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Impacts, synergies, and rebound effects arising in combinations of Product-Service Systems (PSS) and circularity strategies

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Abstract

Product-Service Systems (PSS) are potentially the pivotal enablers of the Circular Economy (CE), a promising approach towards sustainable development. Yet, in practice, and when not designed mindfully, the development of PSS can result in limited benefits to the triple-bottom-line of sustainability for a manufacturing company, not least due to the sub-par return on investment or socio-environmental rebound effects (RE) caused by negligent product use or lower customer acceptance. Approaching sustainability through CE requires systemic and concurrent consideration of multiple circularity strategies during PSS design. However, existing research predominantly focuses on isolated circularity strategies rather than bundling them together to achieve super-additive effects. This article explores the impacts, synergies, and RE arising in different combinations of PSS types and circularity strategies in the early design stages. The findings stem from the state-of-the-art literature review, followed by a three-step analysis that utilises the Business, Environmental, and Social Screening Tool (BESST) for PSS and the Rebound Effect Framework (REF) to discern seven identified configurations of PSS and circularity strategies in a capital good manufacturing company.

Keywords: circular economy; circularity strategy; product-service system; business model; rebound effects

1. Introduction

Circular Economy (CE), as opposed to the current linear ('take-make-use-dispose') economic system, is considered one of the crucial approaches to contribute to sustainable development [1,2] The transition to CE in which economic growth is decoupled from virgin resource consumption has become one of the principal initiatives for reaching the 2030 sustainability targets in Europe [3]. This decoupling can be achieved with the application of CE strategies [2]. Several CE strategies can be used individually or in combination with each other to reduce the consumption of natural resources and contribute to circularity, such as refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover [4,5]. However, environmental burdens are not automatically achieved by the utilisation of CE strategies, as discussed in the existing literature [6,7].

Out of the listed strategies, product-service systems (PSS) which fall under the 'rethink' CE strategy are considered a primary means of changing the current economic system [8]. PSS are life cycle-oriented and marketable combinations of products and services supported by the infrastructure and the network of actors, designed to deliver more value than traditional product sales [9] PSS show great potential to positively impact the triple-bottom-line (TBL) of sustainability [9,10] but are not by default more sustainable than the sole product [11]. Therefore, their impacts must be considered from a systemic perspective already in the early design stages [10].

In literature, the CE strategies (including PSS) and their impacts are often considered individually, and their combinations remain unexplored [12], even though there is evidence that the combinations of CE strategies can help companies achieve higher levels of circularity and resilience during crises [13].

Despite several contributions aiming to support the creation of CE business models (see e.g., [14,15]), there are only initial attempts in the literature to explore CE strategy combinations and their impacts. Multiple retrospective case studies with nine existing companies have been conducted to map how different types of PSS relate to different circular strategies [16]. Another

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case study has been conducted to identify and analyse CE strategy combinations and the role of PSS in the case of Riversimple, a mobility-as-a-company, using the Circularity Compass [17]. Both articles provided invaluable insight into different combinations but with hindsight, in an ex-post analysis of existing solutions. However, scarce attention in the literature has been given to the consideration of the TBL impact of different combinations of CE strategies and PSS in the early design stages of circular PSS offerings [18].

Furthermore, there is a gap in the literature to observe what are the synergies and antagonisms that stem from different CE strategy combinations, i.e., how the concurrent utilisation of two or more strategies can yield super-additive effects and what rebound effects (RE) can they possibly induce together. RE happen due to behavioural or a systemic response in which the actual impact savings of an intended initiative are smaller than anticipated [19]. RE manifest in many shapes and forms, moreover, they can be initiated by various actors, across many levels and types - which makes them hard to identify and measure [20]. There is a limited understanding of the occurrence of RE in the context of CE and PSS in the literature [20], and options to mitigate their impact without various CE strategies are underexplored [21].

This research sets out to explore how to support manufacturing companies in the consideration of different combinations of CE strategies and PSS types in the early stages of design, a priori to the deployment of the offering in the market. The ex-ante consideration is deemed important as research shows that a company's environmental awareness has a pivotal role in the contribution of PSS to circularity [22]. Therefore, the primary focus of this research is the identification of combinations' impact, synergies, and potential RE through the analysis with the existing tools.

2. Methodology

This research is exploratory and has been conducted in collaboration with a single-case capital goods manufacturer in the food processing industry. This case company has been selected because: (i) it is considered typical of many other equipment manufacturers, (ii) of the availability of decision makers to provide input, (iii) it is at an early stage of PSS design, and (iv) of authors' connections through previous action research [23,24]. The selected company hopes that PSS would positively contribute to their TBL strategy, and therefore, they articulated the need to systematically assess impact, synergies, and possible RE in different combinations of CE strategies and PSS.

