9th International Conference on Mass Customization and Personalization – Community of Europe (MCP - CE 2020)
Re-innovating Business in the Digital Era
September 23-25, 2020, Novi Sad, Serbia

PRODUCT-SERVICE SYSTEMS AS AN ECONOMICAL SOLUTION TO IMPROVE THE SUSTAINABILITY OF PRODUCTS

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Abstract: *Todays customers have an increasing interest on the sustainability of the products they purchase. In order to full fill this customer demand many business look into new ways to design their products to balance the sustainability required by the customers and increasing value for their shareholders. These factors are usually viewed as conflicting points, which in most cases leads to the result that sustainability is only considered to the bare minimum necessary. In order to solve this different business models have to be considered in which shareholder value and sustainability are not conflicting. Product-service systems (PSS) are considered as a possible solution to provide economical and sustainable solutions. As a means to evaluate these PSS, life cycle cost (LCC) analysis and life cycle assesment (LCA) are used to evaluate the economic viability and the sustainability respectively. While LCA showcases the positive impact PSS have on sustainability the results are not enough to convince decision makers. Therefore this paper uses LCC analysis focusing on the aspects of maintenance and fleet utilization and how cost reductions in these areas also benefit a products sustainability. With this it is possible to show the economic and sustainability advantages of PSS over conventional products.*

Key Words: ***Product-service systems, life cycle costing, life cycle analysis, Sustainability***

1. INTRODUCTION

In recent years the consumer demand for environmentally sustainable products has been steadily increasing [1]. Additionally many countries have put legislative measures in place to ensure that companies conduct their business in an environmentally sustainable manner. An example for this would be the emissions trading system implemented by the European Union, which incentivizes reducing greenhouse gas emissions. But since all these factors are extrinsic in nature companies are not incentivized to exceed the requirements given to them. Due to the fact that a companies main objective is to generate value for its shareholders.

Therefore significant amount of research has been conducted towards changing the current consumption based economy to something more suitable for environmental sustainability. Currently there are two major ideas that are discussed with regards to their potentially beneficial impact on the environmental sustainability. One of them is the sharing economy in which the ownership of a product is no longer sold but the access to the product [2, 3]. A prominent example for this would be car sharing services which have been increasing in availability over recent years. The positive environmental impact is mainly attributed to that fact that less products overall are necessary to allow access to more consumers [2, 4]. The other one is the concept of the circular economy in which products are usually designed in a way to decrease necessary resource input, improved maintainability and repairability and reuse recycling and refurbishment schemes [5]. With this they aim to decrease the overall resource use required to maintain the system and therefore increase the environmental sustainability [5, 6]. When evaluating case studies many authors come to the conclusion that for the implementation of circular economy concepts an extrinsic regulatory push is necessary to create the necessary economic incentive, which would lead companies to implement them [7, 8]. Therefore finding a business model that does not rely on extrinsic stimuli to encourage ecologically sustainable choices is important to encouraging the implementation of circular economy concepts. One such business model that has recently been in the focus of research as an enabler towards a more environmentally sustainable economy is the product-service system (PSS) [9–12]. This research usually is investigating the positive environmental impact that can be achieved through the use of PSS business models and how these have to be laid out [10, 13]. Depending on the structure of the PSS there can be a greater overlap in economic and environmental interests due to the fact that the ownership of the product does not transfer as it usually would in a traditional sale. But in spite of this there is no wide spread implementation of PSS [14]. A probable explanation is that the economic benefits of implementing a PSS over a conventional product is not clear. Therefore this paper will propose an approach on how to evaluate the economic advantage a PSS might have over a conventional product, while keeping in mind that the final PSS should also have a lower environmental impact.

2. RESEARCH BACKGROUND

The following section will aims to explain the concept of a PSS and how they can be classified so that meaningful constraints can be made towards which area of PSS is focused on. Furthermore the concept of sustainability explained with its three major aspects as to avoid misunderstandings how sustainability is considered in this Paper. Lastly the methods of LCA and LCC, which are already in use, are explained to show how they can be used and where their shortcomings may be with regards to the aims of this paper.

2.1. Product-Service Systems

Product-service systems are business models which not just focus on the sale of product but also combine these products with associated services or even forego the sale of the physical product entirely and instead sell access or the results of using the product. Thus these PSS can be surmised a s a combination of products, services, infrastructure and supporting networks [15, 16]. While all PSS share these components the degree to which they are utilised can be used to classify different types of PSS. This has been done by Tukker who differentiated different types of PSS based on their different levels of service integration [17, 18]. On the one hand there are the conventional products which are sold to the consumer and on the other hand services, with everything in between falling into the category of PSS. As shown in Figure 1. Tukker divided them into three distinct areas which he calls the "Product oriented", "Use oriented" and the "Result oriented" business models.

