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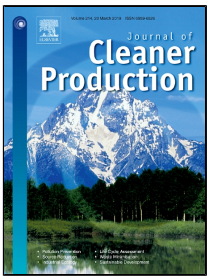

Product-service system business model archetypes and sustainability

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Product-service system business model archetypes and sustainability

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Abstract

The existing literature has largely discussed the sustainability potentials of product-service systems (PSS) business models, but most of them do not distinguish the sustainability of different PSS archetypes. This paper aims to investigate how different PSS archetypes may affect firms' sustainability performance differently, and to identify the main reasons for the differences. We studied three manufacturing firms, each of which has co-existence of various archetypes of PSS. We analyzed the sustainable value generated by each archetype, and observed that, firstly, different archetypes of PSS do create differences in the sustainable value delivered; secondly, the main reason for the difference is the integration level of product maker, owner and user; thirdly, result-oriented PSS is shown to have significant potential to deliver environmental and economic benefits through enhanced resource efficiency in production and consumption; and fourthly, PSS alone does not have significant social sustainability effects. We then proposed a framework of PSS business model archetypes and sustainability based on the literature study and empirical evidence. The proposed framework is novel and provides a comprehensive analysis of the economic, environmental and social sustainable value creation of known PSS business model archetypes. The findings can be applied in manufacturing firms to explore sustainable value sources when developing different archetypes of PSS business models.

Keywords: Product-service system; PSS; sustainable business models; sustainable value; PSS archetypes; servitization

1. Introduction

An increasing number of manufacturing firms are transforming their business models from traditional product-based models to product-service system (PSS) business models, where manufacturers sell an integration of product and service rather than the product alone (Goedkoop et al., 1999). The process of this transition is called servitization (Vandermerwe and Rada, 1988). The well-known servitization examples include the *power by the hour* and *total care* contracts offered by Rolls Royce, in which the customers pay for the availability and reliability of the engines rather than the engines themselves (Neely, 2009). The main driving force for developing such PSS business models is that manufacturers can no longer compete by making and selling high quality products alone (Visnjic et al., 2017). In most markets products become increasingly similar, leaving limited room for product differentiation (Tukker, 2015). To overcome this problem, firms have to go downstream, closer to the customers – selling services, integrated solutions and even experiences – to capture value throughout the value chain (Pine and Gilmore, 1998; Wise and Baumgartner, 1999). Servitization is also driven by customer demands, changing from products to solutions over the past decades (Baines et al., 2009; Martinez et al., 2017). Servitization/PSS has received increasing interest from researchers. The current literature has studied servitization/PSS from various perspectives, such as the drivers and barriers of servitization (Vladimirova, 2012), PSS design (Sakao and Lindahl, 2009; Sakao and Mizuyama, 2014; Song and Sakao, 2017), PSS modularisation (Fargnoli et al., 2018; Li et al., 2018) and the sustainability features of PSS (Tukker 2004, 2015).

The potential benefits of PSS business models are obvious. Many servitized companies have largely gained revenue from continuous services (Martinez et al., 2017). Studies also identified that PSS business models have the potential to improve firms' environmental performance (Goedkoop et al., 1999; Omann, 2003; Tukker, 2015). The argument is that servitized companies have high incentive to internalize the externalities along the entire product life cycle, so that their profits and the environmental benefits have the potential to be synergized (Baines et al., 2009; Tukker, 2015). The existing literature has mostly discussed the sustainability potentials of PSS business models in general. However, different PSS archetypes differ in their characteristics, and may result in diverse environmental, economic and social impacts. Tukker (2004) initiated the discussion by proposing eight types of PSS and analyzing their environmental sustainability potentials respectively, but little empirical evidence has been provided to support the arguments. There is a need to examine the sustainability effects of different archetypes of PSS business models in practice.

The purpose of this paper is to understand how different archetypes of PSS business models create economic, environmental and social value. This paper investigates the questions "*what is the sustainable value created in different archetypes of PSS business models*", "*what are the main differences between each archetype*" and "*what are the main reasons for the differences*". We will first review the current literature on the sustainability effects of PSS business models, and then present the findings from our empirical studies on three manufacturing firms, each of which has transformed to servitized companies and has co-existence of PSS business models archetypes. The sustainable value created in different PSS archetypes and the main reason for the differences will be discussed.

2. Literature review

2.1 Product-service system archetypes

Several scholars have attempted to classify PSS (Brezet et al., 2001; Gaiardelli et al., 2014; Lay et al., 2009; Mont, 2002; Van Ostaeyen et al., 2013). A widely accepted approach is to classify PSS into three archetypes according to the ratio of service involved and the ownership of the products: product-, use- and result-oriented PSS (Hockerts and Weaver, 2002). Product-oriented PSS is when the provider sells products and offers additional service, such as maintenance, consultancy, insurance, repair and training. Use-oriented PSS is when the provider keeps the ownership of the products and sells the utility, availability or function of products, such as leasing, renting, sharing and pooling. Result-oriented PSS is when the provider sells the results of a product, so the provider is also the user of the products, such as selling 'comfortable room temperature' rather than selling 'air conditioners'. Based on the three archetypes, Tukker (2004) further proposed eight specific PSS subcategories under each archetype, and analysed the key economic elements and the value characteristics of each PSS subcategory.

Neely (2009) identified twelve different types of services from empirical data, and grouped them into five archetypes that extend the standard, three PSS archetypes: integration-, product-, service-, use-, and result-oriented PSS. Integration-oriented PSS is when companies integrate services vertically by going upstream or downstream along supply chains, such as integrating retail and distribution services. Service-oriented PSS is when companies incorporate services into products as an integral part of the offering, such as Intelligent Vehicle Health Monitoring services. It seems that service-oriented PSS is not significantly different to product-oriented PSS apart from the degree of integration of services into the products. These five archetypes were used by Clayton et al. (2012) in evaluating the existing PSS design approaches.

