Chapter 7
Material-service Systems for Sustainable Resource Management

Marco Aurisicchio, Anouk Zeeuw Van Der Laan, and Mike Tennant

Abstract In current supply chains, material suppliers sell raw material resources to producers who sub-sequentially sell produced resourced to consumers. Ownership of resources, therefore, shifts from a few organisations to many consumers who are responsible to deal with them at the end of life. Product-service systems are business models where producers retaining ownership of produced resources have increased control on obsolete resources. Motivated by the need to facilitate an unlimited use of materials and eliminate waste, this research has introduced the concept of material-service systems, which are business models where material suppliers offer *materials as a service* to product producers. These systems offer the advantage that material suppliers are in control of resources and are incentivized to revalorise them. A scenario is explored in which a material-service system operates in conjunction with a product-service system and one in which it functions on its own. Finally, the benefits and incentives of the proposed service systems are discussed along with potential enablers and challenges.

Keywords Material-service system · Business model · Resource efficiency · Circular economy · Sustainability

7.1 Introduction

For a long time, our economy has been linear. We have taken material resources from our planet; used them to make products; and disposed of them as waste. Within this system, consumerism and population growth have propelled a use of resources that has outpaced the sustainable capacity of the ecosystem and led to the accumulation of waste (Stahel 2010). The depletion of material resources is making their prices

M. Aurisicchio (✉) · A. Z. Van Der Laan
Dyson School of Design Engineering, Imperial College, London, UK
e-mail: m.aurisicchio@imperial.ac.uk

M. Tennant
Centre for Environmental Policy, Imperial College, London, UK

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volatile and creating uncertainties in resource markets (Ellen MacArthur Foundation 2015). Importantly it is increasingly acknowledged that if we do not intervene now to preserve our material resources, we risk compromising the ability of future generations to source and use materials to address their manufacturing needs.

At present, consumption is predominantly based on one-off payments made by consumers to own products and dispose of them at the end of use. Despite the present recycling infrastructure aiming to close resource loops, acquisition and recovery of products and materials is poor. Disposed products largely end up in landfills because either the infrastructure for recovery does not exist or is not suitable for many types of products; and because not all consumers are willing or able to access the infrastructure (Steg and Vlek 2008). The products and materials that are intercepted for recovery are generally cascaded to lower level applications as the collected streams remain contaminated. This is due both to the way products are designed (Mestre and Cooper 2017; Bocken et al. 2016) and the ability to revalorise material resources, which is limited by sorting and separating technologies, material properties and material recovery technologies.

To transition to an economy that is circular, products can be designed in conjunction with use and result oriented services to offer value to consumers, while efficiently using fewer resources. These product-service systems (PSSs) offer consumers access to products, while ownership of the products remains with or returns to producers (Ellen MacArthur Foundation 2015). Rather than paying to obtain ownership of products, consumers are charged for the time spent with products as they 'pay per use'. A notable application is the 'Pay-per-lux' intelligent lighting service introduced by Philips (Rau and Oberhuber 2016). In this product-service system, Philips retain control over the products that they produce enabling better maintenance, reconditioning and recovery. The producer, therefore, is incentivised to increase its control over resources that are consumed to deliver the performance of resources and dematerialise the performance where possible. Increased control over the flow of resources offers two main opportunities for the circular management of materials. First, producers would be expected to design products according to circular design principles (Mestre and Cooper 2017), e.g. easier to disassemble, sort, identify and separate. This improves the ability to produce pure or purifiable resource flows. Second, centralised ownership of products encourages to develop product-specific recycling infrastructure and activities. This permits companies to reduce the risk of contamination of the collected resources and optimise the recovery and reuse of products, components, and possibly materials. Despite the opportunities to flow materials continuously using this model, the resources in these models will eventually become obsolete and producers still have to dispose of them (Zink and Geyer 2018). The issue of whether resources are revalorised and returned to materials suppliers to function as a continuous feedstock remains dependent on the response of producers to obsolescence; and the roles to be fulfilled by collectors, recovers and recyclers.

This paper introduces preliminary research to investigate the concept of offering *materials,* not products*, as a service.* Material-service systems (MSSs) are positioned as new business models for the circular economy where material suppliers shift from the selling of material resources to the provision of material services.