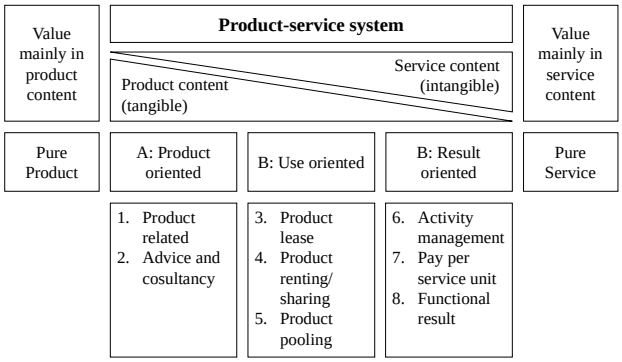

Fig. 1. *PSS Classification [17]*

Below these three main categories of PSS he defines eight more specific PSS in subcategories assigned to these [17]. In the product oriented category there is still a transfer of ownership between the PSS operator and the customer and the services are only supplementary. Use oriented PSS are where the traditional sale of products is no longer an objective and the product ownership remains with the PSS operator. The product is then made available to customers for limited times. Third is the category of result oriented PSS in which only a result is agreed upon and not a predetermined product that will be used to achieved said result [17]. But there are also other researchers that suggest the scope of the subcategories described by Tukker are not comprehensively able to describe all possible PSS. Therefor Tan has described PSS as a combination of seven strategic characteristics that can take different form depending on the PSS [19]. These strategic characteristics are: orientation of benefit, transfer of ownership, responsibility during use, management of life cycle activities, availability of offering, expansion of benefits and basis of economic value. While these allows for different combinations of characteristics then described by Tukker, it also shows that they can still be aligned with the tree main categories proposed by Tukker. Because for each of the strategic characteristic there is a finite number of general principles that can be employed, for example transfer of ownership can either be carried out or not. The further focus of this paper will be on use oriented and result oriented PSS where not transfer of ownership takes places and the PSS operator retains ownership of the product. This is due to the fact that many sources that investigate the environmental sustainability of PSS often focus in this area as well [9, 10, 14, 20].

2.2. Sustainability

As a concept, sustainability was introduced in 1987 by the World Commission of Environment and Development in the *Brundtland Report*: "Sustainability is the development which meets the needs of the present without compromising the ability of future generations to meet their own needs" [21].

Since this is a far reaching and abstract concept, the Triple Bottom Line and the Three Pillar Model break it down into the dimensions economic (profits), enviropnmental (planet) and social sustainability (people) [22].Thereby, economic sutainability puts the focus on the question whether resources are used in an efficient and responsible way to enable long-term competitive advantages. Enviromental sustainability adds the perspective how the consumption of resources results in environmental impacts, e.g. energy use, emissions and waste. Social sustainability is concerned with ensuring the well-being of the people involved in an organisation (internally and externally), e.g. by improving working conditions, equality and health.

The implementation of sustainability in production, or more generally in a business model, is possible by following three strategies [23]: (1) Efficiency means the improvement of resource performance and usage, e.g. the reduction of environmental damage by optimizing production. (2) Consistency targets on circular approaches where unwanted outputs can be used as input for other value leveraging activities or reuse of resources is emphasized. (3) Sufficiency means a more fundamental change in the consuption behavior, e.g. towards a sharing economy [3], where innovative business models are necessary [24].

2.3. Life Cycle Assessment

According to ISO 14044 life cycle assessment (LCA) is defined as method which is meant to evaluate the environmental aspects and impacts of a product over its entire life cycle spanning from gathering of the required resources until its eventual disposal, also known as cradle to grave [25, 26].