The actions in this research have been structured in four main steps: (1) preliminary literature review, (2) selection of configurations of PSS and CE strategies deemed feasible for further analysis in collaboration with the case company, (3) the expert analysis of TBL impact (positive and negative) of the selected seven configurations, and (4) the expert analysis of the synergies and possible RE for the selected configurations.

Step 1. Building on the previous systematic literature review conducted by the authors [20] a further review was executed using the Scopus database which targeted the following keywords and their synonyms: product-service system, circularity strategy, and RE. The literature review aimed to study the state-of-the-art literature on combinations of different CE strategies with PSS and potential RE. The most relevant articles were selected due to their comprehensiveness and sharp focus on the combinations of CE strategies and were summarised in the Introduction.

Step 2. The selection of configurations, i.e., the combinations of different CE strategies that might go well together was conducted by using an adapted version of the Framework for analysing the relationship between CE strategies (listed in the Introduction) and PSS types [16], where the eight PSS types are defined based on Tukker [25]. This framework was used to select seven configurations of CE strategies for further analysis.

Step 3. Upon the selection, seven configurations were designed and screened to find the drivers of positive and negative impact on the TBL. The screening was done employing the Business, Environmental, and Social Screening Tool (BESST) [23]. BESST is a comprehensive screening tool constructed to address the relevant aspects that were missing in the existing tools beforehand, such as the complete view of the TBL, PSS elements, life cycle stages and value (Fig. 1.). The tool enables practitioners to anatomise the configuration into 36 data points (smaller dice) to get a clear picture of where the most significant positive and negative impacts (hotspots) occur.

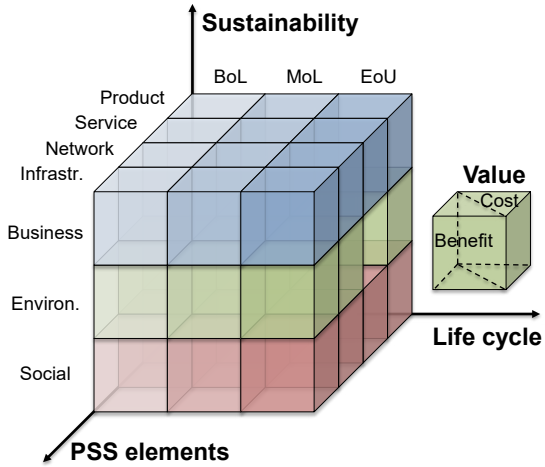

Fig. 1. BESST [23].

Step 4. The configurations were further analysed to map out synergies and RE between different combinations of CE strategies. This analysis builds on the previous two steps and uses the Rebound Effect Framework (REF) [20] to identify triggers, drivers, and mechanisms (Fig. 2). This framework was chosen due to its strong theoretical background and holistic focus on RE stemming from a systematic literature review.

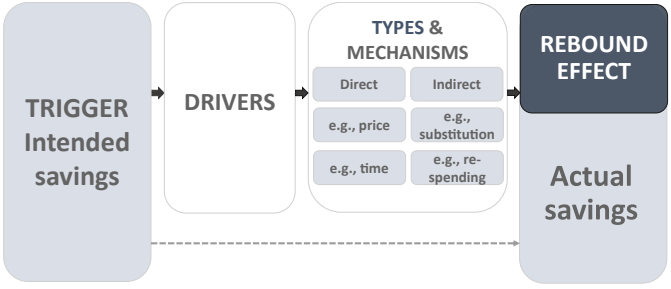

Fig. 2. REF [20].

3. Configurations selection

The selected configurations of PSS types and CE strategies can be seen in Fig. 3. Each of the seven configurations is showcased with a distinct hatching pattern and colour. There are many possible combinations of CE strategies and PSS types, and they might overlap. In practice, a company would often simultaneously run several configurations to satisfy the needs of different customer segments [16].

The case company prefers to use two of the CE strategies in several configurations, namely 'reduce' and 'repair & maintain', while almost all the PSS types apart from product pooling appear to be feasible. Pooling is not considered feasible in the industry where the case company operates (food processing) because of the hygienic and trade secret restrictions that would be violated if the product is used simultaneously by several users.

