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Demonstration of a multi-criteria based decision support framework for selecting PSS to increase resource efficiency

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Abstract

One important aspect of sustainable societies is the efficient use of resources. The consideration of resource efficiency aspects when designing business models such as product service systems (PSS) allows incentivizing such efficiency increases in business relationships. Particularly PSS are able to increase resource efficiency by intensifying product use or decoupling volume from profitability by allowing the provider to participate in efficiency gains. Yet, the diffusion of PSS in resource-intensive industries is low, which can be explained in two ways: Firstly low awareness of the potential benefits of PSS on the customer side and secondly the lack of approaches from the customer perspective. The presented research therefore works out an approach to compare PSS as well as traditional business models from the customer perspective. A multi-criteria based decision support framework based on the method PROMETHEE is developed to support decision makers. The multi-criteria based decision support framework considers the benefits and perceived risks of introducing a PSS in a structured way to help potential customers evaluate the pros and cons of the selection of a specific PSS. The application of the multi-criteria based decision support framework simultaneously raises awareness for potential benefits of PSS. This publication demonstrates the use of the developed framework with possible PSS for supplying refractory linings at an electric arc furnace for steel production. The results discuss the advantages and disadvantages of the presented multi-criteria based decision support framework. The strengths of the methodology, implementing qualitative and quantitative criteria, avoiding scaling and compensation effects as well as the possibility to vary the preferences of the decision maker, facilitate the decision-making process.

Keywords: PSS; material efficiency; energy efficiency; multi-criteria decision making; PROMETHEE; refractories

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1 Introduction

A growing world population and strong economic developments in newly industrializing countries lead to an increasing demand and, therefore, rising and volatile prices for resources. Consequently, uncertainty about the availability of resources is increasing (O'Brien et al., 2011). Thus, an efficient use of resources is desirable and particular resource-intensive industries such as the steel making industry should employ technologies, concepts and strategies which focus on resource efficiency in order to remain competitive (Bender et al., 2008). Apart from technological developments, service innovations such as changing the design of the existing business relations by implementing product service systems (PSS) is a strategic option to achieve this objective.

PSS imply a change from transaction-based to relationship-based business models between the provider and the customer and result in a different value proposition (Oliva and Kallenberg, 2003). In traditional business models a provider maximizes his profit by selling large quantities of a product or production equipment with additional services to his customers. However, when offering PSS, the service provider is paid for meeting the customers' needs (Tukker, 2004). For instance, instead of selling a machine tool for a one-time payment up front, the provider takes over the production and is paid for the produced units (Lay et al., 2007). Thus, PSS can be understood as particular business models, which differ regarding the business partner's incentives: By decoupling the volume (selling large quantities of goods) from profitability, the focus is put on increasing the value of the service by guaranteeing a certain level of functionality and quality of the product (Reiskin et al., 2000). By this means, PSS are able to enable more efficient production, e.g. by applying the specific expertise of a provider or by implementing a payment mode that provides all involved players with an incentive for resource efficiency. PSS are, therefore, able to reduce the impact of the production system on the environment (Maxwell and van der Vorst, 2003; Reiskin et al., 2000).

Taking Germany as an example for a highly developed country, a representative large-scale survey of the manufacturing industry by the Fraunhofer Institute for Systems and Innovation Research in 2009 with a sample of 1,484 companies reveals a low diffusion of PSS in resource-intensive industries[1], such as the chemical and metal producing industries (Bollhöfer and Mattes, 2012). Although the potential of PSS to reduce resource consumption has been shown (e.g. Hypko et al., 2009; Tukker, 2004), only 24 % of the companies in resource-intensive industries use at least one of the following PSS which offer the potential to increase material or energy efficiency: chemical leasing, contracts for continuous optimization, pay-on-production and guaranteed life cycle costs (Bollhöfer and Mattes, 2012). The following two possible explanations on the customer side could be identified by Mattes et al. (2013) for this low diffusion: Firstly, little awareness of the benefits of PSS regarding their potential to increase resource efficiency and secondly the complexity of a decision on different PSS. Complexity and the strategic nature of the decision are mainly induced by the scope of the decision's impacts such as changes in property rights and the degree of integration in existing processes. Hence, the assessment of PSS seems to be a challenge for potential customers (Mattes et al., 2013).

Several assessment approaches for selecting between different business models have been identified (summarized in Table 1) with the help of a comprehensive literature review. The analysis of the approaches has revealed four major findings. Firstly, with the exception of Tasaki et al. (2006), all approaches assess the economic outcome when deciding between different business models. Secondly, the methods used or developed show a broad variety. Thirdly, there are many approaches that evaluate the impacts of an introduced PSS from an overall system or providers' perspective, but only Mannweiler et al. (2010) and Steven et al. (2012) take the customer's perspective. Fourthly, those two approaches do not include ecological aspects such as material and energy efficiency, even though Mannweiler et al. (2010) emphasize the need to incorporate ecological aspects into their outlook. Thus, this analysis reveals the lack of a decision framework from the customer's perspective that considers both the aspect of resource efficiency (ecological dimension) and the financial outcome (economic dimension) of a decision between different business models.

[1] Resource-intensive industries: NACE 17, 19, 20, 21, 23, 24, 26, 27 (WZ 2003, Rev. 3.1, NACE: Nomenclature statistique des activités économiques dans la Communauté européenne, Statistical Classification of Economic Activities in the European Community).

Table 1: PSS assessment approaches by assessment dimensions from a systemic, provider and customer perspective

Authors	Dimension		Perspective	Method	Subject of evaluation
	Economic	Ecological			
Kim et al. (2011)	✓	✓	Overall system	Criteria based assessment from customer (regarding costs and quality) and supplier perspective (regarding economic, ecological and social outcome)	Overall assessment of PSS regarding economic, ecological and social outcome.
Lee et al. (2012)	✓	✓	Overall system	System Dynamics Model based on triple bottom line	Comprehensive sustainability assessment of a PSS. Demonstration of the approach with a case study of a public bicycle system.
Hammerl and Jasch (2006)	✓	✓	Overall system	Survey tool	Criteria based qualitative and quantitative assessment of economic and ecological outcome of a PSS.
Paci and Chiacchio (2009)	✓	✓	Overall system	Sensitivity Cost-Benefit Analysis applying the Analytic Hierarchy Process technique	Costs and value benefits of new PSS.
Schröter et al. (2010)	✓	✓	Overall system	Expert interviews	PSS alternatives are assessed with respect to the added-value to provider and customer.
Waltemode et al. (2012)	✓	✓	Overall system	Life cycle oriented assessment of PSS quality based on indicators	Assessment of PSS results quality.
Komoto et al. (2005)	✓	✓	Overall system	Life Cycle Simulation	Alternative PSSs are compared from an environmental and economic perspective. Demonstration of developed approach with the case study of washing laundry.
Burianek et al. (2008)	✓		Overall system	Analytical model with input or output formulas	Quantification of the customers' utility of a PSS, to enable the provider to design the revenue model accordingly.
Kim et al. (2007)	✓		Overall system	Multi agent simulation	Analysis of resource allocation between provider and customer for different performance-based business PSS for After-Sales in aerospace and defense industry.
Lange (2009)	✓		Overall system	Generic assessment procedure with KPIs for service provision	Evaluation of the PSS' service processes. Demonstration with case studies (e.g. PSS for wind power parks service management, customer integration projects of a producer of packing machines).
Urhahn et al. (2011)	✓		Overall system	Framework for quantified productivity assessment	Quantifies the productivity of a PSS in the analysis-, development-, implementation- and use-phase.
Tasaki et al. (2006)		✓	Overall system	Comparison of indicator ‚annual product demand'	Evaluation of the level of material use in lease/ reuse systems of electrical and electronic equipment.
Ahlert et al. (2008)	✓	✓	Provider	Utility oriented pricing framework for PSS based on customer value map, value in use analysis and conjoint analysis.	Utility of a PSS to derive a price or the product-service-bundle.
Bertoni et al. (2011)	✓	✓	Provider	Multiattribute utility theory	Considering the expectations and requirements of the customer the best possible PSS configuration is derived by assessing the customer's utility. The aerospace domain is taken as a data basis.
Goedkopp et al. (1999)	✓	✓	Provider	Expert interviews, Life Cycle Analysis, Eco-pool	Assessment of PSS regarding ecological impact, economic impact,