The method of LCA contains four major phases:

1. Defining the goal and scope.
2. Inventory analysis.
3. Impact assessment.
4. Interpretation.

In phase one a goal and the target group of the analysis are defined, as well as the functional unit to be analysed and its intended function. Furthermore the boundaries of the system have to be defined to determine which parts of the process have to be included. A method for estimations of impacts und the relevant impact. Additionally the datatypes and sources for this analysis have to be identified and requirements for their quality have to be set. Lastly in case of a comparative study the comparability of the two systems has to be established and the aspects of critical discussion. The second phase inventory analysis is there to determine all internal flows between the process modules within the system and the input and output from the system to the environment. For this flowcharts can be used as a visual aid [26]. The data used must be limited to the functional unit and the goal defined in the previous phase. Phase number three is where the results from phase two are assigned to impacts categories and then these are, using impact indicators, assessed with regards to their environmental impact. In the last phase it is evaluated which kind of issues the results of the other steps might indicate. But it also contains an evaluation of the analysis performing sensitivity and consistency analysis. Thereafter giving a final conclusion, mentioning the analysis limitations as well as recommendations if possible. With this it is evident that the result of the LCA are only useful when assessing the environmental impact of a PSS. While some of data that is collected might also be useful for assessing the economic sustainability, the method over all is clearly not.

2.4. Life Cycle Cost

Life cycle cost (LCC) was initially developed for decision support in the US Department of Defence when making procurement decisions and remains in use until today [27]. But today's usage of LCC as a measurements for economic costs of a product over its entire lifetime hast expanded. For example it is now used for a variety of different products and use cases [28]. In some cases it is used to support the tasks of portfolio managers or product developers for an early assessment of LCC during product development [29, 30]. LCC is also prevalent in the construction industry [31–33]. There are also industrial norms written on how to calculate LCC with the IEC 60050-191:2014 describing general approach towards LCC allowing the reader to gaining a general understanding on life cycle costs and different methods to determine them. Due to the fact that these methods are not very specific it is necessary to adapt them to each use case as required. The models developed for the construction industry focus on immovable assets, since this is not predetermined in the case of PSS the IEC 60050-191:2014 is cannot be directly applied. But there are already models that focus on PSS particularly on use and result oriented version. One of these is the model developed by Johannknecht [34, 35]. Johannknecht divides the lifecycle costs into two distinct areas: capital expenditure (capex) which are mainly the initial production costs and operational expenditures (opex) which are the costs occurring during operation like material costs, labour costs and third-party costs [29]. As shown in Figure 1, these costs are then further divided into wear parts, consumable parts, maintenance, repairs, external repairs and external inspections.

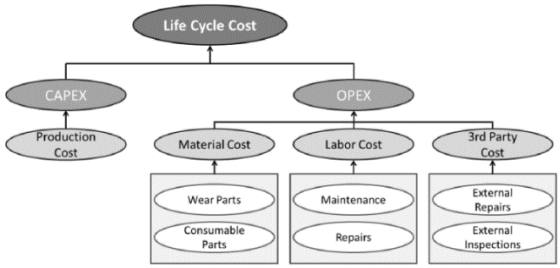

Fig. 2. *LCC composition [29]*

The LCC of the product is then calculated as: The sum of capital expenditure plus operational expenditure, times the total time of use. For the calculation of the six components the following equations are defined by [36]:

$$Wear\ Parts = \sum_{component\ x=1}^{component\ n} \frac{Costs\ of\ individual\ component\ x}{Estimated\ lifetime\ of\ component\ x} \quad (1)$$

$$Consumable\ Parts = \sum_{component\ x=1}^{component\ n} \frac{Costs\ of\ individual\ omponent\ x}{replacement\ intervall\ of\ component\ x} \quad (2)$$

$$Maintenance = \sum_{component\ x=1}^{component\ n} \frac{Time\ for\ maintenance * labour\ cost}{maintenance\ intervall\ of\ component\ x} \quad (3)$$

$$Repairs = \sum_{component\ x=1}^{component\ n} \frac{Time\ for\ repair * quantity * labour\ cost}{repair\ intervall\ of\ component\ x} \quad (4)$$

$$External\ Repairs = \sum_{component\ x=1}^{component\ n} \frac{Costs\ for\ external\ repair\ of\ component\ x}{repair\ intervall\ of\ component\ x} \quad (5)$$

$$External\ Inspections = \sum_{component\ x=1}^{component\ n} \frac{external\ inspection\ cost\ of\ component\ x}{maintenance\ intervall\ of\ component\ x}. \quad (6)$$

Because all equations are component specific, it is possible to calculate the operational expenditures for the complete product and the operational expenditures on a component level. With this information this method enables more than a comparison of entire product designs; it identifies cost drivers enabling the targeted planning of cost-reduction measures [34]. These LCC structures are taken into consideration when comparing the LCC of a PSS with those of a conventional product to determine the economic advantage that a PSS might provide.