The CE strategies 'refuse', 'recycle', and 'recover' have been left out of the analysis because they were deemed unfeasible from the case company's perspective. The 'refuse' strategy in which the function should be delivered by a radically different product or technology (e.g., replacing DVDs with streaming services) was not deemed realistic at this point and in the context of the case company. Finally, the 'recycle' and 'recover' strategies were considered beyond the scope of the foreseeable future initiatives.

The 'upgrade' strategy[16]was considered particularly promising in this case due to its potential to have a significant impact on the TBL of the large installed base of products.

			Circular strategies							
			Smarter product use and manufacture		**Extend lifespan of a product and its parts**					
			Rethink	**Reduce**	**Upgrade**	**Reuse**	**Repair & maintain**	**Refurbish**	**Re-manufact.**	**Repurpose**
			Use multi-functional products, more intense use of product's capacity	Increase efficiency by using fewer resources & energy in manuf. and use	Improving product function with respect to previous one	Product in good function, use in original function by new user	Correct defective part to return it to its original function	Return worn part or product to satisfactory working condition	Return worn part or product to original specification	Use a part of product in a new product with different function
PSS types	**Product-oriented**	Product related service (e.g., inspection contract)								
		Product related advice (e.g., monitor. & training)								
	Use-oriented	Product lease								
		Product sharing/renting								
		Product pooling								
	Result-oriented	Pay per service unit (e.g., €/h or €/kg)								
		Outsourcing/activity management								
		Functional result (e.g., X€/job)								

Fig. 3. Configuration based on PSS types, accompanied by a combination of different CE strategies. Seven configurations are represented with a distinct hatching pattern and colour. Framework adapted from [16].

4. Configurations analysis with the BESST

The seven identified configurations have been analysed using the BESST (shown in Fig. 4 together with descriptions of configurations). For each of the configurations, positive and negative hotspots have been identified and coded according to the dice where they occur (e.g., Business-MoL-Service, where MoL stands for 'Middle-of-Life') in the BESST to get a clearer picture of the benefits and criticalities that accompany each configuration. For example, in the first configuration (blue hatching), 'product related service' is combined with 'reduce' and 'repair & maintain'. In practice, the product is sold to a customer together with a time-limited maintenance contract that can include periodical inspections of wearable and consumable parts by the providers, recommendations and sales of spare parts and the actual repair should the product break. These preventive actions help ensure greater product availability due to timely maintenance and smoother (e.g., properly lubricated) operation that consumes less energy and produces less scrap and excess heat. The benefits (positive hotspots) and costs (negative hotspots) of such a configuration mostly manifest in the MoL of the offering. The benefits materialise through an additional revenue stream from the provider (business), less energy use and longer life (environment), and more customer touchpoints (social) because of more frequent interaction about maintenance and spare parts which creates a stronger relationship. While the costs manifest through risks taken over by the provider, where the price and the timing of a possible repair intervention at customers' sites are difficult to predict (business). More travel is required due to the inspection visits which can have a significant environmental impact (environment). There is also a possibility of a loss of technician jobs at the customer, as the provider takes over maintenance and repair activities (social).