Cusumano et al., (2015) classified product-related services into three types: smoothing, adapting and substituting services. Smoothing services refer to services which do not change the product functionality, such as maintenance, warranty and financing services. Adapting services are services that add new product functionality or new ways of using the product, such as customized products and services. Substituting services refer to services that replace the purchases of product, for example, leasing and renting services. Lay et al. (2009) defined eight parameters that differentiate service-based businesses, which resulted in a morphological box that allows for the description of new service-based business concepts in B2B market. Gaiardelli et al., (2014) proposed a classification model for product-service offerings according to product-service offering orientation, focus and the nature of interactions. Other scholars studied outcome-based contracts (Visnjic et al., 2017), which means that manufacturing firms provide specific outcomes of products and services according to customer needs.

The current studies show that there is no consensus on how best to categorise PSS (Beuren et al., 2013). However, among the different classifications, Hockerts and Weaver (2002) and Tukker (2004)'s three-archetypes of PSS is the most widely used and considered the most appropriate for use with the PSS business model (Aurich et al., 2010; Geum and Park, 2011). Most of service types proposed by other authors could be fitted into the three-archetypes of PSS or eight sub-categories. For example, the smoothing and adapting services are part of product-oriented PSS, and the substituting services can be regarded as use-oriented and result-oriented PSS, and the outcome-based contact is a format of result-oriented PSS.

2.2 PSS business models and Sustainability

The existing literature has mostly studied the sustainability potentials of PSS business models. When PSS was first coined, Goedkoop et al. (1999) have already emphasised its potential benefits to both business and the environment. Since then many authors have regarded PSS as an innovative and effective way to move society towards sustainability due to its significant potential to synergise profits and environmental benefits (Manzini and Vezzoli, 2003; Tukker, 2015; UNEP, 2009; Yang, et al., 2017). In general, PSS enables the discovery of new market opportunities (Baines et al., 2007; Tan et al., 2010), creates strategic (Chase and Erikson, 1988; Mathieu, 2001) and economic benefits (Wise and Baumgartner, 1999), improves environmental performance (Tukker, 2015) and decreases negative social impact (UNEP, 2009). In recent years, PSS are regarded as the pioneering

business models to shift the production and consumption from the linear model towards circular economy (Yang et al., 2018; Spring and Araujo, 2017).

We reviewed the existing literature and summarised the sustainable potentials of PSS business models in Table 1. Many researchers recognized that PSS business models could lead to a significant reduction of negative environmental impact through the following dimensions: *contributing to longer product life*, *increased resource and energy efficiency and reduced carbon emission*, *increased recycling, remanufacturing and reuse*, *increased product usage*, *dematerialisation and freedom to design for sustainability*. The economic benefits of PSS business models are *better fulfilment of customer needs*, *stronger customer relationships*, *differentiation*, *increased revenues*, *identification of new markets and faster response times*, *access to service data*, *reduced ownership responsibility for customers, improved technology, reduced risk and reduced life cycle cost*. The specific social benefits are mainly through an increased number of jobs.

Table 1. Sustainable potentials of PSS business models

Three pillars of Sustainability	Sustainability potentials	Literature sources	Explanation
Environmental	*Longer product life*	(Baines et al., 2007)	Professional services (such as maintenance and repair) can avoid products or components being thrown away unnecessarily and can extend product life to some extent.
	Increased resource and energy efficiency and reduced carbon emission	(Tukker, 2004; Tukker, 2015; Byers et al., 2015)	In most situations, both customers and manufactures have the incentive to increase resource and energy efficiency in the use phase of products. Customers pay per use or per service unit, so increasing efficiency in use will reduce the total cost. If manufacturers are the owners or even users (in result-oriented PSS) of products, they are incentivised to use products as efficiently as possible in terms of materials and energy in order to reduce costs.
	Increased recycling, remanufacturing and reuse	(Yang et al., 2018; Guidat et al., 2014; Ijomah et al., 2006; Sundin et al., 2009; Sundin and Bras, 2005)	Use- and result-oriented PSSs have the potential to increase the reuse of products at their end of life by recycling, reconditioning and remanufacturing. They increase customers' acceptance of remanufactured products since customers do not own the products and care less about how new the products are. Moreover, manufacturers find it easier to collect used products as they can more easily predict the timing and quantity of returns. They also incentivise firms to reuse parts as much as possible at the end of the product life cycle, to improve remanufacturing technology and to design for remanufacturing.
	Increased product usage	(Beuren et al., 2013; Tukker, 2004; UNEP, 2009)	PSS providers own products and therefore have the incentive to maximise product use (to ensure that products are used as intensively as possible) by keeping them in good working order. The utilisation of products is increased since more people can use the same product at less cost. As makers of the products manufacturers are usually more expert than customers at using products (e.g. installing, maintaining and operating products). They are incentivised to fulfil customer needs using the least resource-intensive products and services, to achieve a more efficient use of the products.
	Dematerialisation	(Lin et al., 2010)	PSS enables a total reduction in the use of materials, energy and products because the same number of products can meet the needs of more people (termed dematerialisation).
	Freedom to design for sustainability	(Tukker, 2004)	Result-oriented PSS has higher potential to enable the freedom to design for sustainability.
Economic	Better fulfilment of customer needs	(Baines et al., 2007; Tan et al., 2010)	PSS enables a more tailored offering with new functionalities and different combinations of products and services.
	Stronger customer relationships	(Baines et al., 2007; Neely, 2009; Tan et al., 2010; UNEP, 2009)	Service contracts can result in a stronger, longer and more direct customer relationship. They can also increase customer loyalty and even lock in customers.
	Lock out competitors	(Annarelli et al., 2016; Neely, 2009)	PSS business models are usually hard to be imitated due to the uniqueness of services.
	Differentiation	(Baines et al., 2007; Cavalieri and Pezzotta, 2012; Gebauer et al., 2006; Mathieu, 2001; Neely, 2009; Wise and Baumgartner, 1999)	Technologies and products in mass markets tend to be similar. Services can differentiate a firm's offering. Services can create barriers for competitors and even lock out competitors by creating stronger customer relationships.
	Increased revenues	(Mathieu, 2001; Tan et al. 2010; Wise and Baumgartner, 1999)	Services provide a more stable and continuous revenue stream, and higher profit margins compared to product sales.
	Identification of new markets and faster response times	(UNEP, 2009)	Services are more flexible compared to products and allow a rapid response in changing markets.
	Access to service data	(Baines et al., 2007; Tan et al., 2010)	Service data can provide information about product performance and customer behaviour, and can be used to improve the design of products and to analyse changing customer demand.
	Reduced ownership responsibility for customers	(Baines et al., 2007)	Customers are released from the responsibilities of owning products (Baines et al., 2007), which reduces the burden of caring in some situations.
	Improved technology	(Sakao et al., 2013)	Integrated Product Service Offering (IPSO) enables the producers to keep intellectual property and improve technology innovation.
	Reduced risk	(Sakao et al., 2013)	IPSO could reduce risks such as the changes of regulation, business environment and market.
	Reduced life cycle cost	(Lindahl et al., 2014; Sakao and Lindahl., 2015)	IPSO could reduce the life cycle cost and environmental impact.