With these systems, material suppliers are in control of resources and therefore have significant incentive to revalorise them in collaboration with collectors, recoverers and recyclers. After introducing the concept of MSS, the paper explores the expected benefits, enablers and challenges of the proposed service systems. In this research we take a resource-centric view of materials and the outcomes of their transformations over the production, use and end of life phases. We pose that resources have multiple states including raw resources, produced resources, wholesale resources, operative resources, obsolete resources, recoverable resources, recovered resources and revalorised resources. We define materials as raw resources and products as produced resources.

7.2 Literature

7.2.1 Materials as a Service

This research on *materials as a service* has been influenced by two main concepts: Material Matters (Rau and Oberhuber 2016); and Chemical Looping (Stoughton and Votta 2003). Materials Matter is the title of a book by Thomas Rau and Sabine Oberhuber capturing their vision that it is service, not ownership, the answer to facilitate an unlimited use of materials and the elimination of waste in the construction sector (Rau and Oberhuber 2016). To enable this shift, they have proposed an online registry of material passports, which allows to know where materials are located, and preserve and reuse materials while saving costs. With this information, obsolete buildings become a mine of materials.

Research on chemical leasing (Stoughton and Votta 2003), referring to the selling of the function performed by a chemical, is also related to offering *materials as a service*. However, this work has mainly focussed on effective use of chemicals for cleaning and coating purpose in manufacturing (e.g. charging customers by m2 of coated surface rather than Kg of paint). Hence, it does not address the proposed vision to manage material resources throughout the entire supply chain.

7.2.2 Ownership and Business Models

Ownership is the state or fact of exclusive rights and control over property including objects such materials and products, and land, real estate and intellectual property. In traditional business models, the property of objects and the rights over them are exchanged as a result of financial transactions between sellers and buyers. Consumers, for example, buy goods from producers or retailers and as a result own new products. Use and result oriented product-service systems are business models where producers grant consumers access to products or offer consumers the performance of products as experiences. Ownership of products in these business models is retained by producers. Futures have been proposed where business models based on access, not ownership, will become the dominant market offering and the idea of ownership is perceived as old fashion (Rifkin 2000). In a market where consumers are granted access to goods that they feel theirs though they do not legally own them, research has emerged to understand how to design to satisfy psychological ownership using a human centred approach (Baxter et al. 2018, 2015).

In recent reviews of business models for the circular economy and sustainability (Pieroni et al. 2019; Lüdeke-Freund et al. 2019; Bocken et al. 2014), models are reported where access to products is granted by paying-per-use instead of paying per-ownership (i.e. by delivering functionality rather than ownership), but there is no reference to a model where materials are offered as a service.

7.3 Approach

This research is based on literature review and the experience of the authors in the fields of ownership, design, product-service systems, the circular economy and business along with insights gathered during research projects with industrial partners. The paper presents a theoretical exploration of the concept of *materials as a service*. Two scenarios are used to explain how a material-service system would work. In the first scenario we explore its interaction with a product-service system. In the second scenario we review its independent use in the resource lifecycle system.

7.4 The Concept of Material Service System

The concept of MSSs revolves around the fact that the principle to 'pay per use' can be moved up the supply chain. In a MSS, suppliers of materials offer producers the use of material resources through services. MSSs can be thought of as marketable sets of materials and services capable of jointly fulfilling the needs of producers. They offer producers access to the performance of materials, while ownership of resources and corresponding responsibility of material management remains with suppliers. A MSS, therefore, implies a new role for producers, as they shift from consuming, to using material resources, which remain owned by material suppliers. Producers enter a business relationship with suppliers based on a 'pay per use' model rather than traditional purchasing of material resources. In Table 7.1 a MSS is contrasted to a PSS. As it can be seen the fundamental difference between the two models is that in a MSS material suppliers retain ownership of material resources and sell the function of materials, whereas in a PSS producers retain ownerships of produced resources and sell the function of products. It is noteworthy that material suppliers retain ownership of resources, not of the intellectual property resulting from the

Table 7.1 Main differences between a MSS and a PSS

Material service system	Product service system
Material suppliers offer producers the use of materials through services	Producers offer consumers the use of products through services
Marketable set of materials and services capable of jointly fulfilling the needs of producers	Marketable set of products and services capable of jointly fulfilling the needs of consumers
Selling the function of materials	Selling the function of products
Producers enter a business relationship with suppliers based on a ‘pay per use’ model	Consumers enter a business relationship with producers based on a ‘pay per use’ model
Material suppliers retain ownership of the resource	Producers retain ownership of the resource
Ownership of the IP for materials, manufacturing processes and products remains with the inventors	Ownership of the IP for materials, manufacturing processes and products remains with the inventors

downstream transformations made to resources by producers or other stakeholders. Two scenarios are envisaged to deploy a MSS, namely a MSS used in conjunction with a PSS and a MSS used on its own. The scenarios are explored in the next two sections.