Config.	Configuration description	Positive hotspots (benefits)		Negative hotspots (costs)	
		Coord. (BESST)	Description of main benefits	Coord. (BESST)	Description of main costs
1.	Sell products and time-limited contracts incl. repair, maintenance, and spare parts to ensure greater product availability, and optimal operation and energy use. Benefits and costs both manifest mainly in MoL due to increased service activities.	Business-MoL-Service	Additional revenue stream	Business-MoL-Service	Risk of variable costs
		Environ.-MoL-Service	Less energy use, prolonged life	Environ.- MoL-Service	More travel, i.e. pollution
		Social-MoL-Service	More customer touchpoints	Social-MoL-Network	Loss of internal service jobs at the customer
2.	Sell products and monitoring equipment to get data about product use. Provide advice, training, updates, and upgrades based on data. Benefits manifest through increased knowledge sharing and data-based actions. Cost incur in mainly in BoL to establish the monitoring infrastructure and acquire data analytics capabilities.	Business-MoL-Infrastr.	Getting use insights for future development	Business-BoL-Infrastr.	Cost of monitoring equipment
		Environ.-MoL-Product	Enable optimised use due to monitoring	Environ.-MoL-Infrastr	More energy spent on monitoring
		Social-MoL-Network	Trained personel at customers	Social-MoL-Network	Customers afraid to share data
3.	Lease product and take responsibility for monitoring, preventive maintenance and repair. Benefits similar to the above configurations, but also evident through stable subscription revenue over time. However, costs and risks are introduced with additional responsibility as well as investment into product ownership retention.	Business-MoL-Service	Predictable, recurring revenue	Business-BoL-Product	Cost of ownership retention
		Environ.-BoL-Product	More intensive use by the customer to make the most of the lease	Environ.-BoL-Product	Building more material intensive (robust) product
		Social-MoL-Service	Less injuries because professionals do the service	Social-MoL-Network	Intensity of work increases for service employees
4.	Repeatedly rent several products. Restore the products and their parts between the rents. Benefits manifest through the flexibility of offering in terms of scalable capacities when needed, new markets, and lower access bar. Costs incurred due to increased logistics and initial infrastructure investments to handle the more frequent turnover of products.	Business-BoL-Network	New markets open for smaller customers or seasonal production	Business-BoL-Infrastr.	Build additional storage, workshops and tools
		Environ.-MoL-Infrastr.	Infrastructure can be shared for many products.	Environ.-EoL-Service	Increased logistics operations
		Social-BoL-Network	Lowering access bar for customers	Social-EoL-Network	Hygienic challenges when changing users
5.	Instal products at a customer and charge according to the use level. Take responsibility for monitoring and preventive maintenance and repair. Many shared benefits with config 3. Moreover, benefits through the ability to streamline product operation according to customer needs and ensure customer lock-in. Costs due to the complexity of monitoring and pricing schemes, and difficult to predict earnings.	Business-MoL-Service	Recurring revenue	Business-MoL-Service	Difficult to predict revenue
		Environ.-MoL-Service	Streamlined product operation	Environ.-MoL-Service	More service operations to keep the product running optimally
		Social-MoL-Network	Longer lasting relationships	Social-MoL-Network	Possible lack of trust from customers due to feeling of being surveilled
6.	Find third-party service providers to cover upgrades, repair, refurbishment, and remanufacturing. Benefits due to rapid increase in market share coverage through partnership and opportunities to gain insights into more customer operations. Costs due to increased relationship management and possible distancing from customers because of the third party in between.	Business-BoL-Network	Secure more projects because of expanded capabilities	Business-MoL-Service	Losing a part of the service business
		Environ.-EoL-Product	Use products and parts that would otherwise go to waste	Environ.-MoL-Network	More pollution due to inefficiency in ecosystem coordination
		Social-BoL-Network	Form external partnerships and get knowledge from them	Social-MoL-Network	Burden of partnership coordination
7.	Agreement to deliver a result to the customer, regardless of the product used. Benefits stem from a high level of offering customisation which enables higher margins. Costs can incur due to unforeseen overheads, risks and and increase in responsibilities to deliver the total solution on time.	Business-MoL-Service	The highest profit margins	Business-BoL-Infrastr.	Large initial investment to ensure product performance
		Environ.-MoL-Product	Flexibility to combine less impactful modes to get results	Environ.-BoL-Infrastr.	All the infrastructure to support (many) offerings has to be built
		Social-BoL-Network	Eliminated unnecessary communication with customers	Social-MoL-Network	Stressful for employees due to expected performance

Fig. 4. Analysis summary of the seven configurations using the BESST. BoL stands for the 'Beginning-of-Life' and EoU stands for 'End-of-Use'.

5. Synergies and RE in different configurations

The seven configurations were further analysed using REF to map synergies and RE of PSS types and CE strategies (Fig. 5).

Config.		Synergies	Rebound effects		
			Triggers	Drivers	Mechanisms
1.		Timely maintenance and repair can increase product availability and less energy when worn parts are quickly replaced.	- Increase in resource efficiency - Decrease in energy use	- Increase in profits - Increase in interaction with customers - Easier access to spare parts	- Output - selling more spare parts, even when not needed, because of more frequent interaction with customers
2.		Leveraging technologies (IoT) to be closer to customers and empower them through training	- Increase in resource efficiency - Innovation and Investment - Data based improvement	- Increase in profits - Information accessibility - Time savings	- Re-investing into data collection, advice and training – possible data breaches disturbing the competitive advantage
3.		Incentive to design sturdier machines because the ownership is retained and salvage value should be as high as possible.	- Increase in resource conservation - Increase in resource and product utilization	- Convenience - Easier access to repair and maintenance - Time savings - No obligation of ownership	- Motivational - careless use because the machine is not owned by the customer
4.		Bigger machine changeover can enable builing a stock and processes for refurbish, remanufacture and repurpose	- Increase in product and resource utilization - Increase in resource efficiency	- Convenience - Time savings - More often access to machines	- Substitution to more transportation, as well as installation and comissioning operations overpowerring the benefits achieved with renting
5.		Incentive to design easy-to-use and easy-to-service products to save time and money on service visits.	- Increase in efficiency - Increase in product and resource utilization	- Time saving - Convenience - Cost savings	- Substitution to having an underustilised machine that is rarely turned on by the customer
6.		Possibe to offer a wider portfolio of services in collaboration with external partners.	- Increase in resource efficiency - Increase in product and resource utilization	- Time savings - Convenience - Cost savings - More often access to machines	- Substitution - thrid party providers can cannibalise on own business
7.		A possibility to truly decouple value creation from resource consumption, especially when providing the offering to many customers and suporting it with the same network and infrastructure.	- Increase in resource efficiency - Increase in resource conservation - Increase in resource and product utilization	- Convenience and flexibility - Time savings	- Re-investing - significant underestimation possible in terms of the costs of running such solutions