Social	*Increased jobs*	(Beuren et al., 2013)	The provision of service could create more jobs since it could be more labour-intensive.

The existing literature also described some industrial cases or examples of sustainable PSS (Bandinelli and Gamberi, 2012; Morelli, 2003; von Weizsäcker et al., 1998). We summarised some of them in Figure 1. For instance, Manzini and Vezzoli (2003) asserted that the detergent home delivery service provided social value by increasing customer comfort, and environmental value by optimising the distribution process. They also claim that by shifting from selling lubricants to selling a lubricant service (e.g. aerosol treatment plants and sewage treatment), the company reduced costs, avoided accidental pollution and improved operator safety. Mont et al. (2006) argued that leasing prams increased social and environmental value because more people could use the same product while paying less. Lovins et al. (1999) and Boons and Lüdeke-Freund (2013) asserted that carpet leasing aligns ecological goals with profit goals. Tonelli et al. (2009) adopted action research to assess and implement PSS strategies in the healthcare industry (retrieving, recycling and disposing of equipment for hospitals) with the aim of reducing environmental impact.

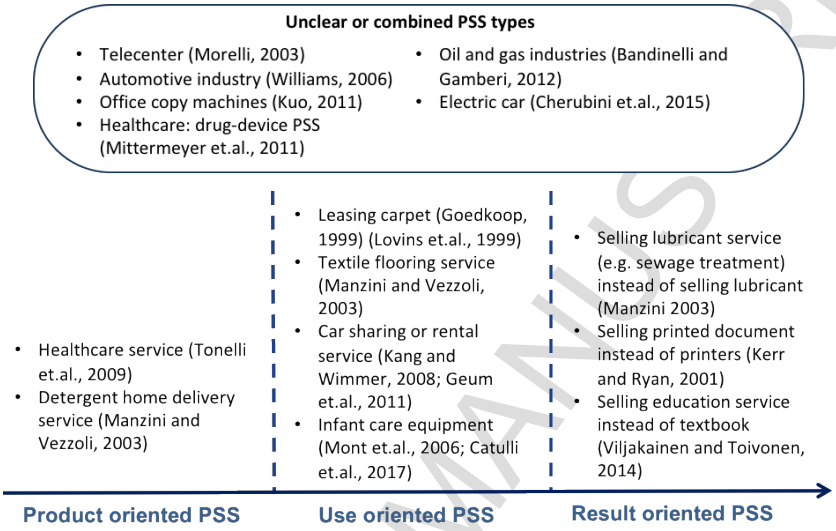

Figure 1. Industrial cases or examples of sustainable PSS business models

In these cases, the authors have claimed that these PSS examples offer sustainable value. However, the evidence is still not clear in some of the literature. The authors do not seem to have firm data to support their arguments, except in the case of the textile flooring service, in which the floor firm sells an installed, textile flooring for trade fairs and exhibitions instead of selling floors (Manzini and Vezzoli, 2003). Here, Manzini and Vezzoli (2003) firmly stated that this is "*a real sustainable PSS case*" and "*there is a remarkable saving of raw materials and waste disposal*."

Table 1 and Figure 1 show that most of the current literature have explored one or more pillars of sustainability, but very few of them covered all three pillars (Annarelli et al., 2016). Moreover, most of the studies do not differentiate the sustainability effects among different archetypes of PSS. Tukker (2004) discussed the environmental sustainability potential of the different archetypes of PSS at conceptual level with little empirical evidence. Therefore, there is a need for a comprehensive analysis of all three dimensions of sustainability potentials of each archetype of PSS business models supported by strong empirical studies.

3. Methods

In order to understand how different archetypes of PSS business models have contributed to each of the three pillars of sustainability, we performed a multiple-case study (Yin, 2009). We used two criteria to select cases. The first criterion is firms with co-existence of various archetypes of PSS – this is to enable a fair comparison of the sustainability effects of the types within one firm. The second criterion is the maturity of the firms' servitization, to ensure that the PSS business models have brought changes to the firms. Following the sampling guidance, three case studies were selected for this research. We collected primary data from interviews, workshops and focus group; and secondary data from annual reports and company documents.