7.4.1 *Use of a MSS with a PSS*

A MSS can be operated in conjunction with a PSS, see Fig. 7.1a. In this scenario a material supplier markets *materials as a service* to a producer, and in turn the producer markets products as a service to consumers. Consumers have an obligation to return obsolete products to the producer, while the producer has an obligation to return them

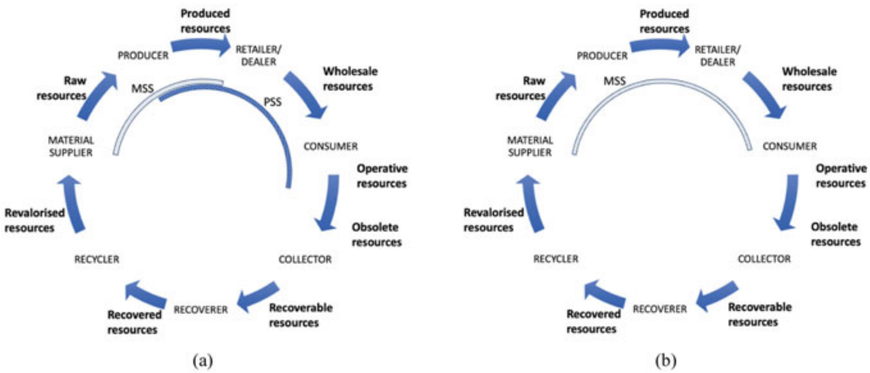

Fig. 7.1 **a** MSS and PSS versus **b** MSS only over the resource lifecycle and stakeholders

to the material supplier. This scenario is now explored using the case of energy storage through lithium-ion batteries. A material supplier of lithium cobalt oxide (i.e. cathode material) or lithium titanium oxide (i.e. anode material) offers to the producer of e-vehicle batteries the possibility to use its *materials as a service*. The material supplier requests that its materials are used on standardised battery designs, which follow predetermined design for disassembly rules. The material supplier also requests that the materials are returned at the end of the contract stipulated with the producer. After entering this contractual agreement, the producer manufactures battery cells, modules and packs for e-vehicle applications thinking carefully about the life of its battery products. The battery producer, conscious of the requirement to return the batteries to the material supplier, offers the batteries to manufacturers and consumers of e-vehicles as a product-service system. This means that consumers lease batteries from the producer and have a requirement to return them to the producer at the end of life as they have to be returned to the material supplier. Depending on the contractual agreement with the material supplier, the producer could decide to keep the batteries longer before returning them to the material supplier for recycling. For instance, the producer could repurpose the batteries for less energy intensive applications or operate a refurbishment service and offer them for appropriate applications.

7.4.2 Independent Use of a MSS

A MSS can also be operated independently of a PSS, see Fig. 7.1b. In this scenario the material supplier markets *materials as a service* to a producer, and the producer markets products to consumers. Consumers, however, have an obligation to return obsolete products to the material supplier. This scenario is now explored using the case of energy storage through lithium-ion batteries. A material supplier sells lithium cobalt oxide or lithium titanium oxide to a producer to manufacture batteries for e-vehicles. The battery producer then markets batteries to manufacturers and consumers of e-vehicles with an obligation to return them to the material supplier at the end of life. The collection or take-back service is, however, offered by the material supplier. In this scenario the battery producer is free from the responsibility to recollect obsolete batteries as this is transferred to the material supplier.

7.4.3 Expected Benefits to the Whole System

Leaving the ownership of resources at the top of the supply chain, MSSs have the potential to allow suppliers to exert more control on the flow of resources and consequently to use resources more efficiently (Allwood et al. 2011), for example, by collaborating closely with collectors, recoverers and recyclers. Specifically, MSSs would allow to reduce the dependency on virgin resources and permit to bring to life the concept of pure and closed resource flows, i.e. less contamination.

7.4.4 Expected Benefits for Material Suppliers

The following benefits and incentives have been identified for material suppliers, see Table 7.2.

