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Sustainable Value Analysis Tool for Value Creation

Abstract

Product-service systems (PSS) have been regarded as a promising business model to achieve sustainable production and consumption. Recent research and practice suggest the need for tools to help companies integrate sustainability into the development of PSS. The purpose of this paper is to present a Sustainable Value Analysis Tool (SVAT), and provide empirical evidence for the development and use of the tool. The tool builds on a multi-disciplinary literature analysis and qualitative data from five Chinese manufacturing companies. It is developed to assist manufacturing companies in identifying opportunities for sustainable value creation in the process of PSS development. The use of the tool in an industrial context is illustrated.

Keywords: Sustainable Value Analysis Tool; product-service systems; PSS; industrial sustainability; sustainable value.

1. Introduction

In recent years, manufacturing companies are facing challenges from depletion of resources, rising price of material and energy, environmental legislation, and pressure from society (Evans et al., 2009). These challenges have been forcing manufacturing companies to develop new technologies and strategies to do business in a more sustainable way, in which less environmental and social negative impact is caused. Developing product-service systems is an innovative business strategy, which shifts manufacturing companies' main business from selling products to providing service. It has been considered by both researchers and practitioners a promising approach to achieve industrial sustainability (Goedkoop et al., 1999; Maxwell and Van Der Vorst, 2003; Mont, 2002). The main reason is that in the context of PSS, manufacturing companies have the incentive to prolong the lifetime of products and gain a long-term profit from service and end-of-life strategies, e.g. remanufacturing, reconditioning, repair, and recycling (Baines et al., 2007). This approach leads to a reduction of total material consumption throughout life cycle – dematerialisation, as well as a change of customers' behaviour from buying products to buying service (Goedkoop et al., 1999). Therefore, PSS is regarded to have the potential to re-orient both production and consumption towards a more sustainable direction (UNEP, 2009).

However, sustainable PSS still has not been widely implemented due to various challenges (Vezzoli et al., 2012). One of the difficulties is the lack of appropriate tools for supporting sustainable PSS development (Vasantha et al., 2012; Vezzoli et al., 2012). This paper aims to address the need for such tools, and investigates how sustainability could be integrated into PSS development. We present a Sustainable Value Analysis Tool (SVAT) for supporting decision-making process in the development of sustainable PSS. An analysis of literature and case studies is conducted to develop SVAT. The following sections describe the theoretical background from literature, the research method adopted in this paper, and the findings from case studies. Then, the tool and its use are presented. This is followed by the demonstration of using the tool in an Air Separation Units manufacturing company.

2. Theoretical background

Various definitions for PSS have been proposed in academic literature, however, the nature of PSS is the same - a system of product and service as an offering delivered by producer as an exchange of economic value (Baines et al., 2007; Goedkoop et al., 1999; Manzini and Vezzoli, 2003; Mont, 2002). PSS aims to pursue an added value from service (Geng et al., 2010), and the nature of PSS could bring some incidental benefits to the environment and society (Roy, 2000). PSS has been viewed by many researchers as a natural eco-friendly solution without compromising companies' economic benefits (Baines et al., 2007; Kimita et al., 2009; Maxwell and Van Der Vorst, 2003; Roy, 2000; Tan et al., 2010).

PSS is commonly classified into three types depending on the rate of service: product-oriented PSS (e.g. maintenance); use-oriented PSS (e.g. leasing, sharing, and renting); and result-oriented PSS (e.g. selling the result of products rather than selling products) (Tukker, 2004). All three PSS types have the potential of reducing environmental impact (Tukker and Tischner, 2006). For example, the retaining of products ownership enables manufacturers to have the incentive to design for remanufacturing, recycle, reuse, and repair, which aligns with the purpose of sustainable design (UNEP, 2009); the delivery of function or result increases the utilisation of products (Beuren, 2013). The use- and result-oriented PSS could deliver a higher potential to be dematerialised due to the retaining of ownership for manufacturer (Beuren, 2013), and thus are considered as the key of sustainable PSS (Roy, 2000). Apart from environmental benefit, PSS also has the potential to be beneficial to society. For example, more jobs could be created from labour-intensive service (Beuren, 2013).

However, it does not imply that PSS would inherently bring sustainable effects (Tukker and Tischner, 2006). The implementation of sustainable PSS is still challenging (Vezzoli et al., 2012).

Sustainable PSS needs to be carefully designed at an early stage, since the design of PSS affects the material and energy consumption, cost, and customer behaviour through the entire life cycle (Ullman, 2003). Various PSS development methods and tools have been proposed in literature, for example, "Service Explorer" (Sakao et al., 2009), "Sustainable Product and/or Service Development (SPSD)" (Maxwell and Van Der Vorst, 2003), "Methodology for Product-Service System Development (MEPSS)" (Van Halen et al., 2005), and "Solution oriented partnership" (Manzini et al., 2004). However, the existing methods and tools show that the development of sustainable PSS is still at an early stage. Few of the existing tools fully consider the social and environmental aspects of sustainability (Vasantha et al., 2012), which emphases the need for methods and tools to support sustainable PSS development.

In order to build a tool for embedding sustainability into PSS development, we further explored the literature, and identified three key concepts for successful PSS development as below.

Concept 1. Life cycle thinking. Life cycle thinking has been regarded as an essential concept to develop sustainable PSS in a holistic way. It seeks to identify possible solutions of improving goods and services by reducing resource use and environmental impacts throughout the entire product life cycle (European Commission, 2011). The product life cycle can be divided into beginning of life (BOL), middle of life (MOL), and end of life (EOL) (Jun et al., 2007), as shown in Figure 1 (a). BOL is when the product is designed and manufactured; MOL is when the product is distributed and used; EOL is when the used product is reprocessed (e.g. recycled, reused, remanufactured) and disposed. Traditional manufacturers usually focus on the value creation in BOL since selling products is their main source of profit. The nature of PSS extends the business relationship between manufacturer and customer from BOL to MOL and EOL, and thus brings more opportunities of value creation in MOL and EOL. For example, PSS could enable a long-term profit for manufacturers from service, allow their access to data in use, and could achieve an improved utilisation of product. This motivates servitizing manufacturers to identify the opportunities for value creation in MOL and EOL (Toossi, 2011).