3.1 Data collection

The primary data was collected from a one-day focus group (24 participants) and 17 semi-structured interviews/workshops (25 participants). The focus group took place before any interviews were conducted. It lasted 6 hours and took the form of a group presentation and discussion on the theme of manufacturing servitization/PSS. The interviewees were the CEOs, presidents, directors, managers, and designers of the companies. The interviews were guided by a semi-structured interview guideline and included three parts.

Part 1. PSS business models

- What PSS business models has your firm developed?
- What are the archetypes of these PSS business models?

Part 2. The sustainability effects of each PSS business model

- For each PSS archetype, what economic, social and environmental value has been created?
- Please provide detailed examples of how this PSS business model creates sustainable value.

Part 3. The comparison of the levels of sustainable value creation in different PSS archetypes

- What is the level of sustainable value of each PSS business model?
- What are the differences of the levels between different PSS archetypes?
- What are the main reasons for the differences?

In order to ensure the reliability of the answers, we asked the interviewees to provide at least one practical example to illustrate how each PSS archetype has generated sustainable value in their firms. The sustainable value is broadly regarded as a set of benefits derived by a stakeholder from an exchange (Rana et al., 2012). During the interview, we clarified two important concepts of sustainable value (Yang et al., 2017a).

First, what kind of sustainable value is generated? Sustainable value includes economic value, e.g. stability of the business, increased profit, and financial resilience; social value, e.g. poverty alleviation, social justice, improved health and safety, quality of life, equality and education; and environmental value, e.g. renewable resource use, low emissions, reduced pollution, bio-diversity, resource and energy consumption.

Second, for whom is the sustainable value generated ? The value created is not only for shareholders but also for other relevant stakeholders, such as employees, government and communities (Freeman, 2007). The engagement of multiple stakeholders is crucial in the context of sustainability (Short, 2014). Stakeholders might come from different stages of a product life cycle and play key roles at those stages.

However, it is still not easy for the interviewees to identify all economic, social and environmental value of each PSS business model within a short interview. We therefore used a poster which is part of the Sustainable Value Analysis Tool (Yang et al., 2017b) to inspire them to answer the questions, shown in Figure 2.

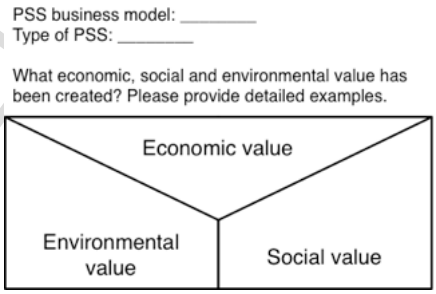

Figure 2. Data collection tool for this research

The reason for using the data collection tool in our interviews was that the visualised format greatly increased the engagement of the interviewees, triggered more structured and detailed data and therefore improved the data collection. The interviewees were asked to identify the economic, social and environmental value and their overlaps (e.g. economic-environmental value), explain it with specific examples, write the data on post-it notes and stick them onto the relevant places of the poster. We also collected secondary data from company reports, articles and websites.

3.2 Data analysis

Data analysis for this research started by analysing each individual case study with the aim of describing and understanding the PSS business models in each firm, and identifying the environmental, economic and social value and their overlaps of each archetype of PSS. Cross-case analysis was then conducted to enhance the generalizability of the findings and deepen the explanation through replication (Eisenhardt, 1989; Yin, 2009).

The focus group, interviews and workshops were recorded and transcribed, yielding 41 hours 32 minutes in total, resulting in a large amount of transcribed data. We used content analysis, coding and pattern identification to analyse the transcripts. We followed three procedures of data analysis: *data reduction*, *data display* and *conclusion drawing and verification*; and undertook three stages of coding: *open coding*, *axial coding*, and *looking for explanation and patterns in coding* (Miles and Huberman, 1994). Several coding techniques were adopted and 319 codes emerged from the data. These codes were clustered into common themes. MAXQDA software was used for data analysis. Each transcription was analysed at least five times by the authors in order to avoid missing interesting themes.

4. PSS business model archetypes and sustainability

4.1 PSS business model archetypes in the firms

The participating firms in this research are three large, state-owned manufacturing firms in China. All of them have developed multiple types of PSS business models and four archetypes are identified in each firm. Table 2 shows the details of the four archetypes of PSS business models in the three firms.

Table 2. PSS business model archetypes in the studied firms

	Industries	PSS business model archetypes			
		Product-oriented PSS	Integration-oriented PSS	Use-oriented PSS	Result-oriented PSS
Firm A	Gas generator (3 interviews)	Products and technical services, e.g. installation, maintenance and repair	Engineering Procurement Construction (EPC)	Leasing	Industrial gas projects, i.e. selling gas rather than gas generators
Firm B	Steam turbines (6 interviews)	Products and technical services, e.g. installation, maintenance, consultation and repair	Engineering Procurement Construction (EPC), Build Operate Transfer (BOT)	Leasing	Energy management projects, i.e. selling electricity rather than steam turbine
Firm C	Turbo machinery (5 interviews)	Products and technical services, e.g. consultancy, installation, testing, maintenance, technological upgrading and remote monitoring, repair	Engineering Procurement Construction (EPC), Build Operate Transfer (BOT)	Leasing	Wind power projects, i.e. selling wind power rather than turbo blower

Product-oriented PSS

The traditional business models of the three firms were making and selling products only – Firm A selling gas generators, Firm B steam turbines, and Firm C turbo machinery. In addition to selling products, all three firms also provide customers with technical services, such as installation, maintenance, consultation and repair. The ownership of products belongs to the customer and the technical services are included as part of the original sales package.