Table 7.2 Expected benefits for material suppliers

Benefits and incentives	Description
Ability to *develop long term business relationships with producers*	Retaining customers through new value propositions
Ability to *sustain feedstock*	Sourcing obsolete returned resources rather than finite resources
Ability to *sustain business*	Building business that is based on services and partnerships (McAloone and Pigosso 2018) rather than the single transaction of finite resources
Ability to *exert control on material resources prior and after use*	Controlling flows of material resources similarly to how PSSs take control over product flows
Incentive to ensure that *resources flow uncontaminated* and in high volume to function as feedstock	Motivation and encouragement to exert control on systems across the resource lifecycle, as returning resource flows are seen as creating value (Krikke et al. 2013) and suppliers have a demand for their own used product (Zeeuw van der Laan and Aurisicchio 2019a)
Incentive to *develop a portfolio of material resources that are recyclable* and retain high quality after multiple cycles	Motivation and encouragement to develop materials that perform across multiple successive resource lifecycles
Ability to *react to emergent legislation*	Anticipating emerging legislation which could set tighter targets on the uptake of cycled materials e.g. recycled plastics (Ellen MacArthur Foundation 2019)
Ability to *react to new competition*	Reacting to the emergence of suppliers of recycled materials and suppliers of biodegradable materials
Ability to *lower material development pressure*	Lowering the pressure to develop alternative materials, e.g. biodegradable or compostable materials
Ability to *react to volatile raw material costs*	Reducing the need for and dependency on costly finite resources
Ability to *protect IP*	Protecting IP by retaining ownership of resources

Table 7.3 Expected benefits for producers

Benefits and incentives	Description
Ability to benefit from *material services offered by the supplier*	Repairing, maintaining, replacing or upgrading materials as part of contracted services, and avoiding material disposal taxes
Incentive to *set more ambitious sustainability targets*	Motivation, encouragement and opportunity to set and achieve realistic sustainability targets (Ellen MacArthur Foundation 2019)
Incentive to *design circular products that can be easily disassembled and in which materials remain identifiable*	Motivation and encouragement to design for disassembly to suit the demand of suppliers (Mestre and Cooper 2017)
Incentive to *optimise the time spent with resources*	Motivation and encouragement for lean consumption (Womack and Jones 2005) e.g. timely delivery and collection of obsolete resources from consumers, operating lean disassembly processes and returning obsolete resources to materials suppliers
Ability to lower social pressure	Mitigating the transfer of social pressure from producers to material suppliers

7.4.5 Expected Benefits for Producers

The following benefits and incentives have been identified for producers, see Table 7.3.

7.4.6 Expected Benefits for Consumers

If the time spent with material resources is charged, producers or consumers respectively will have incentives to optimise the time spent with them (Stahel 1982). The incentives include using only what they really need, for the time they need it. Similar to the effect of slowing loops of PSSs (Bocken et al. 2016), resources will consequently be flowing slower as they will become available quicker to consumers e.g. no hibernation of resources.

7.4.7 Expected Enablers of MSSs

A concept such as MMSs would benefit from the following enablers to come to life, see Table 7.4.

Table 7.4 Expected enablers

Enablers	Description
Material identification	Technology and systems to identify materials (Corbin et al. 2018)
Material monitoring	Technology to track and trace materials (Corbin et al. 2018) such as IoT, sensors, blockchain, RFID, etc.
Material processing at the end of life	Technology for sorting, separating, and further purifying materials, for example through chemical recycling (Rahimi and García 2017)
Product design guidelines	Rules on design for disassembly and design for material identification (Mestre and Cooper 2017)
Standardised material portfolio	Standardised materials to optimise revalorisation processing and increase recovered volumes (Prendeville et al. 2014)

7.4.8 Expected Challenges for the Adoption and Implementation of MSSs

The following challenges have been identified for MSSs, see Table 7.5.

7.5 Discussion

At present, material suppliers make business by sourcing, processing and selling virgin material resources extracted from our planet. Producers buy these material resources and manufacture products that are sold to consumers. At the end of product life only a small proportion of these resources are recovered and recycled. PSSs are business models through which producers sell the performance of products. PSSs can help control the flow of material resources as product ownership is shifted from consumers to producers. MSSs depict a future where resource usage is transformed and where business models, design and manufacturing processes, and product value and ownership are redefined compared to both traditional business and PSS models. MSSs have the potential to disrupt the current linear economy by shifting us faster towards a circular economy in which resources are more effectively managed and reliance on new resources is reduced. In particular, MSSs can extend the circular economy as a regenerative system to the material level (as opposed to the component level) contributing to increasing the recycling of technical materials. MSSs can transform the future manufacturing landscape by:

- Introducing new business models and performance offerings. Material suppliers will sell the performance of material resources as a service to producers, who in turn will sell access to products.