Concept 2. Sustainable value. Value refers to a broad set of benefits derived by a stakeholder from an exchange, which, in the context of sustainability, does not only include monetary profit, but also include social and environmental aspects (Rana et al., 2013). Figure 1 (b) shows the three dimensions of sustainability and their interactions. Many researchers suggested that a sustainable PSS needs to take all three dimensions of sustainability into consideration (Maussang et al., 2009; Morelli, 2002; Sakao et al., 2009). Sustainable value should cover all three dimensions, and sustainable value creation is proposed as a promising way of integrating sustainability into business modelling (Rana et al., 2013). Therefore, the concept of sustainable value creation could be integrated into PSS development in order to also consider environmental and social aspects of benefits.

Concept 3. Multiple forms of value. This is derived from the 'value mapping tool' for sustainable business modelling (Bocken et al., 2013). The value mapping tool has been used in companies from various sectors, aiming to assist companies in the analysis and design of sustainable business models. This tool proposes the concepts of value destroyed and value missed to present the negative aspects of a current business model. Figure 1 (c) illustrates the rationale of the tool - by mapping various forms of value (i.e. current value captured, value destroyed, and value missed), companies can identify value creation opportunities through analysing value exchanges from the perspective of multiple stakeholders across the industrial network. Although the forms of value in the value mapping tool are useful for stimulating and generating ideas and discussions on sustainable business modelling through a multi-stakeholder perspective, neither does it incorporate life cycle stages nor is it specifically designed for PSS. Likewise other tools and frameworks for exploring forms of value such as value network analysis (Allee, 2011), value tree analysis, and value framework (Den Ouden, 2012) are focused on value network/system analysis and shared value creation, and they may be complex to engage with in a business environment. As such the need for a tool that incorporates the three concepts to assist manufacturing companies in the development of sustainable PSS is identified.

----- Insert Figure 1 -----

Life cycle thinking is discussed in sustainable PSS literature (Maxwell and Van Der Vorst, 2003), and is considered a crucial concept for sustainable PSS development. Sustainable value and multiple forms of value are found in the sustainable business model literature, as mentioned above. Since PSS has the potential to be a sustainable business model (Tukker and Tischner, 2006), we believe that the analysis of sustainable value and multiple forms of value can be applied to support the development of sustainable PSS. The proposal of detailed

multiple value forms for PSS has been presented by Yang et al. (2013) and is further developed in Section 4.3. The novelty of this paper is that it further develops the multiple value forms for PSS, and proposes the integration of the three concepts to build a Sustainable Value Analysis Tool (SVAT) for enabling sustainable PSS development. The tool aims to analyse multiple forms of value across the entire PSS life cycle through the dimensions of economic, social and environmental sustainability.

3. Research method

The purpose of the research is to explore how sustainability concerns could be embedded into the development of PSS. One way of doing this is to build a tool based on the understanding of the phenomenon and the hypothetical solutions to the research question. This research aims to use the concepts to develop such a tool - Sustainable Value Analysis Tool. The aim of developing this tool is firstly to help manufacturing companies integrate sustainability into PSS development, and secondly to help researchers better understand this process, test the hypothesis, and further explore the research. It requires an in-depth theoretical study and empirical inquiry within the real-life context. Therefore, the research method adopted in this paper is literature analysis together with case studies.

The case studies consisted of two stages of data collection. Table 1 shows the overview of the data collection. The first stage consisted of seven semi-structured interviews (Yin, 2009) in five manufacturing companies. The companies are all large-sized manufacturing firms with well-developed PSS solutions in China. They are regarded as the pioneers on servitization in China, although their main businesses are still selling products. One of the five companies is regarded as the model example of successfully servitizing manufacturing company since its PSS solutions have generated big portion of the profit. The other four companies also have the reputation of leading the pace of manufacturing servitization in their province. The purpose of the interviews is to understand the three concepts in practice and use the findings to enhance SVAT.

Based on analysis of the interviews, the initial version of SVAT was developed and pilot used as a research tool in the second stage of data collection. It was used in three workshops with two manufacturing companies, which were interviewed in the first stage. The purpose of the workshops is to test the reasonability and usability of the tool, and to better understand how this tool can be further improved to assist manufacturers in embedding sustainability concerns. Qualitative data analysis method (Miles and Huberman, 1994) is used to analyse the data from the two stages.

----- Insert Table 1 -----

4. Results

4.1 Findings from 1st stage data collection

The first stage of data collection consisted of seven interviews with eleven managers/directors from five manufacturing companies. Each interview was divided into two sessions. In the first session, the interviewees described the journey of servitization in the companies, with an emphasis on explaining the driving force behind servitization and the challenges of developing sustainable PSS. Several common themes emerged from the interviews, which further confirmed the need for developing a tool to help companies integrate sustainability into PSS development.

- The main driving forces of all types of service are a better fulfilment of customer requirement and the pursuit of economic sustainability (long-term profit) from service. It indicates that environmental and social sustainability are not their initial targets or even concerns in the PSS development.
- PSS solutions have incidentally generated positive environmental and social effects, e.g. more resources and energy are saved due to a better utilization of products, and more jobs are created due to the labor-intensive nature of service. This shows that PSS solutions have the potential to create environmental and social sustainable value if they are well designed.
- The interviewees do regard environment and society as important issues to consider in the decision-making of PSS strategies, but they currently lack practical methods, tools and knowledge.

In the second session of the interviews, the interviewer explained the three concepts, and the tool was tested. Several commonalities emerged.

- The life cycle thinking provides an extended view to look at the value creation opportunities at MOL and EOL, which are currently missed in most companies.

- The concept of value destroyed is clear - negative value outcome. Using this concept could help identify the negative impacts to environment and society. However, the concept of value missed needs further clarity – value currently squandered, wasted or inadequately captured by a current business model. Besides, selling service is intangible, flexible and unpredictable, therefore requires a broader analysis on more value forms to identify the hidden value opportunities. The value surplus (e.g. waste) and value absence (e.g. need) proposed by the interviewers were regarded as helpful value forms.
- The tool provides the interviewees with a comprehensive way of thinking about the economic, social and environmental dimensions of a particular PSS solution in the whole life cycle. A common interest to use a practical tool based on this rationale was raised from all of the five companies.

4.2 Findings from 2nd stage data collection

Combining the theoretical and practical insights, the rationale for SVAT was proposed: by analysing multiple forms of value from the three dimensions of sustainability across the entire life cycle, manufacturing companies can identify opportunities of sustainable value creation. In the context of PSS, the tool could help manufacturing companies integrate sustainability into PSS solutions. Based on this rationale, the initial version of the tool was built, and tested in three workshops. The purpose of the workshops was to evaluate the usability, effectiveness and facilitation process of the tool, so as to further refine the tool. The evaluation included examining whether it would have helped companies in identifying opportunities of sustainable value creation, and observing the difficulties for interviewees in terms of using the tool. Several common key findings emerged from the workshops as shown in Table 2.