				approach	Identity and strategy, customer acceptance. Case studies: Car sharing, Laundry-services, Vegetables by subscription
Lee and Park (2010)	✓	✓	Provider	Analytic hierarchy process and niche theory	Assessment of gains and losses for a shift from product to PSS elaborating on the case study of laundry washing.
Manstein et al. (2003) Omann (2003, 2007)	✓	✓	Provider	Multi-criteria assessment	Comparison of a PSS with the equivalent stand-alone product for the economic, ecological and social dimension.
Steven et al. (2009), Rese et al. (2009), Richter (2010) Richter et al. (2010), Keine genannt Schulte and Steven (2012)	✓		Provider	Method mix: Activity-based costing, direct costing, real options approach, net present value	Assessment of the value of a PSS for a customer (potential revenue for the provider) and the cost of provision (for the provider) including the costs of potential changes of the PSS in the future.
Huber and Spinler (2012)	✓		Provider	Combinations of ‘full service’ and ‘on-call-service’ PSS are assessed with stochastic modeling of damages	A pricing model quantifies the value of a ‘full service’ contract and identifies the optimal configuration of ‘full service’ and ‘on-call-service’
Kimita et al. (2009a)	✓		Provider	Satisfaction-attribute (S-A) function (non-linear)	Estimates the customer satisfaction. Applied in a case study of domestic in-flight services.
Kimita et al. (2009b)	✓		Provider	Cost evaluation method based on activity based costing	The costs of different service designs are quantified. An exemplary application is the support service for the introduction of an IT system
Kortmann (2007)	✓		Provider	Builds upon the method ‘SERVQUAL’	Assessment of customer acceptance and satisfaction
Lay et al. (2009a)	✓		Provider	Method mix: Cost-utility analysis, net present value of life cycle costs, scenario analysis	Strategic goals are assessed regarding the best organizational structure for exporting PSS; the NPV is used to determine the best service provision.
Mont and Plepys (2003)	✓		Provider	Method mix to assess customer acceptance and satisfaction: Kano model, diffusion of innovations, SERVQUAL , interviews etc.	Assessment of customer acceptance and satisfaction
Niederauer (2009)	✓		Provider	Overview of different methods to assess the willingness to pay	Approach to assess PSS customers’ willingness to pay
Sadek and Steven (2010)	✓		Provider	Formalized revenue model considering the risk distribution between PSS-supplier and PSS-customer	The revenue model is applied to the case study of outsourcing of production processes
Schmitz (2008)	✓		Provider	Development of an analytical model to capture costs and benefits of a PSS	Assessment of costs and benefits of a PSS
Seiter et al. (2008)	✓		Provider	Analytical utility model with derived utility categories	Quantification of utility of the PSS provision to determine the price for an PSS offer
van Halen et al. (2005)	✓		Provider	Conceptual procedure for the development and assessment of PSS	Assessment of PSS’ market potential
Mannweiler et al. (2010)	✓		Customer	Life cycle oriented assessment of PSS quality based on costs.	Cost of PSS from the customer perspective.
Steven et al. (2012)	✓		Overall system	Cost management system based on target costing, (time-driven) activity-based costing and value analysis.	Conceptual cost management system for PSS for all life cycle phases to compare current and actual costs.

In summary, the literature review reveals that there is low awareness of the potential benefits of PSS on the customer side and a lack of approaches from the customer perspective. Thus, this paper aims at filling this gap by further expanding a previously developed multi-criteria based decision support framework (MDSF) for PSS by Mattes et al. (2013) which considers both economic and ecological objectives. Furthermore, the demonstration of an exemplary decision process for selecting a business model for supplying refractories in the steel production process by using this MDSF gives decision makers insights into how PSS can contribute to a more resource efficient production and allows a more transparent decision finding process.

Figure 1 visualizes the described starting point and the aim of the paper's research. As pointed out in the sections above, the potential of PSS to increase resource efficiency has been shown in different cases (e.g. Hypko et al., 2009; Tukker, 2004). However, deciding in favor of PSS to tap resource efficiency potentials is impeded by barriers such as perceived risks of the decision's outcome. The presented research, therefore, develops an approach based on the method PROMETHEE to compare different business models – among traditional business models also PSS – from the customer perspective. This MDSF considers the benefits and perceived risks of introducing a PSS in a structured way and supports decision makers – potential customers of PSS – by evaluating the pros and cons of selecting a specific business model.

Thus, this publication demonstrates the use of the developed framework with possible business models for supplying refractory linings at an electric arc furnace for steel production, which can be applied and respectively adjusted by decision makers in resource-intensive industries. Consequently, the aims of this paper are twofold:

1) *Advancement of a multi-criteria based decision support framework (MFS) for PSS from the customer perspective*

2) *Demonstration of the MFS to raise decision makers' awareness about the advantages of PSS in a transparent way*

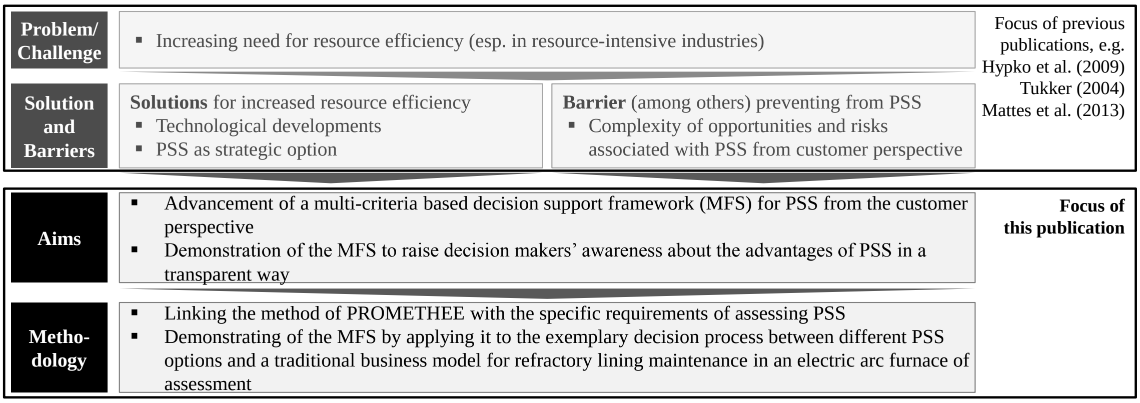

Figure 1: Synoptic structure of the paper

To achieve the aforementioned aims of this research, the paper is structured as follows. The methodology section explains the methodological approach regarding the advancement of the PROMETHEE-based MDSF and the demonstration example. The application of the MDSF is demonstrated by applying exemplary PSS alternatives in the subsequent section. The discussion and conclusion section then discusses the advantages and drawbacks of the developed MDSF from a methodological point of view.

2 Methodology

Equivalently to the twofold goal of this paper, the methodological elaborations are structured in two parts. The advancement of an MDSF-based framework is described first. Afterwards, an exemplary use case for the MSDF is demonstrated, which shows potential decision makers the applicability in resource-intensive industries.