Integration-oriented PSS

The integration-oriented PSS in the three firms mainly include Engineering Procurement Construction (EPC) and Build Operate Transfer (BOT). EPC, also called Turnkey, refers to the projects in which firms provide customers with a complete, ready-to-use solution including all the products and services required. For example, the EPC projects in Firm A involved extending the business from just selling a gas generator to selling the entire functional air separation system needed by customers. Such a system would include engineering system design, procurement and production of facilities, engineering construction, installation of equipment, and related services. BOT projects happen when the firms build the entire systems, and provide operational services after it is built. The customers pay an additional service fee over an agreed period. EPC and BOT are integration-oriented PSS business models because they provide vertical integration services (Neely, 2009).

Use-oriented PSS

All three firms provide leasing services, the main motivation of which, however, was to reduce the financial pressure on customers who cannot afford the products. The ownership of products remains with the manufacturing

firms and the customers pay a rental fee over an agreed number of years. The leasing projects are not common in any of the three firms.

Result-oriented PSS

All three firms have developed result-oriented PSS business models. Firm A sells industrial gases rather than gas generators; customers only pay for the gases used instead of buying the entire gas generators. Firm B sells electricity rather than steam turbines, as part of their energy management contract with their customers. Firm C sells wind power rather than turbo blowers; customers pay per quantity of wind flow with a certain speed, rather than buying blowers. In these projects, customers pay for the result of the products without owning the products.

4.2 What is the sustainable value created in different archetypes of PSS business models?

We analysed the detailed examples of how each PSS business model has created economic, environmental and social value in the three firms, in order to identify the patterns behind the examples. Three hundred and nineteen codes of sustainable value creation from the interviews emerged and were grouped into different dimensions, which were further synthesized into the bullet points in Table 3. Each point contains several real examples. For example, in Firm A, there were 17 codes related to economic-environmental value from the use of gases (i.e. gas generators' product), which were grouped into four dimensions: *comprehensive utilisation of different gases for different customers*, *coordinated use of gases among customers during peak and off-peak times*, *reduced gas emissions*, and *greater incentive to increase the use of gases*. The four dimensions were then further grouped into "*increased utilisation of products' products and co-products"*. Similar ways of coding and grouping were used to generate all of Table 3.

Table 3. The sustainable value creation in different archetypes of PSS business models

	Product-oriented PSS	Integration-oriented PSS	Use-oriented PSS	Result-oriented PSS
Economic value	• Increased revenue from service (ABC) • Provide more professional service to solve customer problems (ABC) • Reduced cost for customers (ABC) • Increased customer loyalty (C) • Improved resource efficiency (C) • Better understand customer needs (C) • Guide the direction of product development (C)	• Increased revenue through service income and expanded businesses (ABC) • Provide more professional service to solve customer problems (ABC) • Reduced total cost for customers (ABC) • Better understand customer needs (C) • Build a business eco-system with the firm as the core firm (C) • Use of service data (C) • Lock out competitors (C)	• Continuous revenue from leasing (AB) • Provide more professional service to solve customer problems (ABC) • Reduced financial pressure for customers (ABC) • Reduced risk for customers and banks (C) • Increase market by making previously unfeasible projects feasible (C) • Build a business eco-system with the firm as the core firm (C)	• Improved technology (A) - Experiment and test on products (A) - High incentive for long-term technology development (A) • Expanded groups of potential customers (ABC) • Reduced life cycle cost for manufacturer (A) - Less restricted by customer need and more freedom to control cost (A) - Fewer products produced and fewer workers needed (A) - Reduced life cycle cost due to improved service efficiency in MOL (A) • Reduced risk on market (A) • Long-term continuous and stable revenue (ABC) • High gross profit rate (ABC) • Use of service data (ABC) - Prediction of problems (ABC) - Quick response to problems (ABC) • Improved design - more freedom in design (AB) • Reduced costs for customers (ABC) • Provide more professional service to solve customer problems (ABC) • Reduced financial pressure for customers (AB) • Lock in customers (C)
Environmental value	• Saved energy for customers (B) • Upgraded high energy efficient technology (C) • Longer product life (ABC)	• Saved energy for customers (BC) • Reduced total emission (C) • Longer product life (ABC)	• Saved energy for customers (BC) • Longer product life (ABC)	• Saved energy for customers (BC) • Reduced total emission (C)
Social value	• Improved safety (ABC) • Improved employee salary and satisfaction (C)	• Improved safety (ABC) • Domestic production of heavy industrial equipment (ABC) • Improved employee salaries and satisfaction (C)	• Improved safety (ABC) • Domestic production of heavy industrial equipment (ABC) • Improved employee salaries and satisfaction (C)	• Increased job opportunities for local community (AC) • Improved safety (ABC) • Domestic production of heavy industrial equipment and therefore no dependence on other countries (ABC)
Economic-environmental value	• Reduced energy consumption in usage phase (A) • Improved resource efficiency (C) • Utilisation of customers' waste (C) • Improved utilisation of resources (C)	• Improved utilisation of resource in production (AC) • Reduced energy consumption in production and usage phase (A) • Longer product life (ABC) • Improved utilisation of resources in production (B) • Utilisation of customers' waste (C) • Improved resource efficiency (C)	• Improved utilisation of resource and products (ABC) - Reuse of products for different markets (B) - Increased remanufacturing activities (B) • Reduced energy consumption in production (AC) • Longer product life (ABC) • Utilisation of customers' waste (BC)	• Increased utilisation of products' products and co-products (AC) • Improved utilisation of resource, assets and products (ABC) • Utilisation of customers' waste (AC) • Improved resource efficiency (ABC) • Reduced waste in use (ABC) • Increased incentive to improve sustainable technology and design (AB) • Increased energy efficiency and reduced energy cost (AC) • Reduced life cycle energy and life cycle cost (ABC) • Longer product life (ABC) • More freedom and incentive to design for sustainability (AB)
Economic-social value	• Improved customer relationships (AC) • More efficient use of human resources (AC)	• Improved customer relationships (AC) • Improved local business ecosystem (A) • More efficient and sufficient use of human resources (AC)	• Improved customer relationships (AC) • Improved local business ecosystem (A) • More efficient and sufficient use of human resources (AC)	• Improved customer relationships (AC) • Improved local business ecosystem (AC) • Improved service efficiency (AC) • More efficient use of human resources (AC) • Improved local GDP (AC)
Environmental-social value	No data	No data	No data	No data