----- Insert Table 2 -----

4.3 Sustainable Value Analysis Tool (SVAT)
Developing SVAT

Value forms in SVAT include value captured (VC), value absence (VA), value surplus (VS), value destroyed (VD), value missed (VM), and value opportunity (VO). Figure 2 explains the definitions of the value forms and the process of value analysis in SVAT. Among the value forms, the value destroyed and value missed are adapted from the value mapping tool; value absence and value surplus are newly proposed to enhance the development of PSS. Considering the implications for the tool from the workshops (see Table 2), SVAT groups the value forms into three parts (value captured, value uncaptured and value opportunity) by merging the value absence, value surplus, value destroyed and value missed into 'value uncaptured (VU)' (see Figure 2).

----- Insert Figure 2 -----

VC is the benefits delivered to the company and its stakeholders; VU is the value that is not captured by the company but has the potential to generate value opportunities; and VO is the new opportunities for value creation. The identification of VC and VU can assist companies in understanding the positive and negative aspects of their current business models. The analysis of VU can assist companies in identifying VO. However, the identification of VU in service-oriented companies is difficult since they are usually hidden and invisible in service process. The rationale of SVAT is to use separate forms of value (i.e. VA, VS, VD, and VM) to inspire the identification of VU, and to further identify VO by analysing the identified VU (e.g. aligning VA and VS, and reducing VD and VM).

Based on literature analysis and the empirical data, SVAT is developed as shown in Table 3. The aim of the tool is to help PSS companies identify value opportunities by analysing the current value captured and value uncaptured across the entire life cycle. As shown in Table 3, the tool combines the life cycle thinking and value forms analysis. The three phases of a product life cycle (BOL, MOL and EOL) could be further divided into more specific stages. For example, MOL can be further divided into distribution, use, maintenance and service. The value forms consist of value captured, value uncaptured and value opportunity. Value uncaptured could be considered from the perspectives of value destroyed, value missed, value surplus and value absence. Each block in Table 3 represents a certain value form in a certain life cycle phase. For example, the "BOL-VC" represents the value captured in BOL. The task for the tool users is to fill in each of the blocks.

----- Insert Table 3 -----

How can sustainability be integrated into the PSS development? As analysed in the theoretical background (Section 2), in the context of sustainability, value does not only mean economic benefit, but also includes social

and environmental aspects (Rana et al., 2013). Therefore, each value form needs to be considered from the three dimensions and their intersections, as shown in Figure 3.

----- Insert Figure 3 -----

The workshop data shows that the value from intersections is usually identified to be of higher importance than others since it covers multiple aspects of sustainability. For example, the under-utilised resource in BOL could be the value uncaptured both in economic and environmental dimensions, and it is recognised to be an important factor because solving the under-utilised resource could reduce the value uncaptured in two dimensions. Therefore, SVAT should distinguish the overlapped areas so that the important value could be highlighted.

Using SVAT

SVAT can be used in facilitated workshops with managers or designers in PSS companies. It can be a stand-alone tool without support from other tools, and can also be complementary to design tools by focusing on the value analysis of PSS design concepts. For the former case, the tool can be used to support decision-making by identifying the value forms in the current business. For the latter case, the tool can be used during the conceptual design of product and service to support the integration of sustainability into PSS design.

The following illustrates the process of using the tool.

Step 1. Define product life cycle

BOL, MOL and EOL are general life cycle phases, and more specific sub-division of life cycle stages can be defined. A more detailed product life cycle stages are provided in the tool as the inspiration for the tool users, e.g. the recycling, remanufacturing, reuse and disposal stages in EOL. The sub-division is flexible depending on the level of depth the analysis desired and the time available.

Step 2. Describe the value captured

This step is to describe the benefits delivered to stakeholders in each life cycle stage (BOL-VC, MOL-VC and EOL-VC). The stakeholders mainly include customers, suppliers, business partners, and government. In the context of sustainability, the value captured should be considered from economic, social and environmental dimensions, which means, the benefits delivered to environment and society are emphasised. Figure 4 shows the facilitation for identifying BOL-VC as an example. An in-depth analysis of the value captured in each stage of the life cycle can help users and researchers understand better the positive aspects of the current business model.

----- Insert Figure 4 -----

Step 3. Identify the value uncaptured

This step is to identify the value uncaptured in each stage of life cycle, i.e. BOL-VU, MOL-VU and EOL-VU. Similar to the value captured in Step 2, the value uncaptured should also be considered from the economic, social and environmental aspects of sustainability, with an emphasis on the social and environmental aspects since they are easily forgotten by companies. The identification of value uncaptured is a process of identifying value destroyed, value missed, value surplus and value absence (shown in Figure 2).

This step is fundamental because it helps users and researchers understand the negative aspects of the current business model. The identification of the value uncaptured is difficult since they are usually invisible and hidden. Therefore, the facilitation plays a key role in this process. Firstly, this process needs substantial knowledge and experience of the entire life cycle. Secondly, due to the intangibility and flexibility of service, the identification of the hidden value uncaptured in MOL and EOL is difficult. Therefore, a facilitated brainstorming with practical examples, inspiration with practical examples and guidance is required. Furthermore, as analysed above, there will be overlaps among two or three dimensions, which means some situation causes value uncaptured in environmental, social and economic dimensions. For example, “no recycle and remanufacturing strategies” is the value uncaptured both in economic and environmental dimensions at the EOL stage. The advantage of grouping them is that it helps companies to identify sever value uncaptured which loses value in two or three dimensions of sustainability. Figure 5 shows the facilitation for identifying MOL-VU as an example.

----- Insert Figure 5 -----

Step 4. Analyse the value uncaptured, and explore value opportunities

Each identified value uncaptured should be analysed deeply – the root causes of value uncaptured and how they can be reduced. The potential solutions to reduce value uncaptured are value opportunities. As analysed above, value uncaptured should be considered from the perspectives of value absence, surplus, destroyed and missed. Value opportunities could be identified by aligning value absence and surplus, and reducing value destroyed and missed (as illustrated in Figure 2). For example, the under-utilised space in one department of a company (value surplus) could be utilised for storage required by another department that needs more space (value absence). The alignment of value absence and value surplus could drive the value flowing from surplus to absence, resulting in the reduction of the two negative value elements. The facilitator should try to lead the discussion on the alignment of the two elements.

The identified value opportunities (potential solutions) can be assessed briefly by discussing their changes on the economic, social and environmental impacts. The assessment is optional and should be qualitative since it is at an early stage of decision-making.