3. PROPOSED APPROACH

When the economic advantage of a product is determined in this paper it is always done from the side of the PSS operator. Since this way only the costs that are actually incurred by the company are taken into consideration. This means that the LCC of a PSS have to be compared to the prime costs of a conventional product. With this in mind it would make it exceptionally difficult to have a PSS with lower total LCC than the prime costs of a traditional product. For example if a car manufacturer had the choice between selling the car he manufactured directly to the customer and renting the car to consumers as a PSS. He would have to incur the prime costs in both cases but in case of the PSS he would also have to pay for

operation of the service as well as the repair and maintenance of the product to ensure availability to the customers. If this were the only difference between PSS and traditional products they would be economically unsustainable and thus see no use at all. But the revenue structures of a PSS are different as well allowing for the possibility that the overall profits can be greater as well. Therefore when comparing the economic advantages of a PSS and a conventional product their profits for the entire time in which the operator (manufacturer) retains ownership of the product. Additionally there needs to be a consideration with regards to the risk that is involved with generating the revenue. With conventional products the product is only sold once and therefore it is always the entire revenue that is lost but the chance for loss is not as frequent. With PSS the individual cash flows are typically not as large but they have to occur multiple times in order for the PSS to generate enough revenue to balance its cost. From this the method show in Figure 3 can be derived consisting of five distinct phases.

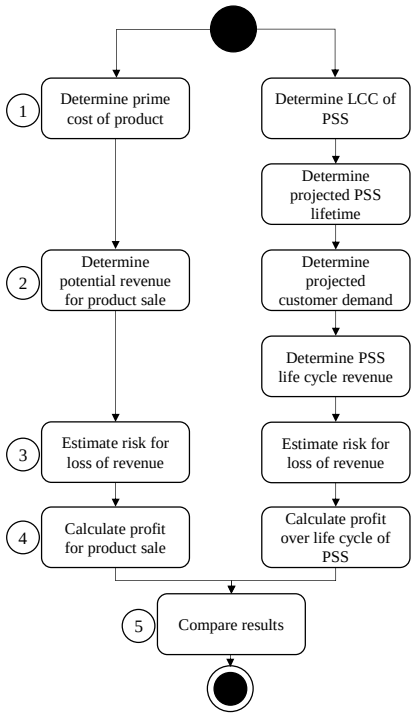

Fig. 3. *PSS economic evaluation method*

Phase 1: Phase one can be completed by calculating the prime costs for the traditional product and by using the methods described in section 2.3. to calculate the initial investment that has to be taken to create the PSS and its ongoing expenses during its operation.

Phase 2: In the second phase the potential revenue has to be determined for both. While determining the potential revenue possible for traditional product based on market research and using product demand functions to determine a realistically achievable market price for the product. For the PSS it is important to first look at the potential time that the product used to provide the service can stay in use. Because a product that can be used over a longer time is preferable. This is based in the fact that the longer a product can be used the higher its profits will be since there is an initial stage where the PSS is generating less profit since it has to balance the initial investment to acquire the product used to provide the service. Whit this in mind it is at least equally important to generate scenarios of customer demand over time to determine whether or not the service will be bought by customer during the time the product is available to the PSS operator. While generating these scenarios it is especially important to consider if there is going to be a seasonality to the customer demand or other fluctuations in demand that could lead towards an inconsistent generation of revenue. Also here is where one of the advantage of a PSS lies since the revenue necessary to make a PSS profitable can be generated over a longer time period the individual price for the sale can be lower than the costs of the product used to provide the service. This can open up a whole no area of potential customers since the financial barrier to use of the product is in many cases considerably lower than the cost to buy and own the product for one self. Also once a customer has used a PSS for the first time there are certain switching cost associated with using a competitor's product or PSS instead. Thus giving an advantage to PSS operators once an initial sale was made. Lastly the PSS lifetime and the potential sales over its lifetime have to be combined to determine the overall revenue the PSS will generate.

Phase 3: Following that in phase three there needs to be an evaluation on the likelihood with which there might occur a potential loss of revenue. While for the conventional product this would be signified through a single probability of the product being sold or not while in the case of the PSS there many instances where the service will be sold and therefore a potential loss of revenue can occur. Therefore each revenue event has to be matched with a probability of occurrence although these might remain stable over a certain amount of time and only change based on seasonal factor. But they can also be very irregular. If the LCC of the PSS and its overall cost contain costs that only occur when the product is actually used the risk should also be considered with these variable costs since they also don't occur if the sale does not take place. This means that the negative impact of individual lost sales events is mainly impacted by initial investment cost of the product and other fixed expenses that are required for operating the PSS.