Table 7.5 Challenges

Challenges	Description
Suitability of materials	Not all materials will be suitable for this model due to their qualitative properties (Zink and Geyer 2017)
Volume of materials	Available volumes will influence the value of materials in flows
Degradation of materials	Some materials are subject to degradation when recovered. Technology is needed to retain quality. There is a risk that 'secondary' materials come to exist next to 'primary' materials and instead of replacing the need for virgin, and reducing the demand, they create a new market (Zink and Geyer 2017)
Environmental impacts of material revalorisation	Many recycling or recovery processes are energy intensive. There will be critique around choosing material recovery over component recovery (Allwood et al. 2011)
Competing with resource flows at higher utilities	The reuse of products and components typically seems to have a higher economic value than the recovery of materials (Schenkel et al. 2015)
Decontamination of resource flows	The purification of contaminated waste streams of material resources is dependent on technology (Rahimi and García 2017)
Material identity	The current market is producer-led. Materials are anonymous i.e. it is rarely possible to identify which company has supplied a material. The anonymity has advantages for the suppliers, as they cannot easily be blamed. Instead, the blame goes to the producers who put their name and identity on the products that the materials embody. To make MSS work, material suppliers may have to come out of the anonymity and materials be branded
Consumer behaviour	MSSs involve a systematic change with new roles for consumers (Zeeuw van der Laan and Aurisicchio 2019b). Eliciting the required behaviour has been found to be one of the main barriers to adopt PSSs
Dependence on product-service systems	In general, the adoption of PSSs by industry is low due to corporate, cultural and regulatory challenges that require structural systemic changes (Ceschin 2013; Vezzoli et al. 2012)
Circularity performance metrics	Until there is agreement on and adoption of the indicators of material flow and circularity, it will be hard to prove the success of circular business models (Moriguchi 2007; Saidani et al. 2019)

(continued)

Table 7.5 (continued)

Challenges	Description
Viability of business model	There is a need for research to estimate the revenue streams and expenses of the proposed business model. There is also a need for empirical research on the business model and for methods to validate and implement them (Pieroni et al. 2019)
Collaboration and supply chains	There is a need to understand the implications on collaboration and supply chains of the proposed business model. It is in fact possible that MSSs will disrupt existing inter-firm relationships and power dynamics resulting in new collaborative structures or vertical integration
Maintaining the status quo	Politics around material markets that aim to retain current practice for governmental and industrial benefits (Gregson et al. 2015)

- Helping secure material resources. Material suppliers will retain ownership of the materials embodied in products contributing to treating resources as banks; this will be useful to guarantee that material suppliers have their own future supply, and facilitate resource management between material suppliers, producers and consumers.
- Supporting new partnerships. Collaborative production of products and services between suppliers, producers, consumers, collectors, recoverers and recyclers will emerge with the aim to achieve pro-environmental outcomes.
- Propelling the development of a new industrial sector. Robust reverse supply chains have to emerge to recover value from obsolete material resources.
- Incentivising new approaches to material development and product design. Material suppliers have to introduce better recyclable materials and producers have to design products that perform effectively in the whole lifecycle.

7.5.1 Limitations and Future Work

This research has shown how repositioning ownership of material resources has allowed to introduce and explore a novel concept such as material-service systems. The work presented in this paper is based on a theoretical exploration of the concept and its relation to a construct such as product-service systems. Empirical work is necessary to deepen current understanding of material-service systems and shed light on their feasibility and viability.

To advance the concept of MSSs it would be beneficial to work in collaboration with industrial organisations including material suppliers, producers, collectors, recoverers and recyclers. Specifically, there is a need to identify what material and product types are more likely to benefit from MSSs; demonstrate the feasibility of

MSSs as new business models for materials that need circular management; map and address the technical, social and business challenges posed by resources in supply chains based on MSSs; and understand how MSSs would disrupt current business models and supply chains.

7.6 Conclusions

MSSs introduce new business models, in which material suppliers sell material performance as a service to producers, who, in turn, sell access to products to consumers. MSSs can help secure resources as material suppliers retain ownership of the materials embodied in products contributing to treating resources as banks and guaranteeing a future supply. MSSs have the potential to contribute to a paradigm shift in existing thinking about material resource management, leading to new and disruptive business models and accelerating the shift towards a structural change in consumption systems for a circular economy. Research on MSSs is ambitious and risky, but it has high potential to produce findings that could be transformative for industrial ecology and our society.

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