4.4 Using the tool in an Air Separation Unit manufacturing company

This section illustrates an example of using the tool in an Air Separation Unit manufacturing company in China. The main business of this company is selling air separation units, petrochemical equipment and industrial gases. This company has a yearly capability of designing and manufacturing more than 50 sets of large and medium air separation units sold to more than 40 countries and regions of the world. The reason for choosing this company is that it has successfully transformed from a traditional product-dominant manufacturing company to a company selling various types of PSS solutions.

PSS solutions

Four main PSS solutions have been implemented in this company: technical service, special leasing, engineering procurement construction (EPC) and industrial gas projects. According to the classification of PSS types proposed by Tukker (2004), the four PSS solutions in this company are mapped into their related PSS types in Figure 6. It should be noted that the PSS solutions mapped in Figure 6 are based on the case of this specific company, and the potential sustainable value of each PSS solution was qualitatively generated from the data provided by the company.

----- Insert Figure 6 -----

(1) Technical service: Apart from just selling air separation equipment to customers, this company provides around 20-year technical service (such as maintenance, repair, and installation) as added package to their products. This is the most common business model in this company. It is the product-oriented PSS because the ownership of products belongs to the customer. Due to the long-term service contract, the company has been gaining a stable and continuous profit through professional technical service (i.e. economic value). Besides, the company has the incentive to design the products for easy repair and remanufacture (i.e. environmental value).

(2) Special leasing: This company leases the air separation units to customers, and the contract usually lasts for around 10 years. During the contractual years, it is the use-oriented PSS because the company has the ownership of products, and customers pay for the rent of using the products and service. The company has high incentive to design the products for reuse and recycle, and for longer life spans (i.e. environmental value). However, after a certain amount of years, the ownership is transferred to the customer and it becomes a product-oriented PSS. The incentive to recycle and reuse the products is reduced. Therefore, the potential sustainable value that leasing creates depends on the type of PSS it belongs to (see Figure 6). Leasing contracts are not common in this company. They are mainly tailored for customers without the financial ability to buy equipment or build projects.

(3) Engineering Procurement Construction (EPC): A subsidiary company was built to especially run EPC projects in April 2009. The main strategy of EPC in this company is extending the business from only selling a gas generator to selling an entire functional air separation system that customers need. The system includes the engineering system design, the procurement and production of facilities (e.g. refrigerator, compressor, fittings, rectifying tower, heat exchanger), the engineering construction, the installation of equipment, and related service (management, maintenance, etc). EPC has generated a big profit to the company and been regarded as their business trend (economic value). EPC also created environmental benefits by maximising the resource use and energy efficiency of producing the entire air separation system (environmental and economic value).

(4) Industrial gas projects: This is a result-oriented PSS that the company selling 'industrial gas' rather than 'gas generator'. This company started the industrial gas projects in 2003 and has developed its own business model – combining air separation unit manufacturing and industrial gas management. Until 2012, 25 sub gas companies have been built in 17 cities in China, covering the various industrial sectors, and producing gases such as O_2, N_2, CO_2, H_2, rare gases (such as Ar and He), and special gases. The investment is above 6.5 billion RMB. There are four commercial activities of providing gases: bottled gas, liquid gas and cold air separation of liquid, gasification, and pipeline industrial gas supply for industrial parks. Industrial gas projects have the potential to create high sustainable value. The company becomes the owner and user of the gas generators, therefore has high incentive to reduce the resource and energy use in both BOL and MOL, and has the chances to increase the utilisation of gases by selling them to different customers (environmental and economic value).

Findings are identified from Figure 6. EPC and special leasing are across more than one PSS type. It is difficult to locate the 'special leasing' into a specific PSS type due to the complexity of the leasing contract. It starts as a use-oriented PSS with higher sustainable value, and ends up as a product-oriented PSS when the ownership of products transferred to customer. The closer to the result-oriented PSS, the PSS solution seems to create more sustainable value. It indicates that a PSS solution could be purposely designed to create more sustainable value, and moving towards result-oriented PSS might bring more sustainable effects. However, the sustainability of one particular PSS solution is context and project specific.

The driving forces of PSS

All the PSS solutions are carefully designed based on the dominant principle of business – creating value. Table 4 lists the motivations and driving forces for each PSS solution in the company.

----- Insert Table 4 -----

The main driving forces are a better fulfilment of customer demands and the pursuit of added value, both of which are determined by product properties. Figure 7 further analyses how the specific product properties trigger additional customer demands, how they drive the company to make such four PSS solutions, how the PSS solutions affect the customer demands and product design in return, and how the internal business development needs affect this process.

First, the special product properties of air separation equipment trigger additional customer demands for a certain type of service. For example, the air separation equipment is difficult to use and maintain, and it might cause danger if the machines are not operated appropriately. Therefore, this special property triggers additional customer demands for professional training and maintenance service, which creates a direct driven force for this company to develop technical service as an added package to products. Another example is that the results (gases) are more important than the products (equipment), and the products are expensive, which leads to the customer demand for financial support, and the demand for gases more than the ownership of products. In order to satisfy these two demands, the company developed industrial gas project. Besides, the business solutions are also in turn affecting customer demands and product properties. A new business offering could impact customer consumption and behaviour, and trigger additional customer demands. For example, EPC is more as a project leading customer demand for an integrated engineering solution, rather than a project leaded by customer demand. The business innovation and solutions could also affect the design of products, and thus influence the product properties.

However, environmental and social sustainability have not been considered as a driving force for developing PSS, although the interviewees have recognised the importance of these two aspects for long-term value creation. It was also emphasised that PSS solutions incidentally lead to an increased environmental value. The analysis of the driving forces provides a better understanding of the main concerns of PSS development in the company, and how sustainability affect or be affected in this process.

----- Insert Figure 7 -----

Using SVAT in the air separation unit company

SVAT was tested with the director and two designers from the design sector of this company.

- The life cycle of the main products was defined as: BOL - customised design, procurement, part manufacturing, assembly; MOL - distribution, installation, use, maintenance, repair, management; EOL - disposal as scrap metal.