2.1 Introduction of a multi-criteria based decision support framework for selecting business models based on PROMETHEE

Expert interviews have revealed that many opportunities as well as barriers influence the decision of implementing PSS (Bollhöfer et al., 2013). To facilitate the complex decision process, a decision support framework which compares different PSS from the customer perspective is developed. To fully capture the complexity of the decision influencing aspects, a multi-criteria decision approach seems to be suitable for selecting appropriate PSS, as it allows including the different objectives and preferences of decision makers. Furthermore, the approach needs to consider competing objectives.

To fulfill these requirements of assessing different business models, the PROMETHEE method is selected, which structures the decision process and ranks the alternatives according to the decision criteria and preferences of the decision maker (Brans and Mareschal, 2000).[2] This choice is mainly made based on the following reasons: Firstly, it considers different criteria with different scales for measuring simultaneously both qualitative and quantitative criteria, which prevents a distortion of the values. Secondly, the consideration of vague, incomplete, incomparable or contradictory information and preferences is possible. PROMETHEE avoids compensation effects and, thus, even contradictory criteria can be processed by the PROMETHEE algorithm. Consequently, the advantages of one criterion do not compensate the disadvantages of another, which prevents the loss of decision details. From the perspective of the decision maker, the process of specifying his preferences is simplified by using predefined preference functions based on the generalized criteria developed by Brans et al. (1986). By defining threshold values strict preferences, indefinite preferences and indifferences are determined. Moreover, impacts of different criteria weightings according to the preferences of the decision maker are included. By these means, the framework is supposed to support decision makers in evaluating the outcomes by identifying best possible solutions considering preferences and decision criteria as supposed to an optimization result – aggregating all aspects in a single target function. Based on the resulting ranking of alternatives further discussions of resulting actions should follow.

The previously developed MDSF by the authors (Mattes et al., 2013) is based on PROMETHEE and fulfills the aforementioned requirements. The PROMETHEE-ranking is achieved by pair-wise comparisons of the alternatives concerning the different criteria (Brans and Mareschal, 2005; Geldermann, 1999).[3] Figure 2 illustrates the conceptual approach of the decision support framework based on PROMETHEE. After determining the alternatives, the decision criteria which cover all aspects related to the introduction of a PSS-

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[2] The method ELECTRE, which would be a possible alternative, is not as intuitive regarding its application, less transparent and flexible (Zimmermann and Gutsche, 1991; Weißfloch 2013).

[3] Due to space restrictions reference is made to Brans et al. (1986) for the mathematical basics of the method.

business-model are elaborated (Geldermann, 2008). The decision criteria need to be easily understandable, measurable, free of redundancies and contribute significantly to the decision as well as balanced regarding conciseness, completeness, complexity and simplicity (Belton and Stewart, 2002; Roy, 2005).

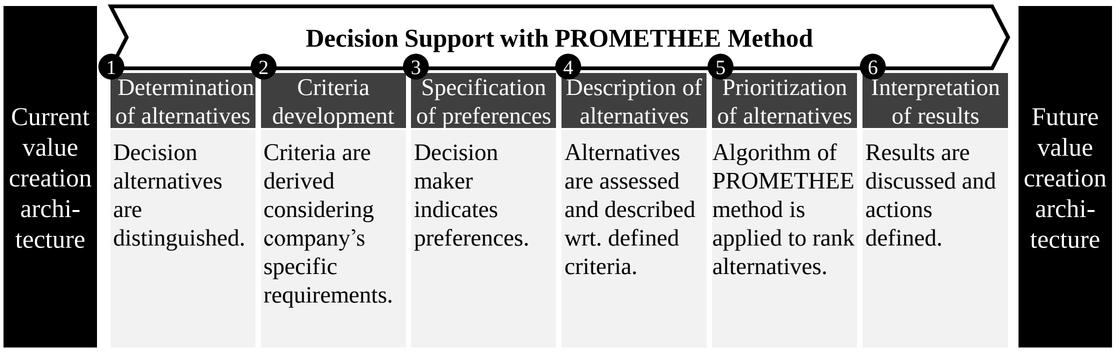

Figure 2: Conceptual approach of a decision support framework (MSDF) based on PROMETHEE (own illustration)

Once the decision criteria have been selected, PROMETHEE requires a decision maker to indicate his preferences regarding two aspects: To weigh each criterion, such that the overall sum is one and to apply suitable preference functions which determine the unambiguousness of the preference over the worse alternative. Depending on the selected preference function the formalized preference ranges from 0 (indifference) to 1 (strict preference).

This step is followed by the description of the considered PSS alternatives with respect to the defined criteria. The algorithm of PROMETHEE then ranks the assessed alternatives according to the identified criteria, the determined values, the selected preference function (including necessary thresholds) and the weighting of the decision criteria. Since this ranking often does not yield an optimal solution, the results have to be discussed.

2.2 Demonstration of the MDSF by using an exemplary decision example

Based on fourteen expert interviews by Bollhöfer et al. (2013), which were conducted with representatives[4] of the recycling, the steel and the chemical industry, the steel making industry has been chosen as a use case to demonstrate

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[4] The interview partners were senior managers in charge of technical operations (Bollhöfer and Mattes, 2012).

the developed MDSF. The expert interviews provided useful insights into these processes and for the development of different PSS alternatives. The decision demonstration example is built upon the use case of maintaining refractory linings in an electric arc furnace (EAF) as described by Gerling et al. (2005) as well as Sauer and Kronthaler (2005). In this use case, the customer is a steel producer and the provider is a refractories producer.

Notwithstanding, input of all interviews is taken into account for the determination of the decision criteria (second step of the MDSF, cf. Figure 2) since these decision criteria can be generalized to all resource-intensive industries. Furthermore, the procedure of the MDSF (cf. Figure 2) is based on a generic procedure which can be applied to other specific use cases in resource-intensive industries. However, the corresponding PSS alternatives, the specification of the preferences and the prioritization of alternatives have to be adjusted to each individual use case. In the following sections the methodological approach of designing the demonstration of the MDSF is described according to the generic procedure outlined in Figure 2.

As the first step, **alternative business models** need to be **determined**. Generally within the steel industry, both processes related to auxiliary materials – such as lime, industry gases or refractory materials – and byproducts – such as dusts, mill scale or slags – were named by steel industry experts as possible bases for PSS. Refractories were chosen because they are particularly able to contribute to an increased resource efficiency of the overall steel production system by reducing the refractory materials needed to produce one ton of steel as well as by enabling lower downtimes and, therefore, an increased utilization rate of the production assets. This addresses the predominant interest of the steel producer: A high reliability of refractory materials, allowing high utilization rates of the production plant by having low and predictable downtimes (McKane et al., 2008). Besides, refractories are suitable, because they are found in several processes apart from the steel industry where chemically and physically stable materials at high temperatures are required. This punctuates once more the goal to make the MDSF available to all resource-intensive industries. The needs of a steel producer regarding refractories elaborated above were taken as the starting point by the authors for designing resource efficiency enhancing business models. By taking the need of the customer as a guiding principle, the overall value creation architecture is designed to fulfill this need and incentives are established accordingly. For the selected decision process demonstration, this requires focusing on the functionality of refractory products. Subsequently, decision alternatives are derived by elaborating services providing the steel producer with a functioning EAF’s refractory lining. The alternatives can be distinguished regarding their ratio of tangible goods and intangible services. Out of many possible services offered around refractory linings in an EAF, the following services were selected to demonstrate the MDSF based framework: monitoring, operations consulting and maintenance. The degree of intangibility can be seen as a measure for the shift towards the provision of a function rather than a product and, thus, decoupling volume from profitability. Consequently, this shift relates to the ability of the PSS to increase resource efficiency. Generally, in business models with a higher rate of intangible elements the provider has more influence on the value creation due to the higher service share. They are called result-oriented, since customer and provider agree on a certain result (Tukker 2004). Moreover, these PSS alternatives focus especially on the functionality of the refractories and the provider of refractories is remunerated for a reliable, long-living, high-quality and resource efficient application of refractories. The remuneration is, for instance, represented by an agreed lump sum per produced ton of steel. Hence, the provider’s earnings are decoupled from the volume of refractories needed to perform the maintenance, which incentivizes him to be resource efficient, i.e. reduce his costs while the same earnings increase his margin.

