrast, PSS offer the possibility to increase the value of the service for both parties involved. The supplier is remunerated for the service provided and not for the volume delivered [5]. Reiskin et al. [5] call this phenomenon "decoupling volume from profitability". Other advantages of PSS are that the provider possesses a more specialized knowledge, e. g. special engineering competencies, which lead to a more efficient use of the product, or an intensified usage of the products.

[2] Data of 2008.

3.2 Barriers to and Opportunities of PSS

Despite the benefits of PSS in increasing raw material efficiency, the usage of PSS in resource-intensive industries is still low. In the literature, various barriers and risks which hamper the diffusion of PSS are described, such as the difficulties new suppliers of PSS face when entering the market due to a lack of information about life cycle costs and other parameters of the equipment's operational phase. This is especially the case for customized solutions [32] [33]. Moreover, the transfer of experiences and information from customers to PSS providers is rather hesitant, because customers fear the loss of technological core competencies – and as a consequence – a threat to their competitive edge. This is particularly true for PSS which focus on harnessing the potentials offered by process optimization [33].

Expert interviews conducted in resource-intensive industries, such as steel and metal production, the chemical as well as the recycling industry, revealed a similar picture [8]: In all three sectors, the loss of know-how was mentioned as a perceived risk. Potential customers fear the loss of their competitive advantage, if PSS affect their core competencies. Amongst others, the perceived creation of a dependency on the supplier was commonly stated as a barrier to PSS. The interviewees assume the reliability and availability of the PSS provider is not guaranteed and that this can lead to severe production outages.

Those interviewed in resource-intensive industries were also questioned about the opportunities of PSS [8]. One advantage mentioned was that the provider of PSS possesses better know-how about non-core processes than their customers. Moreover such suppliers already have the specialized equipment needed and the technological core competencies for using it at their disposal. This reduces the demand for qualifications at the customers, and allows them to focus on their core competencies and increases their flexibility. Other advantages of PSS mentioned by the interviewees are cost savings, fewer quality problems and a long-lasting business relationship between PSS customer and supplier.

4 An Assessment Approach to Raw Material-Efficient PSS

As already indicated, PSS are a means – apart from conventional technical process enhancements – to harness the raw material efficiency potential in resource-intensive industries. However, as was detected in the expert interviews [9], there is still a lack of awareness of these potentials. A useful decision support tool for companies to facilitate the introduction of PSS is the multi-criteria approach based on PROMETHEE described in Section 2, which takes the opportunities and perceived risks of PSS into account. In the following, the decision criteria needed to assess PSS focusing on raw material efficiency in resource-intensive industries are identified and derived from expert interviews [9] and the relevant literature.

To consider all the aspects that need to be reflected in the decision process, the decision criteria should be aligned with universal company targets as shown in Figure 3. The overall value targets, such as profitability or productivity, are operationalized with factual targets, which are classified as *performance*, *financial*, *leadership and* *organizational* as well as *social and ecological goals*. These four factual targets are then captured by the identified decision criteria, which will be introduced in the following sections.

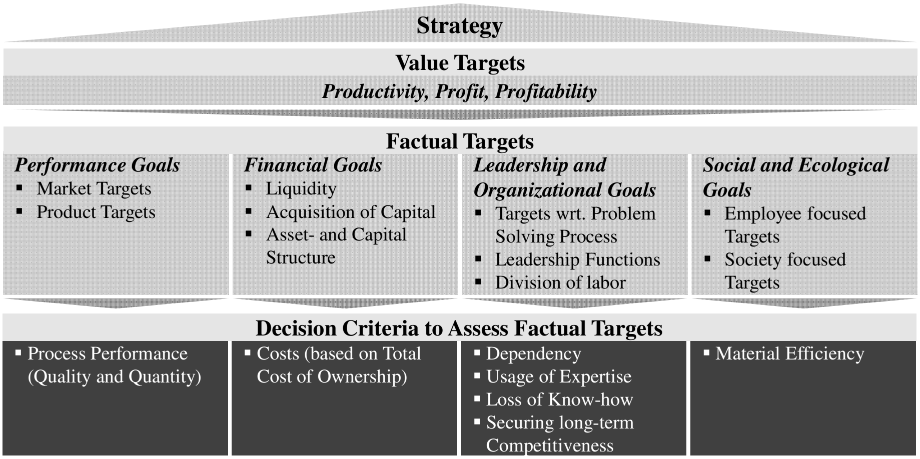

Fig. 3. Decision criteria aligned with universal company targets (Based on targets from [35])

4.1 Performance Goals

Process performance is an important aspect in the application of resource-intensive production value chains. Experts pointed out that technical processes already show a high degree of optimization and that high capacity utilization rates are needed in such asset-intensive industries. Reliability and availability as main drivers of down times contribute significantly to process performance. As a consequence, the evaluation of a PSS is based on aspects such as reliability [9] [36], availability [37] [38], robustness towards peaks (bottlenecks) [9], possible degree of process standardization [38], technical and operational risks [39] and the capacity utilization rate of existing and newly established facilities [9] [40]. Additionally, the robustness of the overall production system and a clear definition of responsibilities with respect to quality measures at process interfaces are taken into account [40].