- The value captured was mainly identified at BOL and MOL phases. For example, the advanced technology has improved the energy efficiency in use (economic and environmental value); the professional service in MOL provided a safer and cheaper maintenance for customers (social and economic value); the PSS solutions brought long-term economic value to the company and saved cost for customers.
- The value uncaptured mainly existed at MOL and EOL phases. The company has implemented lean production and there was little value uncaptured identified at the BOL. However, it has not taken any EOL strategies due to the limited market demand and high cost of recycling and remanufacturing. The participants' awareness and knowledge of EOL is limited, so the value analysis in EOL is challenging. So, the use of the tool is mainly focused on the identification of value uncaptured in MOL phase. Table 5 illustrates the selected identified value uncaptured at MOL in this company based on a sample of the data collected.
- Each of the main identified value uncaptured was analysed, and the value opportunities (potential solutions) were identified as shown in the Table 6. For example, the identified value opportunity for "MOL-VU-12-1" in Table 5 is the co-products (e.g. N_2, O_2, Ar, liquid O_2, liquid N_2). The value opportunity is identified to be "MOL-VO-12-1" in Table 6: Ar can be used for welding and bulbs gas (externally); O_2 and N_2 could be complementarily used for companies who need it (externally). The difficulty of implementing the value opportunity is to identify the 'external' companies that can collaborate with them.

----- Insert Table 5 -----

----- Insert Table 6 -----

Figure 8 illustrates the results of using the tool - some examples of the identified value uncaptured and the value opportunities in the company. For example, the waste of low-grade heat and water was identified to be a major value uncaptured in the MOL, and the value opportunity is that it can be used to produce electricity or drive the compressor, or vaporize the liquid O_2. It can be realised by the company either internally or externally. The tool provides the company a broader vision of value opportunities, which could be identified by analysing the positive and negative aspects of the current business model.

----- Insert Figure 8 -----

5 Conclusion and future research

5.1 Contribution to theory

The paper contributes to theory by proposing that the integration of the three concepts - life cycle thinking, sustainable value, and multiple forms of value - supports sustainable product-service systems development. This integration allows the identification and analysis of value captured and value uncaptured (i.e. value missed, value destroyed, value surplus and value absence) throughout the entire product life cycle, to generate opportunities for sustainable value creation. These three concepts were selected because life cycle thinking provides a holistic picture of the product from design to disposal, which allows for a life cycle approach to examine value creation at each stage. Sustainable value emphasises on the holistic consideration of environmental, social and economic sustainability into value analysis. The multiple forms of value allow for a broader analysis of the positive and negative aspects throughout the life cycle. This research also proposes two new concepts of 'value absence' and 'value surplus' extending the forms of value. By bringing the three concepts together, we build a comprehensive tool for value analysis and embedding sustainability into PSS development.

5.2 Contribution to practice

The paper contributes to practice by presenting the Sustainable Value Analysis Tool (SVAT). Comparing with the existing tools in the field, SVAT is developed to specifically support manufacturing companies in their decision-making process to embed sustainability into the PSS development. The main application of this tool is to support this process through the analysis of multiple value forms. The tool is built on a multi-disciplinary literature review and analysis of qualitative data from semi-structured interviews and workshops in five companies. The feedback of using the tool further confirms the utility and ease of use of the tool.

Future work involves further testing of the tool with companies from different industries with PSS solutions. The tool will be refined to allow the application in different industrial contexts.

Reference:

Allee, V. (2011), "Value Networks and the true nature of collaboration", *ValueNet Works and Verna Allee Associates*, ValueNet Works and Verna Allee Associates.

Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., et al. (2007), "State-of-the-art in product-service systems", *Proceedings of the Institution of Mechanical Engineers Part B Journal of Engineering Manufacture*, Prof Eng Publishing, Vol. 221 No. 10, pp. 1543–1552.

Beuren, F. (2013), "Product-service systems: a literature review on integrated products and services", *Journal of Cleaner Production*, Elsevier Ltd, doi:10.1016/j.jclepro.2012.12.028.

Bocken, N.M.P., Short, S.W., Rana, P. and Evans, S. (2013), "A value mapping tool for sustainable business modelling", *Corporate Governance*.

European Commission. (2011), *Life Cycle Thinking and Assessment - Our Thinking - Life Cycle Thinking*, available at: http://eplca.jrc.ec.europa.eu/.

Evans, S., Bergendahl, M., Gregory, M. and Ryan, C. (2009), "Towards a sustainable industrial system", *International Manufacturing Professors Symposium in Cambridge UK*, Institute for Manufacturing, University of Cambridge, pp. 1–25.

Geng, X., Chu, X., Xue, D. and Zhang, Z. (2010), "An integrated approach for rating engineering characteristics' final importance in product-service system development", *Computers & Industrial Engineering*, Elsevier Ltd, Vol. 59 No. 4, pp. 585–594.

Goedkoop, M.J., Van Halen, C.J.G. and Te Riele, H.R.M. (1999), "Product service systems , ecological and economic basics", *Economic Affairs*, VROM, Vol. 36 No. March, p. 132.

Van Halen, C., Vezzoli, C. and Wimmer, R. (2005), *Methodology for product service system innovation*, *How to develop clean clever and competitive strategies in companies*, Koninklijke Van Gorcum, Vol. 75, pp. 665–669.

Jovane, F., Yoshikawa, H., Alting, L., Boër, C.R., Westkamper, E., Williams, D., Tseng, M., et al. (2008), "The incoming global technological and industrial revolution towards competitive sustainable manufacturing", *CIRP Annals - Manufacturing Technology*, Vol. 57, pp. 641–659.

Jun, H.-B., Kiritsis, D. and Xirouchakis, P. (2007), "Research issues on closed-loop PLM", *Computers in Industry*, Vol. 58 No. 8-9, pp. 855–868.

Kimita, K., Shimomura, Y. and Arai, T. (2009), "A customer value model for sustainable service design", *CIRP Journal of Manufacturing Science and Technology*, Elsevier, Vol. 1 No. 4, pp. 254–261.

Manzini, E., Collina, L. and Evans, S. (2004), *Solution oriented partnership - how to design industrialised sustainable solutions*.

Manzini, E. and Vezzoli, C. (2003), "A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize", *Journal of Cleaner Production*, ELSEVIER SCI LTD, Vol. 11 No. 8, pp. 851–857.

Maussang, N., Zwolinski, P. and Brissaud, D. (2009), "Product-service system design methodology: from the PSS architecture design to the products specifications", *Journal of Engineering Design*.

Maxwell, D. and Van Der Vorst, R. (2003), "Developing sustainable products and services", *Journal of Cleaner Production*, Vol. 11 No. 8, pp. 883–895.

Miles, M.B. and Huberman, A.M. (1994), *Qualitative Data Analysis*, (Holland, R.,Ed.)*An expanded sourcebook*, Sage Publications, Vol. 3, p. 338pp.

Mont, O. (2002), "Clarifying the concept of product–service system", *Journal of Cleaner Production*, Vol. 10 No. 3, pp. 237–245.