Secondly, the **determination of decision criteria** is crucial and the requirements pointed out in the methodology section need to be met. Because the simulated PSS are applied in the resource-intensive steel industry, the decision criteria are taken from the previously published paper by Mattes et al. (2013), which describes in further detail how the criteria are derived and how they comply with the stated requirements. As a third step the **specification of preferences** needs to be indicated. For the purpose of the demonstration of the MDSF based framework the algorithm is simulated in this use case for the three different user profiles. The weighting of those profiles is based on plausible assumptions in order to show different assessment results.

Data necessary to **describe** the **business model alternative’s** attributes such as costs, energy consumption, and material usage are derived from expert interviews, literature review and supplementary assumptions.

The **prioritization of alternatives** is simulated for the selected three different user profiles. A ranking is achieved with the MDSF’s underlying algorithm of PROMETHEE, which compares alternatives pair-wise concerning the different criteria considering the preferences. As a last step, the **results** of the demonstrated decision example are **interpreted** briefly, because the focus of the paper is on the application and the introduction of the elaborated methodology.

3 Demonstration of the multi-criteria based decision support framework

The simulation of the MDSF follows the approach plotted in Figure 2 and is described in the last paragraph.

3.1 Determination of decision alternatives: Business models ranging from a traditional architecture to result-oriented PSS

In this demonstration of the use case, the decision alternatives are business models around the product of refractory linings in an EAF and related services. Five different business models are defined that cover different degrees of intangibility (compared to the tangible products) as shown in Figure 3. The two most characteristic alternatives, being at the end of the spectrum, are explained in more detail in the following. BM5 represents a rather traditional business model. Hence, the interaction between provider and customer is limited to the purchase of the product. No services are being rendered and the material is invoiced on a case by case basis. Therefore, the provider of the refractories does not have an incentive to exclusively focus on the steel producer's needs. The maximization of sold products – given a defined quality standard is ensured – is the primary economic goal and not a guaranteed level of functionality or quality of the product. In contrast, within BM1, the steel producer buys the functionality of the product. Thus, all equipment and the refractory material are owned by the service provider and the payment is solely based on the functionality – enabling steel production with low and reliably predictable downtimes of the EAF – linked to the quantity of steel produced. Apart from the resource efficiency gains, this business model is beneficial for the steel producer in the case of an economic downturn, as costs are equally reduced as the production volume goes down. The business models in between these two extremes show aspects of both, product- and functional-oriented provisioning and payment structures.

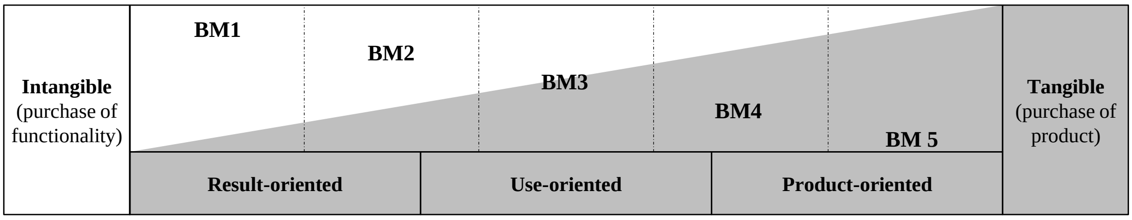

Figure 3: Comparison business models‘ tangibility, inspired by Tukker (2004)

Following Lay et al. (2009b), a morphological box is used to design and distinctively distinguish between different business models. Figure 4 shows a morphological box which lists the features that need to be determined vertically and corresponding attributes horizontally:

- For **maintenance**, the type of used equipment needs to be distinguished which is either a manually operated refractory gunning machine or an automated solution operated by a robot.
- The **financing of the equipment** needs to be indicated, such as leasing, purchase, rental or implicit financing of the equipment as part of a PSS. Implicit financing distinguishes between performance-based and usage-based remuneration inspired by the remuneration model of Burianek et al. (2008). Usage-based remuneration is, for example, linked to the quantity of steel produced. Performance-based remuneration takes the desired result of a service as an indicator. In the case of the demonstration example this would be for instance the highest possible mean time between failure (MTBF) and lowest mean time to repair (MTTR). The executing authority is determined. Internal or external staff (might also be staff of a subcontractor) operate the maintenance equipment.
- The financing modality of the **monitoring** equipment as well as the executing authorities such as leasing, purchase, rental or a lump-sum payment model is specified. In case no monitoring equipment is used, financing is not necessary. Services might be rendered by the steel producer’s, the provider’s or subcontracted staff of the refractory’s provider.
- A steel producer needs to decide whether **operation consulting** is made use of or not.
- The **length of the contracted** business relation and the agreed **exclusivity** of the arrangement are specified. The exclusivity determines whether the business model is only offered to one or several customers within the steel industry. Since the application of the analyzed technologies is limited to the EAF, all described business models are transferable to other customers in the steel industry, but not among other industries.

- The definition of the **payment mode** is crucial for the characteristics of the business model. The option of invoicing the steel producer by the quantity of refractory materials and hours of service received in the cost plus payment model refers to the 'traditional' business model. Performance-based or usage-based payment modes, however, are more directly linked to the provision of the functionality of the products.

Features			Attributes				
Main-te-nance	Equip ment	Type	Refractory gunning machines robot	Manually operated refractory gunning machine			
		Financing	Leasing	Purchase	Rental	No financing necessary (included in a lump-sum)	
	Executing authority		Internal staff	External staff	Staff of a subcontractor of the PSS provider		
Moni-toring	Financing/ use of equipment		Leasing	Purchase	Rental	No financing necessary (included in lump sum)	No equipment used
	Executing authority (location)		External staff (remote)	External staff (located at production halls)	Internal staff (located at production halls)		
Operations consulting			Used	Not used			
Contract period			Single long-term Contract	Defined periods for negotiations	Case by case agreement		
Exclusivity of the used PSS			Offered to several customers in the steel industry	Only offered to one Customer in the steel industry			
Payment mode for services/ PSS			Cost plus (time & materials)	Fixed fee	Performance-based (Durability, Downtimes)	Usage-based (€/ton of steel)	No payment necessary

Figure 4: Morphological box showing PSS design options for the creation of business models for refractories

Five different business models are designed whose specification is shown in the morphological box (cf. Figure 5) and which are used to simulate the application of the developed decision support model for PSS: Usage-based Full Service (BM1), Cost Plus Full Service (BM2), Remote Monitoring (BM3), Internal Operation (BM4) and Sale Only (BM5).

In BM1 the equipment is neither leased nor purchased as the complete service portfolio is rendered by the PSS-provider's staff, which is thus a result-oriented business model. The steel producer pays the provider according to the quantity of steel produced which refers to the usage-based payment mode and the most sophisticated technological solution is applied. Monitoring the refractory thickness is performed by laser measurement and the refractory maintenance is automated by a gunning robot. Since this solution requires a high integration of the PSS into the steel producer's processes and investments on the provider side a long-term contract is applied.