4.2 Financial Goals

Costs are obviously another important aspect. Bearing in mind that some experts stated PSS do not necessarily lead to cost reductions [9], a thorough cost analysis of assets and processes is required covering the whole life cycle. A total cost of ownership approach is beneficial here as this covers all life cycle costs [9] [41]. When comparing the costs of PSS with a traditional business model, internal overhead expenses need to be taken into account. The discount of values is advantageous with respect to the timely distribution of cash inflows and outflows. In addition, the one-time costs of designing and setting up a PSS [36] [41] [42], coordination and control costs [5] [36], investments [43], lower capital costs due to a reduction of the required capital commitments, changes in liquidity [36] [40] [44] and shifts in the share of fixed and variable costs [38] [40] [45] all impact the assessment result. To sum up, this criterion has advantages due to the increased transparency of all the relevant costs on a life cycle basis [40] [44] [45].

4.3 Leadership and Organizational Goals

The experts named dependency on the provider as one of the major concerns of establishing a PSS [9]. Certainly, bargaining power is an important influence when determining the properties of a PSS. Oligopolistic or monopolistic market structures might be a barrier. Looking at a selection of alternative suppliers before signing long-term contracts reduces this risk. Furthermore, a carefully designed and reviewed contractual regulation helps to avoid such dependencies. However, apart from this dependency [9] [39] [43], many authors suggest that passing on responsibilities from the customer company to the PSS provider offers increased flexibility [9] [37] [44]. This area of concern requires an elaborate discussion and assessment.

Experts commonly see the usage of external expertise as a potential driver for a decision in favor of PSS. More and more advanced technologies and the related process know-how are adapted by specialized companies [43]. Therefore, it is necessary to assess the potential benefits of the technical capabilities gained [36] [44] [40]. Due to the incentive structure of PSS, the customer and the provider are often eager to expand the existing expertise cooperatively [36] [43]. Hence, the assessment should help to identify a PSS which is best able to achieve the listed benefits. In many publications the access to external know-how is described as advantageous in the context of using third party offerings [9] [36] [37].

In contrast to the acquisition of know-how and profiting from external expertise, loss of internal know-how is a commonly cited reason for ruling out the usage of PSS in the expert interviews. PSS have to be integrated smoothly into processes and this sometimes requires the transfer of internal know-how to the service provider. The situation might also occur, in which internal employees are no longer able to manage certain processes. This certainly relates to the aspect of dependency. The knowledge that certain know-how will have to be outsourced requires a proactive handling of risks, e. g. through a comprehensive contractual agreement. This is also a common argument in the literature [9] [38] [45].

Experts pointed out that, in the long run, decision-makers have a strong interest in securing future competitiveness. The positive influence of PSS on this aspect can be subsumed as strategic utility [46]. One strategic concept ensuring competitiveness is the concentration on the customers' core competencies [9] [36] [45]. Therefore, the PSS has to be assessed with regard to this demand. Besides this often mentioned aspect, the enhanced ability to react to changes [36] [40] is listed in various publications. As a result, responsiveness is considered in the operationalization of the decision criteria. The advantage of smaller organizational units can be taken into account [38] [40] [45] with respect to their beneficial properties regarding coordinating, organizing and planning. Other positive influences such as the customer-satisfaction-orientation of the

PSS provider [38], the transfer of risks to the PSS provider [38], increased innovativeness [39] [40], an improved image [44], reduced internal transaction costs [40], increased cost awareness [40], optimized depth of added value [40], competitive differentiation [40], reduced warranty and liability issues and stabilized business relations should also be captured and assessed regarding their impact on increased competitiveness [9] [39] [40]. Furthermore, it needs to be evaluated whether the aspects contributing to long-term competitiveness are outweighed by others such as the employees' refusal to accept the PSS, the interruption of related processes or reduced informal communication [38].

4.4 Social and Ecological Goals

As explained in the introduction, material efficiency is very important due to ecological goals, regulatory requirements and potential cost savings. Particularly in resource-intensive production systems, rising material prices result in an increased leverage effect of percentage material reductions. Advanced technology and process know-how and above all the expediently designed incentive structure of a PSS have the potential to improve material efficiency. While many of the other criteria have been handled in the literature, the aspect of material efficiency is rarely mentioned [9] [40]. This can be primarily attributed to the subordinate importance of this issue in the past.

5 Conclusions and the Need for Further Research

This paper shows that PSS are a strategic option to increase raw material efficiency. Nevertheless, the market share of PSS is still relatively low. To support and make the complex decision process of implementing PSS easier, this paper suggests and discusses an assessment approach based on the multi-criteria decision method PROMETHEE. This allows the assessment of the potential of specific PSS in a transparent way by considering the perceived risks and benefits.

In this paper, the decision criteria were determined as a first step towards developing a decision support tool covering all the aspects of the economic, ecological and technical objectives. The criteria are aligned with the general targets of the company, which are classified in four categories: *performance*, *financial*, *leadership and organizational* and *social and ecological*. To measure and compare the effects of different PSS focusing on raw material efficiency with the traditional business model, the following seven criteria are used: Performance is evaluated by the *process performance;* the financial goals are defined by the *total cost of ownership,* and the social and ecological perspective is covered by the achievements regarding *material efficiency*. The fourth category, leadership and organizational goals, is split into four criteria, *dependency on the provider*, *usage of expertise*, *loss of know-how* and *securing long-term competitiveness*.

Future research should focus on the development of the complete decision support model based on PROMETHEE and testing various case studies to validate its applicability.

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