(Note: A, B and C refer to empirical evidence from the Firm A, B and C)

Table 3 shows how the three pillars of sustainable value have been created in each archetype of PSS business model. We identified that a great deal of economic, economic-environmental and economic-social value was created, but very little environmental, social or social-environmental value was identified. It implies that the firms were mainly interested in value that makes an economic contribution to the company. For example, in Firm A, energy consumption was the main cost for air separation units in usage phase as well as having a major environmental impact. Reducing energy consumption was the main approach taken to reduce both cost and carbon emissions. The firm had a high incentive to reduce energy consumption in order to create economic-environmental value. This implies that it was mainly when the value was combined with economic benefits that the company had the motivation to capture it. It should be noted that the level of sustainable value for each PSS archetype was qualitatively assessed using the data provided by the companies.

Similar findings can be observed in Figure 3, showing the frequency with which value was generated across different dimensions of sustainability. It should be noted that the figures were calculated from the number of times the evidence was mentioned. For example, one economic-environmental value is *increased utilisation of products' products*. If it was mentioned by two interviewees, a total of three times, it would be calculated as three. Figure 3 indicates that economic-environmental value was the most value from PSS business models in the three firms, or the captured value that was most frequently mentioned.

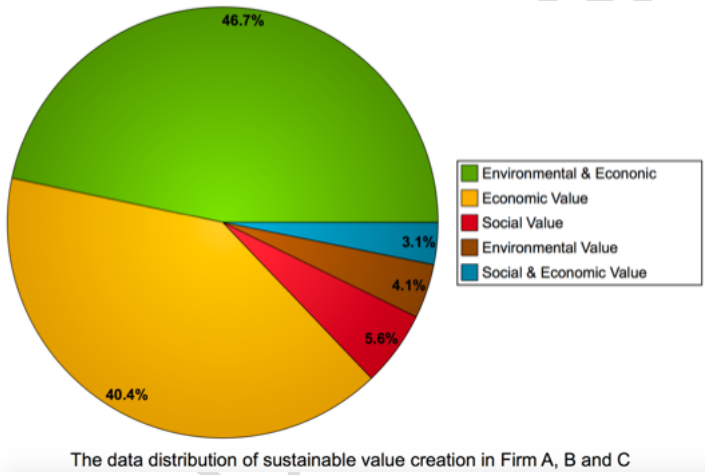

Figure 3. Data distribution of sustainable value creation from PSS business models in the studied firms

The findings further confirm that firms are mainly interested in value that brings economic benefit. Some environmental value was created but only because it was combined with economic value. It was a coincidental benefit produced as part of the process of the company pursuing its economic goals. The findings also empirically confirm that PSS business models, especially result-oriented PSS, have high potential to combine economic and environmental value. There is little evidence for the social-economic value of PSS solutions and no data for social-environmental value.

4.3 A framework of PSS business model archetypes and sustainability

All PSS archetypes resulted in certain levels of sustainability performance improvement. Looking into the details of data, we identified that different archetypes of PSS business models affected the sustainable value creation to different degrees. Based on the data from literature (Table 1) and empirical studies (Table 3), we develop a framework of PSS business model archetypes and sustainability (shown in Figure 4). This framework provides a systematic illustration of the differences of the sustainable value creation in the four PSS archetypes

In Figure 4, the slice (a) summarises the common sustainable value of all four archetypes of PSS. The area of the blocks represents that the more a PSS is result-oriented, the stronger these features become. For instance, all PSS archetypes have the economic value "increased revenue" and "reduced cost for customers". However, the value gets larger the closer a PSS is result-oriented PSS. It means, the result-oriented PSS has stronger features in these common sustainable value than other types. Slice (b) shows the sustainable value of integration-, use- and result-oriented PSS, which the product-oriented PSS does not have. For example, these three PSS archetypes have the economic-environmental value "utilization of customers' wastes", but the product-oriented PSS does not have this value. Again, the applicability of these common sustainability features varies according to context. In general the more a PSS is result-oriented the stronger these features become. Slice (c) is the sustainable value of use- and

result-oriented PSS. Slice (d) summarises the unique sustainable value creation in result-oriented PSS. For instance, result-oriented PSS could increase the utilization of products' product and co-products, and reduce the total emissions which other PSS archetypes do not have. Slice (e) shows the unique value creation in use-oriented PSS. From the cases only the use-oriented PSS has the obvious potential on reducing risks for customers and financial organisations. Product- and integration-oriented PSSs also have some features that use- and result-oriented PSS do not have, shown in slice (f), for example, having ownership means customers are more likely to use products carefully and products might last longer.