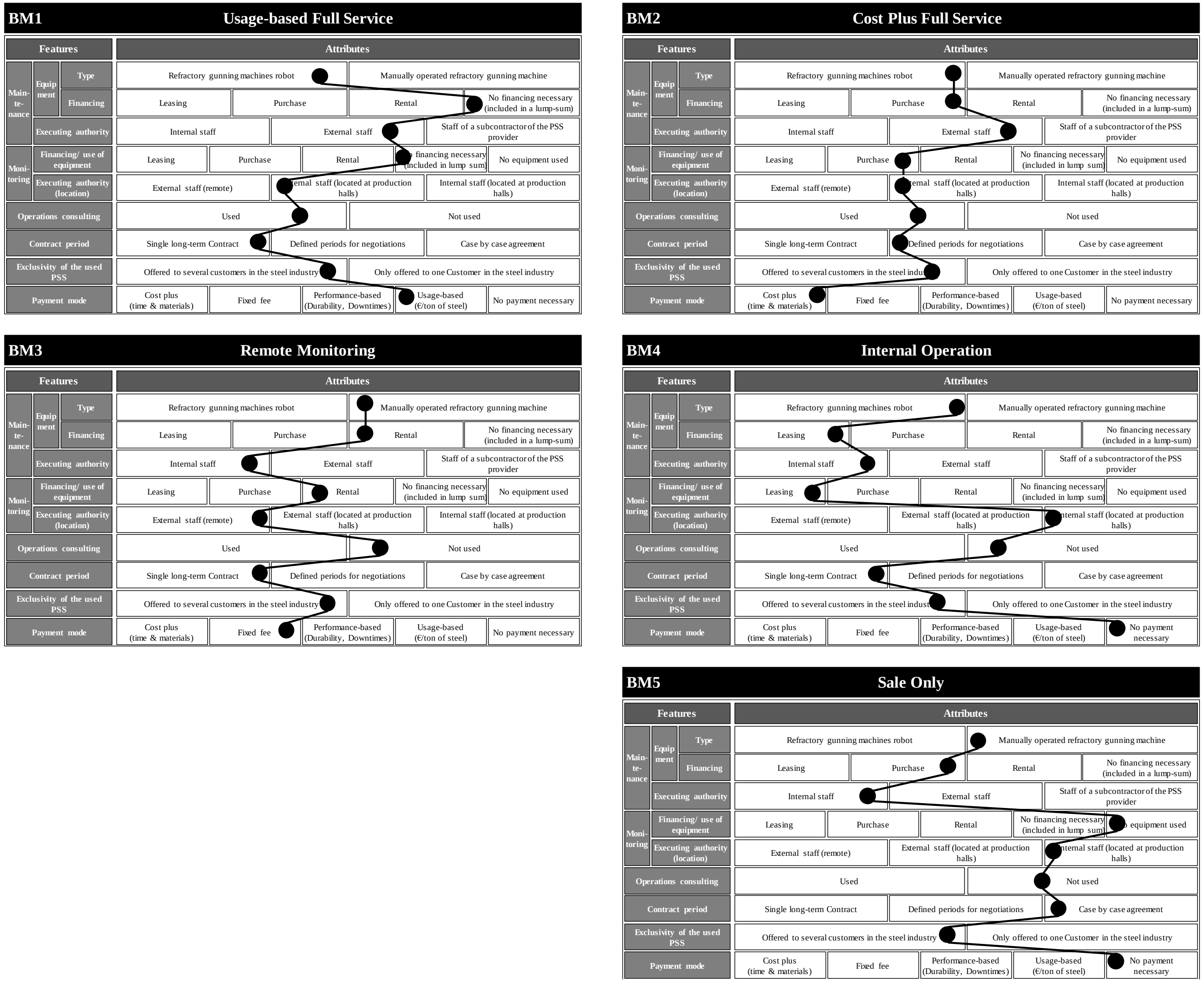

Figure 5: Overview of designed business model alternatives

Complete provisioning of all services – including operations consulting – by the contractor is provided in BM2, which suggests the purchase of both the monitoring and the maintenance machineries. This business model is invoiced by the cost plus payment mode. Thereby, the steel producer pays the provider of the services and the refractory material depending on the time worked and the amount of materials used. For defined contract periods fixed fees per hour and per refractory material are specified.

BM3 relies on external staff performing the monitoring. The condition of the refractory lining is communicated to the steel producer's staff and triggers automatically conducted maintenance works. The automated maintenance is supervised by the steel producer's personnel. The monitoring equipment is rented and the automated maintenance solution is bought. The business model does not include operations consulting and a fixed monthly fee is specified for the remote monitoring, based on a long-term contract.

In BM4 the steel producer is responsible for the maintenance by using an automated maintenance solution and the provider does not render any operations consulting. The monitoring equipment is leased. The steel producer is responsible for training his personnel to perform the monitoring and the maintenance of the refractories in the EAF. The financing modes are laid out to be rather long-term, the contract is also assumed to be long-term. Since the provider does not supply any services, there is no payment needed apart from the payments for the equipment.

BM5 focuses on the sale only and thus minimizes any interaction with external providers of equipment and services. Therefore, no monitoring equipment is used and a manually operated refractory gunning machine is applied. Consequently, the monitoring is carried out only by eye checks. The maintenance equipment is bought, which reduces dependencies on other companies over time. Hence, no long-term contracts are needed and case by case agreements are met with equipment sellers. As all maintenance and operation processes are performed by the steel producer's staff, costs are entailed internally and, for this reason, no payments are made to the provider.

3.2 Criteria development and specification of preferences

The chosen approach stipulates the opportunity to adjust the framework to specific requirements of a decision problem. Part of the generic procedure is to develop the decision criteria. As pointed out in section 2.2 for the case of the demonstration example, the following decision criteria previously developed by Mattes et al. (2013) are used to demonstrate the MDSF: process stability, total cost of ownership (TCO), material efficiency, dependency on the provider, usage of expertise, loss of know-how, securing long-term competitiveness and energy efficiency.

As a next step, the decision maker needs to specify his preferences regarding the decision criteria. To visualize the influence of different weightings, three different decision profiles are simulated: economic-oriented, resource-efficiency oriented und risk averse. For each profile the aspects described in the MDSF section – being the selection of the preference function and the assignment of a weight to each criterion – are indicated. For each criterion, one of the following six predefined preference functions outlined by Brans et al. (1986) and Brans and Mareschal (2005) is selected: Usual Criterion (I), Quasi-Criterion (II), Criterion with Linear Preference (III), Level-Criterion (IV), Criterion with Linear Preference and Indifference Area (V), Gaussian Criteria (VI).

For quantitative criteria Routroy and Kodali (2007) recommend preference function III or V. Due to the relatively higher absolute values of the criterion TCO, the preference function V is chosen and for the criteria energy and material efficiency the preference function III is assumed. This allows that a value range for the TCO is introduced, in which the decision maker is indifferent to specifying q – the preference threshold, defining the maximum delta that is perceived indifferent – at 40,000 EUR. For all other qualitatively measured criteria the preference function II is selected and a value on an eight step scale is assigned (see Table 3). Because it seems plausible to neglect a delta of one on the qualitative scale the indifference threshold q is set to 2. Table 2 displays the determined attributes for the demonstration of the MDSF.