Morelli, N. (2002), "Designing product/service systems: a methodological exploration", *Design Issues*, MIT Press, Vol. 18 No. 3, pp. 3–17.

Den Ouden, E. (2012), *Innovation Design. Creating value for people, organizations and society*, Springer, p. 196.

Rana, P., Short, S. and Evans, S. (2013), *D2.5 - Lessons learned report, documenting the impact from use of the tools & methods and areas for improvement*.

Roy, R. (2000), "Sustainable product-service systems", *Futures*, Unknown, Vol. 32 No. 3-4, pp. 289–299.

Sakao, T., Shimomura, Y., Sundin, E. and Comstock, M. (2009), "Modeling design objects in CAD system for Service / Product Engineering", *Computer-Aided Design*, Elsevier Ltd, Vol. 41 No. 3, pp. 197–213.

Tan, A.R., Matzen, D., McAloone, T.C. and Evans, S. (2010), "Strategies for designing and developing services for manufacturing firms", *CIRP Journal of Manufacturing Science and Technology*, CIRP, Vol. 3 No. 2, pp. 90–97.

Toossi, A. (2011), *A value-centric decision making framework for maintenance services outsourcing*, Cranfield University.

Tukker, A. (2004), "Eight types of product–service system: eight ways to sustainability? experiences from SusProNet", *Business Strategy and the Environment*, Vol. 13 No. 4, pp. 246–260.

Tukker, A. and Tischner, U. (2006), *New business for old Europe: product-service development*, Greenleaf Publishing Limited, pp. 72–99.

Ullman, D.G. (2003), "The mechanical design process", *Mechanics of Materials*, McGraw-Hill, Vol. 3, p. 432.

UNEP. (2009), *Design for sustainability: a step-by-step approach*.

Vasantha, G.V.A., Roy, R., Lelah, A. and Brissaud, D. (2012), "A review of product–service systems design methodologies", *Journal of Engineering Design*, Vol. 23 No. 9, pp. 635–659.

Vezzoli, C., Ceschin, F., Diehl, J.C. and Kohtala, C. (2012), "Why have 'Sustainable Product-Service Systems' not been widely implemented?", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 35, pp. 288–290.

Yang, M., Rana, P. and Evans, S. (2013), "Product service system (PSS) life cycle value analysis for sustainability", *The 6th International Conference on Design and Manufacture for Sustainable Development (ICDMSD)*.

Yin, R.K. (2009), *Case Study Research: Design and Methods*, (Bickman, L. and Rog, D.J.,Eds.)*Essential guide to qualitative methods in organizational research*, Applied Social Research Methods Series, Sage Publications, Vol. 5, p. 219.

Tables:

Table 1. Data collection overview

Manufacturing sector	PSS solutions	Stage 1. Building the tool		Stage 2. Testing the tool	
		Data collection method	Participants	Data collection method	Participants
1. Air separation unit	1. EPC (Engineering Procurement Construction) 2. Gas service 3. Leasing	one semi-structured interview	Technical director	one workshop	Technical director, designers
2. Steam turbine	1. Turbine maintenance and technical support 2. System optimization 3. Device solution 4. Energy management contract (EMC) 5. General project contractor	two semi-structured interviews	General manager, Deputy general manager	two workshops	General manager, Deputy general manager
3. High-end analytical instruments	1. Solutions related to environment monitoring and management, industrial engineering, laboratory, security, energy, water management 2. Equipment maintenance service 3. Third party analysis	one semi-structured interview	Technical director		

4. High definition IP cameras	Surveillance solution	two semi-structured interviews	Technical director, development director, solution director
5. Blower industry	Systematic solutions and services for turbo-machinery in the fields of metallurgical industry, petrol-chemical industry, air separation, environmental protection, national defence, etc.	one semi-structured interview	R&D director

Table 2. Key findings from workshops and the implications for the tool development

	Key findings from workshops	**Implications for tool development**
1	The dividing of life cycle phases (BOL, MOL, EOL) to more specific stages (e.g. the disassembly stage) is helpful. However, the analysis of value forms in each stage is time consuming and repetitive, especially in some adjacent stages with high connection to each other. For example, it is difficult to analyse the value elements in the conceptual design stage and detailed design stage separately. This usually results in similar data from two stages.	The dividing of life cycle stages should be flexible according to the company's need, the level of depth, and the time available. The general division of life cycle (BOL, MOL and EOL) should be sufficient for a quick analysis of key issues. The sub-division for more specific life cycle stages is not necessary.
2	The various forms of value could help the interviewees identify the positive and negative sides of current business model, but there are big overlaps between some value forms (e.g. value missed and value surplus, value missed and value absence).	The value missed, value destroyed, value surplus and value absence are the negative value forms. They could be merged and named value uncaptured.
3	The theoretical explanation of various value forms is confusing to interviewees from industries, and it might lead to a failure of sufficient identification of the value forms in companies. Some real or imaginary business examples are shown to be helpful for interviewees to understand the concepts of value forms. Also, facilitators play an important role in assisting the use of the tool.	More business examples should be prepared, and could be provided as the form of pictures, slides, cards, etc.
4	In terms of negative value forms (e.g. value destroyed) in service, it is usually vague and intangible due to the feature of service – unpredictable and intangible. Therefore, the identification of the intangible value forms needs strong ability of observation and innovation.	The provision of examples could inspire the interviewees to identify the hidden value opportunities.
5	Using the tool requires the interviewees with knowledge and experience in PSS development, sustainable issues, and knowledge from all life cycle phases.	More interviewees from each life cycle stage, or the manager with knowledge and experience of all life cycle phases could be involved in using the tool.