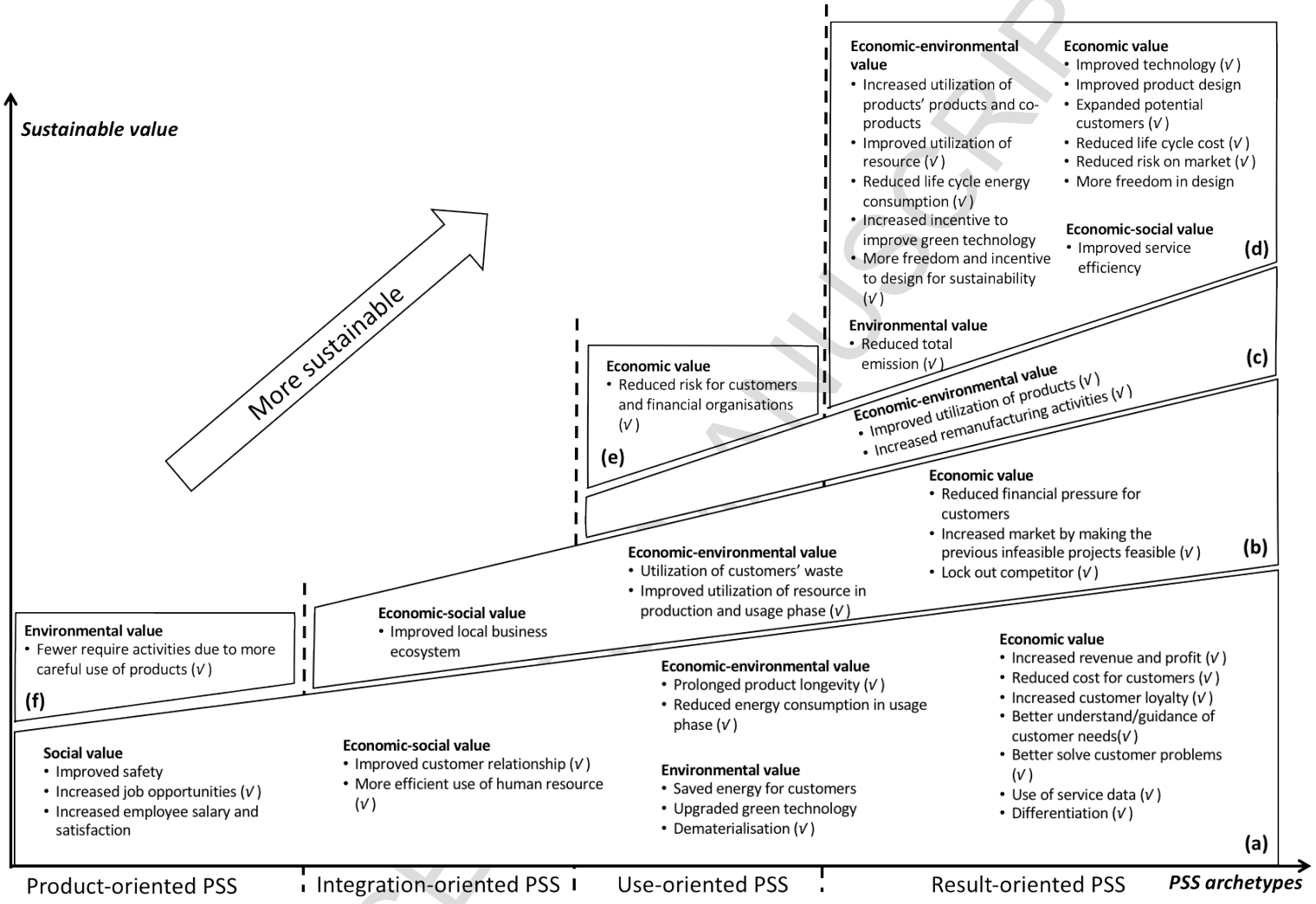

Figure 4. Framework of PSS business model archetypes and sustainability. Slice (a) is the common sustainable value of all four archetypes of PSS. Slice (b) shows the sustainable value of integration-, use- and result- oriented PSS. Slice (c) is the sustainable value of use- and result- oriented PSS. Slice (d) shows the unique sustainable value creation in result-oriented PSS. Slice (e) shows the unique value creation in use-oriented PSS. Slice (f) is the unique sustainable value creation in product-oriented PSS. The area of the blocks becomes larger the closer it gets to result oriented PSS. This symbolizes that the closer to the result-oriented PSS, the stronger the sustainable value becomes.

The symbol (√) in Figure 4 represents that it is also mentioned in existing literature in Table 1, and the others without the symbol is newly found in the case studies. It should be noted that the positions of the four PSS archetypes in this framework are based on qualitative data from the three firms, all of which have the co-existence of the four types of PSS. This provides a general view of the sustainable value creation in different PSS archetypes. The detailed sustainable value for each PSS project is context specific.

4.4 What are the main reasons for the differences?

We further analysed the main reasons for the differences of sustainable value created in each PSS archetype (Figure 4). We identified that the differences are highly relevant to the manufacturer's integration level of product *maker*, *owner* and *user*, i.e. whether or not the manufacturer makes, owns and uses the products, shown in Table 4.

Table 4. The integration level of product maker, owner and user. The symbol (√) represents that manufacturers are the maker, owner or user of the products. The symbol (×) represents that the manufacturers are not the maker, owner or user of the products. In product- and integration-oriented PSS, manufacturers are the product maker, but not the owner and user. In use-oriented PSS, manufacturers are the product maker and owner, but not the user. Result-oriented PSS, manufacturers are the product maker, owner and user. It shows that the result-oriented PSS has the highest integration level of the product maker, owner and user.

	PSS business model archetypes			
	Product-oriented PSS	Integration-oriented PSS	Use-oriented PSS	Result-oriented PSS
Maker	√	√	√	√
Owner	×	×	√	√
User	×	×	×	√

In product- and integration- oriented PSS, the manufacturing firms make and sell products. The sale of products is still the main revenue source. Firms are still incentivised to sell as many products as possible. They have less incentive to extend product life because it conflicts with the economic benefits of selling more products. In theory, the incentives of use-oriented and result-oriented PSS could differ; but in practice, firms do not sell products but the use of products, which means the longer the products are used the more profit the firms will get. So, firms have stronger incentive to extend product life (e.g. by using longer-lasting materials) and more potential to promote sustainability in the context of use- and result-oriented PSS.

In use-oriented PSS, the manufacturing firms make and own the products. The utilization of single products is increased because firms have higher incentive to remanufacture the products and rent the used products to other customers. Besides, compared to buying the products, the monthly or yearly rental payment could reduce the financial pressure for customers.