Table 2: Preference functions and decision profiles

	Type	Preference function[1]	Direction	q[2]	p[3]	σ[4]	Economic-oriented	Resource-efficiency oriented	Risk averse profile
Total cost of ownership [1,000 EUR]	Quantitative	V	min	40	70		58%	40%	50%
Material efficiency [1,000 t]	Quantitative	III	max		5		6%	20%	4%
Energy efficiency [kWh]	Quantitative	III	max		15		6%	20%	4%
Dependence on provider	Qualitative	II	min	2			6%	4%	15%
Loss of know-how	Qualitative	II	min	2			6%	4%	15%
Process stability	Qualitative	II	max	2			6%	4%	4%
Access to external expertise	Qualitative	II	max	2			6%	4%	4%
Sustained competitiveness	Qualitative	II	max	2			6%	4%	4%

(1) Usual Criterion (I), Quasi-Criterion (II), Criterion with Linear Preference (III), Level-Criterion (IV), Criterion with Linear Preference and Indifference Area (V), Gaussian Criteria (VI)
(2) q: Indifference threshold
(3) p: Preference threshold
(4) σ: "The value of σ is the distance between the origin and the point of inflexion of the curve" (Brans and Vincke, 1985), only needed for the Gaussian Criteria (VI)

Although different decision makers might choose other preference functions and thresholds as selected and determined above, those parameters are retained constant for all three assumed decision profiles of the demonstrated decision example, each allocating the weights to the criteria differently (cf. Figure 2):

- The first decision profile simulates a **purely economic-oriented decision maker**. Therefore, the largest weight is put on TCO (58 %). The remaining criteria are assigned a 6 % weight each.
- The second decision maker has a stronger interest in a **resource efficient production** and, thus, puts 20 % weights on each material and energy efficiency. Since the economic impact is fundamental to any company leader, TCO is weighted with 40 % and all remaining criteria with 4 %.
- The third profile represents **risk aversion**, which was a recurrent topic in the conducted interviews about barriers preventing companies in resource-intensive industries from implementing PSS (Bollhöfer et al., 2013). A comparatively higher weighting of the criterion risk of losing know-how and the dependency on the PSS-provider reflects this position with 15 % each. Due to the risk aversion of the decision maker, TCO is weighted higher again (50 %) and all remaining criteria are set at 4 %.

3.3 Description of alternatives

According to the assessment approach laid out in Figure 2, the fourth step focuses on the description of the considered alternatives by assessing each criterion.

The **economic implications** of each alternative are captured with **TCO** in accordance with Geißdörfer (2009), who stresses the usefulness of TCO when changes in a business model occur. Similar to the approach of Mannweiler et al. (2010) who are also assessing PSS from the customer perspective, cost categories are elaborated for the investment, operation and disinvestment phase. By elaborating a cost driver tree, plotted in Figure 6, interdependencies are captured when calculating the TCO for each alternative. Since the utilization rate is crucial for the TCO of the steel production plant, opportunity costs are included (Wasmuth and Steven, 2012). For each business model costs are then calculated based on the identified variables such as wages, material costs, leasing rates, equipment prices and time needed to perform maintenance. Thus, the impact of increased resource efficiency on costs is included in the TCO as well as the chosen financing model. The results of the calculations are summarized in Table 4.

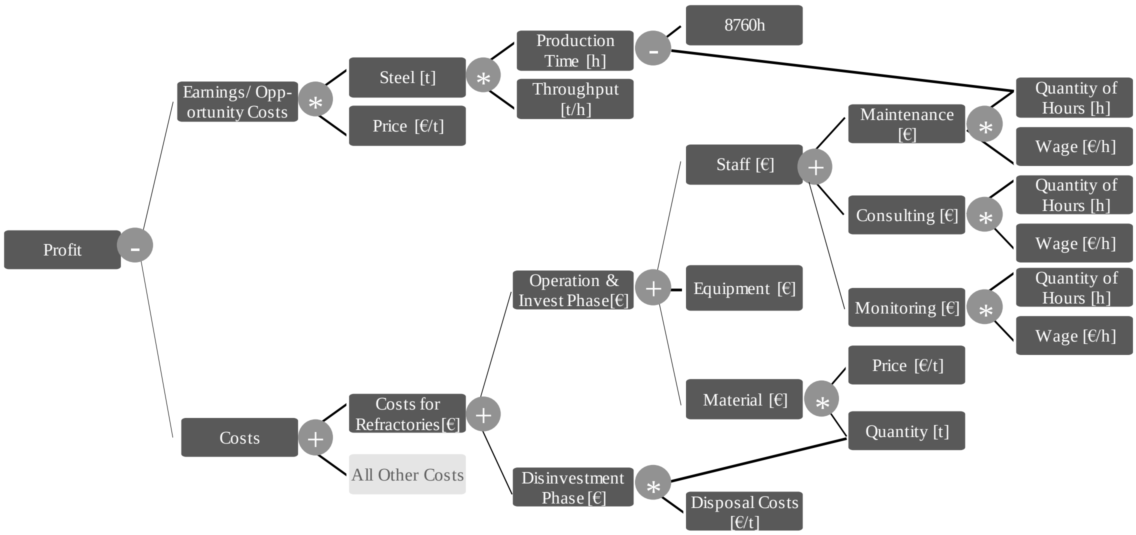

Figure 6: Cost driver tree for the calculation of TCO

BM3 and BM5 have higher TCO due to their opportunity costs resulting from the manually operated maintenance machine, which is more time consuming and consequently reduces the utilization rate of the production plant. BM1 has the lowest TCO since the provider has the incentive to be particularly cost-, material- and energy-efficient and all efficiency gains relate to cost savings (cf. Table 4). These cost savings improve the profitability of the provider's business, since he is not paid by the quantity of refractories sold, but by the quantity of steel produced. As a result, higher earnings can be achieved by producing more efficiently.

Material efficiency is understood beyond the specific material efficiency (reduced kilogram refractories per ton steel, the consumption of a traditional business model taken as a benchmark) by taking the utilization rate of the EAF into consideration as visualized in Figure 7. An increased utilization rate translates into an extended use of the materials bound in the production assets (Sauer and Kronthaler, 2005). Hence, material efficiency is operationalized by adding up firstly increased steel production – made possible through reduced maintenance times – and secondly lower specific refractory material consumption per ton of steel. Calculations are based on the empirical data of an implemented automated maintenance solution documented by Sauer and Kronthaler (2005).

Material efficiency is influenced by many aspects such as the technological components used, the know-how possessed and applied as well as the incentives put in place to increase material efficiency. The impact of the technological choice can be illustrated comparing manually conducted maintenance with the automated solution. An automated solution – as applied in BM1, BM2 and BM4 – achieves higher material efficiency increases, since the reparation by the automated solution is more precise which leads to less material used. Other important aspects apart from technology are product know-how and incentives to achieve a more material efficient operation. For instance, BM1 achieves high material efficiency due to the know-how the provider of refractories applied when rendering the services and due to the incentive structure, as all efficiency gains increase the profitability of its business (cf. Table 4). Know-how and experience particularly pay off during the assessment of the material fatigue, which then allows more precise repair measures and extends the life-time of one refractory lining.

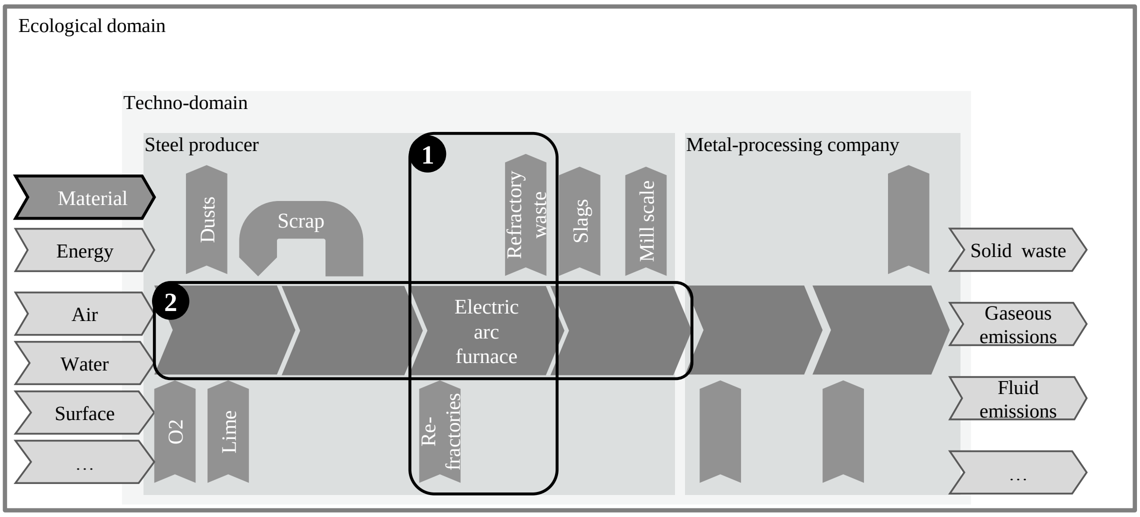

Figure 7: Assessment concept for material efficiency constituted by (1) specific refractory material consumption per ton steel produced and (2) utilization rate of production assets