Table 3. Sustainable Value Analysis Tool (SVAT)

Sustainable Value Analysis Tool (SVAT)		Beginning of Life (BOL)	Middle of Life (MOL)	End of Life (EOL)
		e.g. Planning, design, procurement, production	e.g. Distribution, (retail), use, maintenance, service	e.g. Recycle, remanufacture, reuse, disposal
Value Captured (VC)		BOL-VC	MOL-VC	EOL-VC
Value Uncaptured (VU)	Value Destroyed	BOL-VU	MOL-VU	EOL-VU
	Value Missed			
	Value Surplus			
	Value Absence			
Value Opportunity (VO)		BOL-VO	MOL-VO	EOL-VO

Table 4. The driving forces of PSS solutions in the company

PSS solutions	Technical service	EPC	Special leasing	Industrial gas
Driving forces for PSS	- customer demands - selling more products	- customer demands - selling more products - added value - policy	- customer demands - customer financial issues	- customer demands - customer financial issues - added value - economic sustainability - advantage of ownership

Table 5. MOL-VU in the air separation unit company

MOL-VU	Value uncaptured at MOL in the company (selected)
1	• MOL-VU-1-1: over-staffing;
2	• MOL-VU-2-1: emissions of customer companies;
3	• MOL-VU-3-1: maintainers working far away from home if the projects are located in other cities
12	• MOL-VU-12-1: Co-products, e.g. N2, O2, Ar, liquid O2, liquid N2; • MOL-VU-12-2: Gold gas: Kr (Krypton), Xe (Xenon), etc; (the current amount of the gold gas is very small, but it should be valuable when the amount gets bigger.); • MOL-VU-12-3: High purity O2 and N2; • MOL-VU-12-4: The waste of mechanical energy of expansion engines (already solved); • MOL-VU-12-5: The waste of heat produced by the compressor (this is low grade heat, which is difficult to reuse, but he thinks it's worth investigating how to use the heat); • MOL-VU-12-6: The waste of low grade water (hasn't been solved, but is worth thinking);

Table 6. MOL-VO and assessment of value opportunities

	Value opportunity analysis from MOL-VO						
	MOL-VO	**Value opportunities (Potential solutions)**	**Change impact**			**In/external**	**Potential partners**
			Economic	**Environmental**	**social**		
1	MOL-VO-1-1	Reduce staffs	+	0	-	Internal	
		More work for company	+	0	0	Internal	
		More work for customer	+/0/-	0	+	External	Customer
2	MOL-VO-2-1	Provide emission reduction solution to customer (RPSS)	+/-	+	+	External	Customer
3	MOL-VO-3-1	Hire local employees	+/-	+	+	Ex/Internal	Customer
		More holiday for far staff	-	-	+	Internal	
12	MOL-VO-12-1	Ar can be used for welding, and bulbs gas; O2, N2, etc could be complementarily used for companies who need it;	+/0	+	0/+	External	Bulb company, etc
	MOL-VO-12-2	The gold gases can be used in military industry, lamination;	+/0	+	0/+	External	Lamination company, etc
	MOL-VO-12-3	High purity O2 and N2 can be used in electronic industry;	+/0	+	0/+	External	Electronic company
	MOL-VO-12-4	The expansion movement can produce electricity to directly drive the engine itself or other engines.	+	+	0	Internal	
	MOL-VO-12-5	The wasted heat can be used to produce electricity or drive the compressor or vaporize the liquid O2.	+	+	0	In/external	Steam turbine company
+: bring positive impact; -: bring negative impact; 0: no impact The "+, -, 0" can be numbers from "-5 to 5" so that it is even easier for the comparison between solutions							

Figures:

Figure 1. Life cycle thinking, sustainable value and multiple forms of value

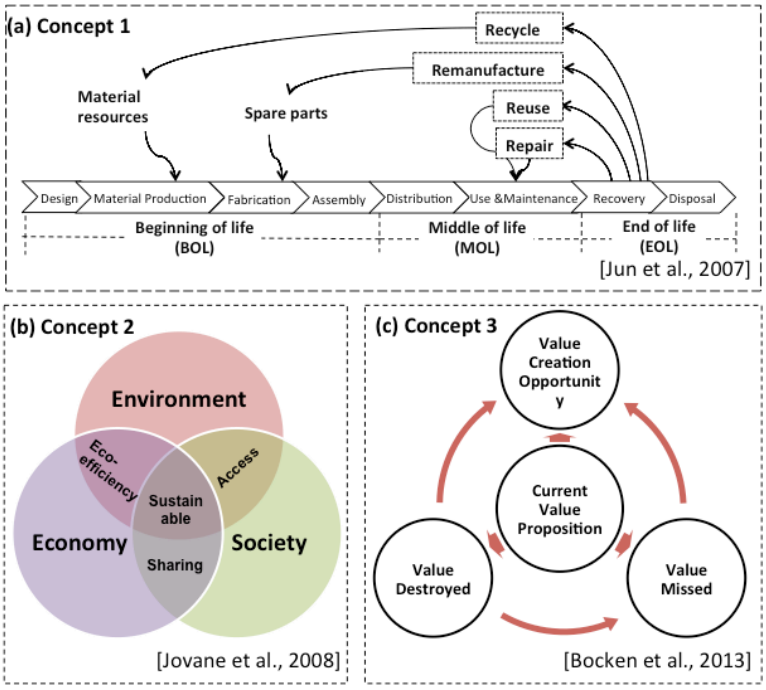

Figure 2. Multiple value forms in SVAT (adapted from (Yang et al., 2013))

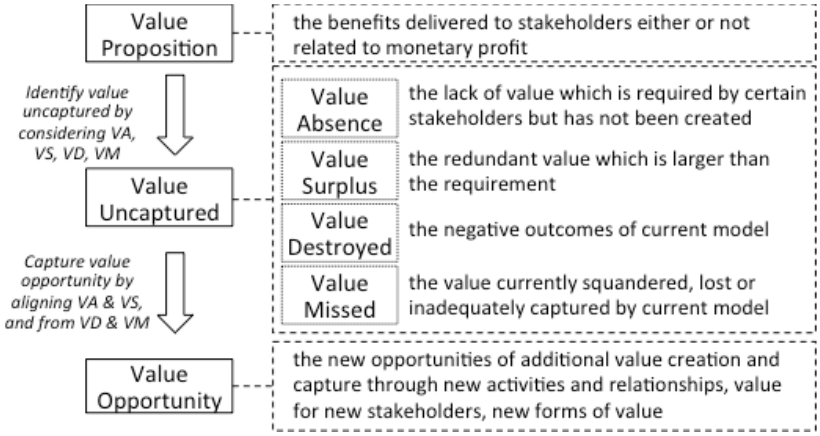

Figure 3. Three dimensions of sustainability and their intersections (adapted from (Jovane et al., 2008))