Fig. 5. Analysis summary of the seven configurations using the REF [20].

In the first configuration, a synergy can be observed between the product-oriented PSS and the two CE strategies, as they are mutually reinforced. Preventive maintenance and repair can positively impact the product's efficiency in operation both with respect to energy use and more effective uptime in terms of performance and quality of the product's output. Further, the consolidated analysis using the REF highlights the interrelationships of possible RE and helps to identify triggers, drivers and mechanisms as the most important aspects of RE. The most prominent triggers were connected to the overall goal of a configuration considering both PSS type and the selected CE strategies, i.e., increase in resource efficiency and decrease in energy use. Further, the possible drivers explain how those triggers are driven to a certain mechanism contributing to overall RE (e.g., increase in profit, increase in interactions with customers, easier access to spare parts). Considering the mentioned triggers and drivers, possible mechanisms occurring can be noted as output mechanisms where the company can sell more spare parts when they are not actually needed to increase profit, due to e.g., more frequent interactions with a customer. This mechanism can be mapped as a causal loop which feedbacks back to the overall goal and possibly reduces the intended resource efficiency and/or increases the energy use.

6. Discussion

The use of the Framework for analysing the relationship of CE strategies and PSS types, the BESST and REF in a sequence provided a relatively quick but exhaustive way to formulate different configurations and analyse their impacts (benefits and costs), synergies, and RE already in the early stages of design for the case company. Given that a method to do such an analysis has not been found in the extant literature, and was needed by the industry, the authors believe that an important knowledge gap has been bridged by this proposal. The identification of the benefit and cost drivers and gauging of their significance is the first step towards a decision to select configurations to develop further, as it can help in painting a clearer picture of their TBL impact. A manufacturing company can, according to the above analysis, consider ways to further strengthen the identified synergies and mitigate RE. In the example of the first configuration, both can be achieved with a careful definition of the maintenance contract, by detailing the specific actions and responsibilities of both parties targeted to achieving e.g., greater energy efficiency. In that way, more clarity can be achieved concerning the influence of individual actions that service technicians execute during a service visit, and greater transparency can be ensured with respect to spare parts sales.

Based on the application of the BESST and REF, the first three configurations have a solid short-term TBL potential and a clearer picture of their mainly direct RE. Configurations 5 and 7, in turn, are considered to have the

greatest long-term TBL potential. However, those are also the riskiest configurations due to the uncertainty of the impact of their primarily indirect RE, which are not researched well enough in the literature.

7. Conclusion

Rather than applying CE strategies individually, manufacturing companies have a much better chance of increasing their TBL sustainability and building resilience by combining them and studying their influence systemically since the early stages of design. Relatively meagre research exists to explore the impacts, synergies, and RE of such combinations, which is primarily focused on a hindsight analysis. This research proposes the application of the BESST and REF for an ex-ante analysis of seven configurations that include different PSS types and CE strategies in a single manufacturing company. The analysis provides a quick but exhaustive insight into benefit and cost drivers for each of the configurations, as well as their synergies and RE that can serve manufacturing companies as a support for decision-making and RE mitigation.

The study is limited to a single case capital goods manufacturing company operating in the business-to-business segment, thus hindering generalisable conclusions. The selection of CE strategies was also narrowed down in the initial selection, thus leaving out some strategies from the investigation (‘refuse’, ‘recycle’, and ‘recover’).

Further research includes the application of the BESST and REF in more cases, to be able to draw more general conclusions. Additionally, it should be investigated which configurations can go well together so that the manufacturers can provide a whole portfolio of configurations to customers at the lowest cost and the highest benefit because of their synergies and avoided RE.

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