Energy efficiency is mainly determined by the installed technological system. Consequently, business models with best available technology (BAT) show the best assessment scores. For the case of monitoring and maintenance of the refractory lining in an EAF, BAT is the laser-monitored repair by an automated gunning machine (Gerling et al., 2005). Since the BAT changes over time, business models ensuring the latest technology in the long-term are assessed to have the largest potential to increase energy efficiency. Accordingly, BM1, BM2 and BM4 show high efficiency gains since they ensure a long-term BAT. The resulting incentive of the payment mode for the PSS-provider ensures the application of the latest technology in BM1. BM5 in contrast shows no improvements at all, since BAT is not even applied in the beginning (cf. Table 4).

The remaining criteria are of a qualitative nature. The scale applied is displayed in Table 3. Each numerical value is translated into adjectives to simplify the assessment for decision makers.

Table 3: Qualitative rating scale

Nonexistent	1
Very low	2
Low	3
Below average	4
Average	5
Above average	6
Strong	7
Very strong	8

The **dependency on the provider** seems to be one of the major risks of engaging in highly integrated PSS (Bollhöfer et al., 2013), since no other provider would be able to fulfill the services in the same way in the short run and further coordination costs would occur. Particularly, the characteristic of PSS to meet specific customer needs leads to this drawback. The dependency is a result of both, the degree of integration into the steel producer's processes and the extent to which services are rendered by the PSS-provider. Taking BM1 as an example, both the equipment and the know-how are completely in the hands of the PSS-provider leading to a very strong dependency. BM2 still has a strong dependency, as all services are rendered by the PSS provider, the maintenance equipment, however, is the property of the steel producer. BM5, on the other hand, shows a very low dependency, because all equipment is in the possession of the steel producer and no services are rendered by the provider (cf. Table 4).

In contrast to the dependency on the PSS-provider, the **access to external expertise** is beneficial for the steel producer. The complexity of the refractory material selection and application – with regard to the physical and chemical stress exposed as well as the quality standards to be met – require experience and expertise with refractory materials and their interaction with reactions during steel production. Particularly, the providers of the refractory materials possess this specific knowledge, since the providers deliver refractories to more than one steel plant enabling them to act as 'purveyors of knowledge' and multiplier.

BM1 benefits very strongly and BM2 benefits strongly from the expertise of the refractory manufacturer, as all three services – monitoring, maintenance and operations consulting – are provided to the steel producer. Although this external expertise is less accessible in BM3, rendering remote control leads to an assessment above average. BM5, however, is assumed to have very low access to external expertise, since neither technology nor service-wise cooperation with the provider is put in place (cf. Table 4).

As opposed to the access to external expertise, the **loss of know-how** was named by experts as a risk of engaging in a PSS (Bollhöfer et al., 2013). Since BM1 and BM2 transfer all responsibilities to the PSS-provider, over time the steel producer's staff will not have the capabilities and know-how to run the monitoring and maintenance processes anymore. Furthermore, these highly integrated PSS might imply the refractories' provider gaining insights into details of production processes that yield the steel manufacturer's competitive advantage. Therefore, those business models are assumed to show a strong loss of know-how. BM3 relies only on remote monitoring, which keeps more expertise with the steel producer's staff. Very low respectively no loss of know-how is assumed for BM4 respectively BM5 (cf. Table 4).

Due to the various interdependencies in a highly optimized production system, the **process stability** is another important criterion. Reliability is crucial to achieve a stable operation state of the overall production system. To achieve this, downtimes of different production assets are synchronized and scheduled in advance. The capacity to forecast maintenance periods depends on the experience and the know-how related to material fatigue. Further, process stability is influenced by the quality of the repairs and the technological capacity to monitor the current material's condition. Consequently, BM1 shows the highest stability due to the more precise maintenance with an automated system enabled by laser monitoring, whereas BM5 lacks technology and expertise to achieve a stable production system (cf. Table 4).

To **sustain competitiveness** in the future, the steel producer needs to assure at least the level of efficiency of his competitors with respect to technology, process design and organizational structure. One possible strategic orientation is to align alongside the company's core skills, which translates into splitting up responsibilities in the demonstrated decision example: The steel producer focuses on processes directly leading to the final product steel, whereas all refractories related tasks are taken over by the PSS-provider, who brings in a higher degree of expertise related to refractories. By exploiting economies of scale, the PSS-provider is able to aggregate expertise among different customers concerning the technologies available, the materials suitable for specific steel compositions and material fatigue. Thus, the assessment of sustained competitiveness varies between the different PSS alternatives as it results from the degree of expertise both the PSS-provider and the PSS-customer align alongside their core competences. Consequently, transferring the responsibilities for the monitoring and maintenance of the EAF refractory lining to the PSS-provider in BM2 is assumed to be beneficial. The design of BM1 is expected to be even superior due to the incentive for the PSS-provider to ensure a competitive advantage in the long-term. Split responsibilities – such as implemented in BM3 – are rated in between the entirely outsourced processes and designs with no outsourcing at all as in BM4 or BM5. Table 4 summarizes the description of all five different alternatives.

Table 4: Evaluation matrix – constituted by a value for each criterion for each business model

	BM1	BM2	BM3	BM4	BM5
Total cost of ownership [m€]	8.3	11.6	12.7	8.4	33.2
Material efficiency [1000t]	63	40.1	31.4	63	0
Energy efficiency [kWh]	302	226.5	220.5	216.5	75.5
Dependence on provider	8	7	6	4	2
Loss of know-how	7	7	5	2	1
Process stability	8	8	7	6	2
Access to external expertise	8	8	6	4	2
Sustained competitiveness	8	7	6	5	3

3.4 Prioritization of alternatives

The prioritization of alternatives is simulated for the three different user profiles described in section 3.2: a purely economic-oriented decision maker, a decision maker focusing on resource efficiency and a risk-averse decision maker. A ranking is achieved by pair-wise comparisons of the alternatives concerning the different criteria and considering the preferences of the decision makers. The results of the MDSF, the ranking of the different alternatives, can be visualized as shown in Figure 8. The best suitable alternative according to the preferences of the decision maker is situated on the very left side, the least suitable alternatives on the very right side of the rank order. Strict preferences are indicated as an arrow. BM1 for instance is strictly preferred over BM4 by a decision maker with a focus on TCO (Profile I) or a decision maker with a focus on material and energy efficiency (Profile II). If two alternatives are neither indifferent, nor one alternative is preferred over the other, an incomparability occurs. Incomparable alternatives do not show a connection arrow, such as BM1 and BM5, simulating a risk-averse decision maker (Profile III). Indifferent alternatives would be visualized by a connection line. However, there are no indifferent alternatives in our demonstration example.