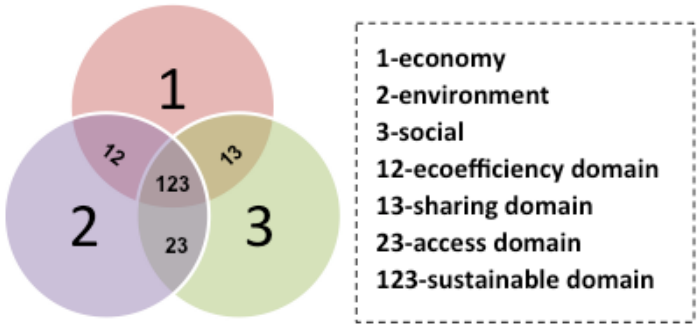

Figure 4. BOL-VC: Value captured at BOL

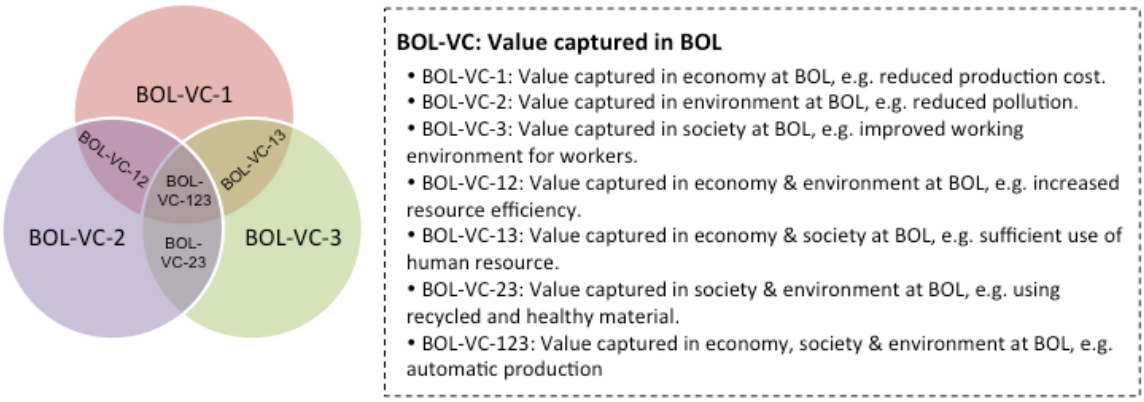

Figure 5. MOL-VU: Value uncaptured at MOL

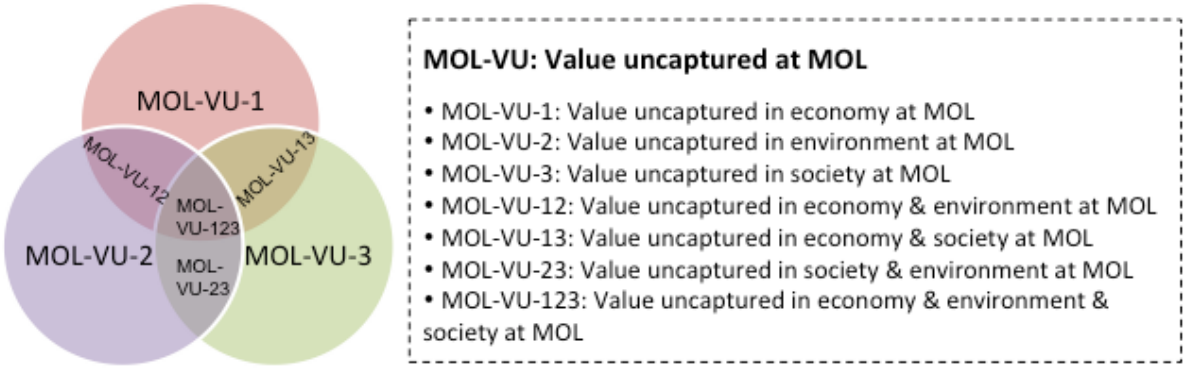

Figure 6. Four main PSS solutions in the Company

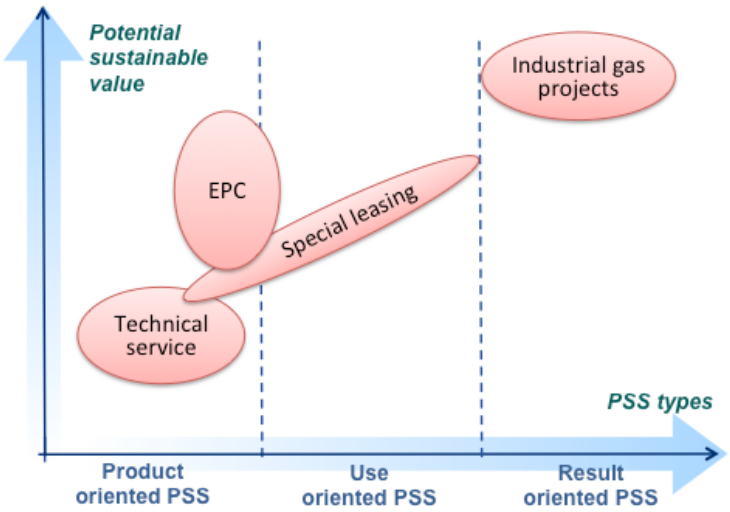

Figure 7. The relationship of product properties, customer demands, business development needs and PSS solutions

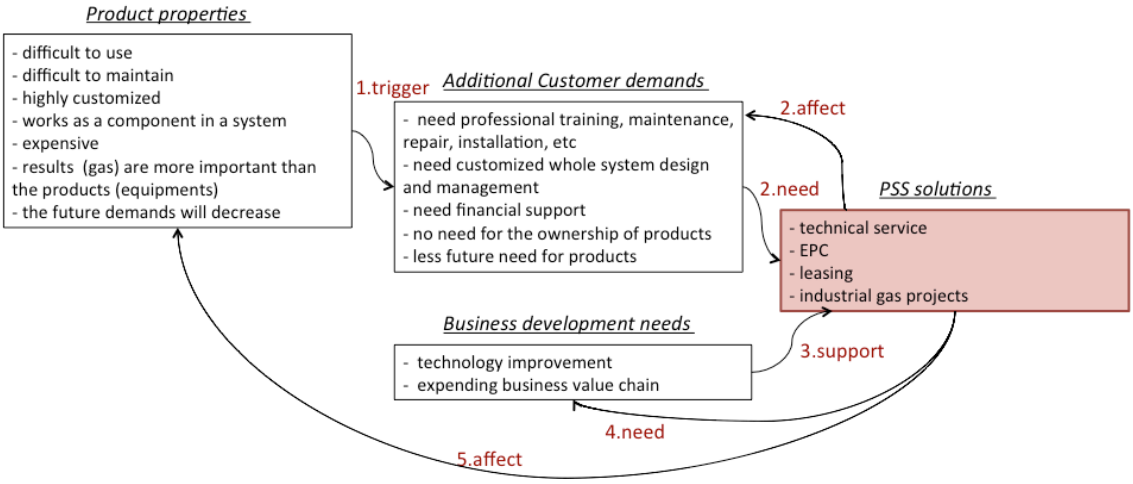

Figure 8. Results of using the tool in the company