In result-oriented PSS, the manufacturer is not only the product maker and owner, but also the product user. This business model gives the manufacturer the most power and control over the entire life cycle of products. The focus of customers and manufacturers is shifted from the product itself to the functionality of products and the quality of services in the product usage phase. Customers care more about the results and less about the products and the processes involved.

5. Discussions and conclusions

We concluded our finding on PSS business model archetypes, their integration level of maker, owner and user, and their sustainability potential in Figure 5. The findings show that PSS business models have positive effects on improving the environmental and economic sustainability and a minor social benefit (little evidence). However, different archetypes of PSS business models' contributions to sustainability vary. The research also confirms that in theory the more a PSS is result-oriented, the higher the potential for sustainable benefits. A similar claim is made by other researchers (Tukker, 2015; Tukker and Tischner, 2006), who believe that result-oriented PSS is the most promising PSS business model in terms of encouraging a move towards a circular and resource-efficient economy. Beuren (2013) also highlighted that result-oriented PSS offer greater potential for dematerialisation. However, this is not always true. Some other authors, e.g. Manzini and Vezzoli (2003), argue that use- and result-oriented PSSs are not necessarily more sustainable than product-oriented PSS. A classic example is that customers

tend to use products less carefully when they do not own them, and this may cause early damage and thus decrease product life. This indicates that achieving sustainability features depends on the PSS context, and also that a sustainable PSS needs to be designed carefully, to mitigate potential negative impacts.

The findings also indicate that the integration level of maker, owner and user plays a key role in affecting the sustainability of PSS. The more a PSS business model involves manufacturers owning products, the greater the potential for creating sustainable value. The propositions regarding ownership have been briefly presented by some other authors, such as Tukker (2015), who explained that ownership of the product brings a feeling of control and encourages more freedom when using products, which can be considered a valuable attribute. However, most such statements in the literature lack the support of empirical data. This study provides rich empirical data from manufacturing companies having co-existence of different archetypes of PSS business models.

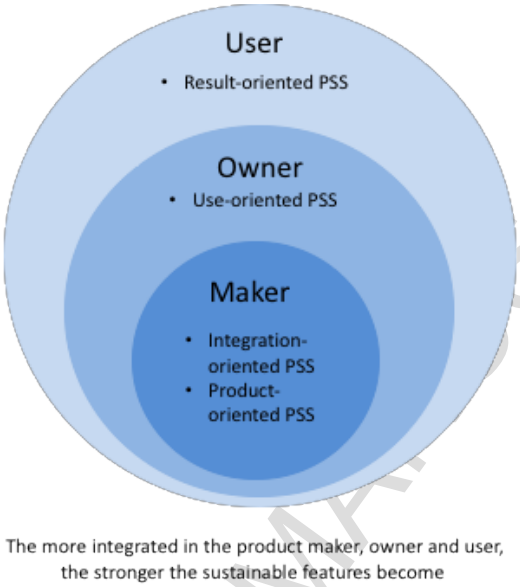

Figure 5. PSS business model archetypes and their integration of product maker, owner and user. The more integrated of the product maker, owner and user, the more sustainable value is created

Theoretical implication

This paper mainly contributes to literature in three aspects. First, we developed a framework of PSS business model archetypes and sustainability based on theoretical and empirical studies. This framework is novel and provides a systematic understanding of the sustainable value of different PSS archetypes in each dimension of sustainability (i.e. economic, social and environmental), as well as the overlapped dimensions (e.g. economic-environmental value). Most of the existing literature either simply analyse the potential sustainable benefits of PSS business models in general, without distinguishing between different PSS archetypes; or only discuss one or more pillars of the sustainability performance of PSS. However, different PSS archetypes differ in their characteristics, and may result in diverse environmental, economic and social impacts. We suggest that it is necessary for manufacturers to consider the sustainable value of different PSS business models, in relation to their varying impact on sustainability. The proposed framework provides a foundation for further study at the intersection of PSS archetypes and sustainability.

Second, we provided empirical evidence to demonstrate the levels sustainable value which are provided by all PSS archetypes, as well as the sustainable value specific only to one or more archetypes. All the studied companies have co-existence of the four archetypes of PSS and the collected data is comprehensive and comparable between different types. This fills the gap that the majority of sustainable PSS literature is based on the conceptual studies with little empirical evidence of one PSS type. The empirically-generated results show some interesting value that has not been addressed in existing literature, for instance, the increased utilization of products' products and co-products. This might not work for all companies, but has the potential to inspire similar B2B manufactures, who produce customised, expensive equipment, to capture value in this way.

Third, we analysed the main reasons for the differences and identified that the integration level of product maker, owner and user play an important role in influencing the sustainability of PSS business models. This is new to the

existing literature, and provides inspiration for the future work on sustainable PSS business model development; for example, different combination of the three varieties could be used to improve sustainability performance.

Practical implication

The research in this paper can be applied to manufacturing firms developing PSS to initiate business model innovation for sustainability. To be specific, the findings can be used in practice to help firms develop sustainable PSS archetypes (e.g. developing leasing models or result-oriented PSS business models) or identify more sustainable value in existing PSS business models (e.g. identifying uncaptured economic-environmental value in the current PSS business models).

6. Limitation and future research

There are mainly two limitations of this research. One is the difficulty for other researchers to replicate this study – a common limitation for qualitative research that required highly interactive engagement between researchers and practitioners. Another limitation is that the research only covers three industrial sectors, and that most of the company case studies are large B2B manufacturing companies, and some departments are not included in the interviews, such as sales department. These might limit the generalisation and applicability of the findings to other sectors or other types of companies. The future work includes adopting quantitative method to further investigate the relationship between PSS archetypes and sustainability in a wider range of industrial sectors and departments.

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