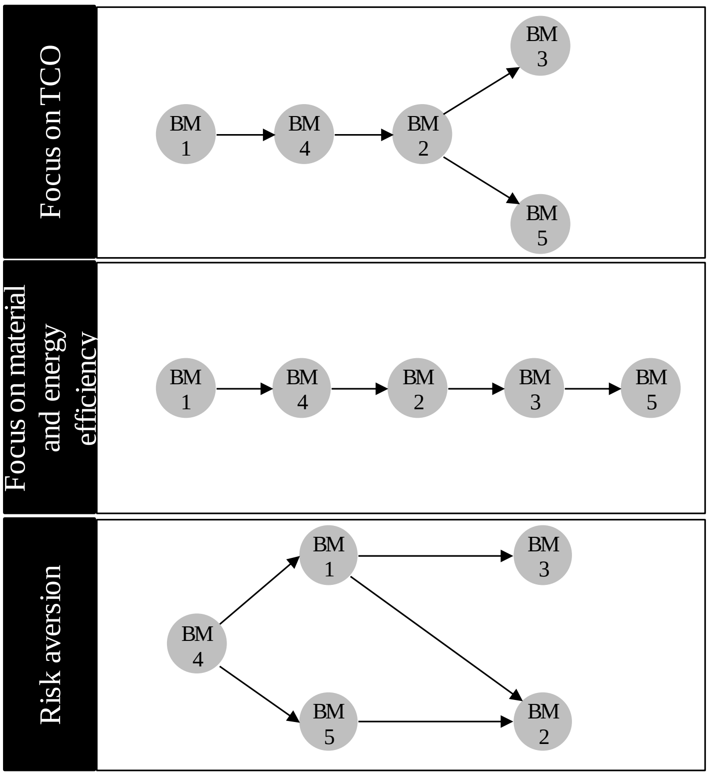

Figure 8: Simulated results for all three decision maker profiles

The decision profile focusing on TCO shows a strict preference of the result-oriented BM1 over all other alternatives. Although renting the equipment contributes to a higher TCO for BM4, the advantage of ensuring the application of the latest and most efficient technology, as well as reduced dependencies, outbalances the higher costs. This comparison demonstrates the importance of material and energy efficiency.

Higher weights on material and energy efficiency (Profile II) similarly lead to a strict preference of the result-oriented PSS over all other business models. This is in line with the remarks regarding the contributions of the result-oriented PSS to resource efficiency gains. BM5 – showing the least advanced technology – ranks lowest and is dominated by the remote monitoring concept incorporated in BM3.

The simulation of a risk-averse decision maker shows different results. Since BM5 transfers few responsibilities to the PSS-provider, it might be rather beneficial to decision makers with risk aversion. BM5 ranked second after the preferred alternative BM4. The result-oriented BM1 turns out to be an alternative less suitable for a decision maker with risk aversion. This lower ranking of BM1 is mainly due to the higher weighting of the criteria dependence on provider and loss of know-how. BM5 is not comparable with both BM1 and BM3. BM2 is not comparable with BM3.

4 Interpretation of results and discussion

The simulated results of the use case are in line with several empirical studies which have proved the ability of PSS to increase resource efficiency (e.g. Behzadian et al, 2010). The comparison of the three decision profiles illustrates how the weighting of criteria distinctively influences the ranking. For instance, Profile II (putting higher weights on resource efficiency) identifies the result-oriented PSS (BM1) as most suitable, whereas Profile III – representing risk aversion – ranks remote monitoring (BM4) first.

The decision support tool helps to choose an adequate solution depending on the respective situation. The simulation of the different strategies shows that BM1 is the most promising PSS with regard to reduced resource consumption and decreased capital spending. Since there is a low diffusion of result-oriented PSS in resource-intensive industries, the decision support framework creates an objectified and structured assessment of decision alternatives. Consequently, it is a useful tool for revealing the contribution of PSS to produce more efficiently with respect to resources as well as costs.

Yet, for aspects to be objectified rationally, the approach seems suitable to capture all significant decision influences, which can be of a quantitative and qualitative nature, and support decision makers in assessing business models. Besides making the decision process more transparent and understandable, the approach allows including indifferences and incomparabilities. Furthermore, the generic framework can be adjusted according to specific use cases with respect to the criteria used and the weightings assigned.

Many beneficial characteristics of the framework have been pointed out in section 2 already. The following two advantages of the PROMETHEE method are particularly contributing to the framework. Firstly, the preference functions can be applied intuitively as all specification parameters directly relate to the decision criterion. Secondly, criteria cannot compensate for one another. That ensures that all aspects of the decision are covered and it remains up to the decision maker which alternative to choose in case of indifferences or incomparabilities.

However, there are also disadvantages. The following four are the most important ones. Firstly, the method does not completely prevent subjectivity, since the selection of the criteria is subject to the decision makers' perception. Yet, the requirements for a 'good' criteria set – as described in section 2 – help to reduce this subjectivity. Furthermore, the actual value for each criterion assigned to each decision alternative tends not to be the result of an isolated assessment of each alternative but rather a relative judgment by comparing the alternatives. This is also reflected correctly in the outcome, as the PROMETHEE algorithm relies on pair-wise comparisons. Above that, the indifference and preference threshold and the weighting of the decision maker highly depend on the decision maker. Secondly, due to the characteristic of the PROMETHEE algorithm the preference between alternatives is mapped on an interval between 0 and 1. Therefore any differences above the assigned indifference threshold are neglected. Thirdly, different results can be expected if different alternatives are available. And lastly, in case of incomparability, the framework helps to reveal this constellation. Yet no actual recommendation on how to decide is provided. Therefore, it is still up to the decision maker which alternative to select.

Basically, the first three disadvantages address the question on how robust the results are. Robustness of the results – as a measure for yielding the same result when marginally changing an input parameter – can be tested by changing the parameters which are subject to uncertainty. A sensitivity analysis should therefore be conducted to analyze the weightings of the criteria, representing the preferences of the decision makers, and the threshold values. The calculation of the interval of stability indicates the range in which a threshold value or weighting factor can be varied ceteris paribus without changing the ranking of the assessed alternatives (Geldermann et al. 2003; Mareschal 1988), the larger this interval, the more resilient the results. For the demonstration described in this publication such an analysis was not performed. However, a real empirical case study would necessitate a sensitivity analysis including a broader analysis and discussion to legitimate the results.

To sum up, the MDSF allows overcoming the barrier of decision complexity through the objectification of major decision influences. However, when implementing PSS further aspects need to be considered. Most importantly, all parties involved in the business models – in the demonstration example machinery producers, material producers, service providers and the steel producer – need to be considered in the design and assessment of the business models. This allows carefully designed contracts which specify responsibilities, payment conditions and incentives. However, even though contracts are important to create a clear and concise basis for working together, but in the end it is trust which is needed for a successful cooperation.

5 Conclusions and the need for further research

This paper proposes a framework for comparing business models regarding their impact. This addresses the fact that although PSS are a strategic option to increase resource efficiency, the diffusion of PSS particularly in resource-intensive industries remains low. By advancing an MDSF based on PROMETHEE to assess PSS from the customer perspective, the paper provides means to overcome the barrier of decision complexity through the objectification of major decision influences. The applicability of the approach was demonstrated by simulating a decision example with different PSS around refractories in EAF.

The example presented in this paper demonstrates the applicability of the methodological approach using a PROMETHEE-based evaluation tool for PSS to support steel manufacturers in their strategic decision which business model to choose. The strengths of the methodology, implementing qualitative and quantitative criteria, avoiding scaling and compensation effects as well as the possibility to vary the preferences of the decision maker, facilitate the decision-making process and potentially enhance the decision outcome.

Furthermore, it could be shown that the positive impact of PSS on resource efficiency is captured by the MDSF. By using the MDSF, decision makers are potentially made aware of the complementary approach of PSS to increase resource efficiency. In order to reap the fruits of the published MDSF, the next step would require the recruitment of decision makers into the research process to empirically validate the approach. This would allow assessing the actual contribution to support customers comparing different business models and increase the diffusion of PSS.

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