Phase 4: This consideration leads right into phase four in which the overall profit that is made by the PSS and the conventional product is calculated. For the conventional product this is as simple as taking the potential revenue times the probability of the sale minus the prime costs of the product. For the PSS the calculation is slightly more difficult the costs of the PSS have to be split into costs that are fixed cost, cyclical costs and variable costs that only occur when the PSS is providing the service to a customer. Then the individual profit of each sale event for a timeframe that aligns with the maintenance cycles of the product can be calculated. With this the cyclic costs have to be subtracted and the results the multiplied with the number of cycles this product can be used until the end of its life. At this point one would have the profit the PSS would generate if there are no fixed costs to operate the PSS over the given timeframe and its initial purchase or manufacturing is free. Therefore the last step is to subtract the fixed costs and the result is the profit the PSS will generate over its life time. This can be simplified into

formula 7 with S_p as a function that represents the sales during a cycle, R_p standing for the revenue per sale, C_V representing the variable costs per sale, p_p the probability of the sale occurring, C_C the costs that occur at the end of each cycle, L the number of cycles the product will have during its lifetime and C_F the fixed costs incurred for its entire life.

$$PSSP = \Big(\big(S_p * (R_p - C_V) * p_p\big) - C_C\Big) * L - C_F. \qquad (7)$$

Phase 5: With all this done the last phase is the comparison of the results of both calculations. While doing this it is important to consider the lifetime of the PSS. If the lifetime of a PSS is so long that customer of the conventional Product might buy a new product during the time of operation it is important to multiply the profit of the conventional product accordingly. Furthermore the PSS and conventional product should be compared with the assumption that there is a singular customer in order to allow for an equal comparison.

4. CASE STUDY

This section will use the previously described method on a coffee machine that was developed as a PSS at the IPeG, which allows for an easy and extensive access to cost data. Additionally the fact that coffee machines are already sold as products as well as PSS makes them a suitable example for this case study.

For the case study the possibilities of the coffee machine being sold as an individual product and on the other hand as a use oriented PSS will be compared. The machine brews a large batch of coffee and then stores it in a thermally isolated tank, to allow for a quick dispense of coffee if required. Additionally it can brew further coffee if the tank volume falls below a predefined threshold. This makes the machine especially interesting for commercial users like conference hotels, which would like to provide their guest with freshly brewed coffee during session breaks.

This coffee machine can be operated as either one of the two business models. But it is still unclear which one would be more economically beneficial. To determine this the previously described method is employed. Thus the first step will be to determine the prime costs of the product and the LCC of the PSS. While the prime costs of the product can easily be calculated with the expense of the required material coming to 2.000 €, the manufacturing and assembly with another 450 € as expenses and administrative and distribution costs contributing another 100 €, the overall prime costs of the product are 2.550 €. With this the initial capital expenditure (capex) for the PSS is also clear because in this case they are identical. Therefore only the operational expenditures (opex) have to be calculated additionally, with the further division into costs that only occur every time a sale is performed and costs that only occur within predetermined cycle time. Opex that occurs with every sale in this case is 17 € for post transport to the customer site 10 € handling cost for packing and unpacking the shipment and 15 € for cleaning the retuned coffee machine, resulting in a total opex per sale of 42 €. The cost for cyclical opex can be calculated using the formulas (1) – (6) and in this case will amount to approximately 53 € per month. With this all necessary cost information about the PSS and product are obtained and can be used in the further calculation.

Table 1. *PSS and product costs*

Type	Capex	Opex per sale	Opex per cycle
PSS	2.550 €	42 € / Sale	53 € / month
Product	2.550 €	-	-

For the next phase the potential revenue of the product has to be determined. In the case of the conventional product a comparison to other fully automatic coffee machines on the market shows that professional models retail for anywhere between 4.000 € and 22.000 €. Therefore assuming a margin of 30% would result in the coffee machine having a retail price of 3.315 € which seems reasonable considering the potentially different feature sets of the competitors and allowing for price to also be a selling argument. For calculating the revenue generated by the PSS the first step is to determine its lifetime. Since this is dependent on a multitude of different factors, like repairability of the product, technological longevity and business strategy decisions, the determination of a distinct lifetime for a product is very difficult. Therefor the lifetime will remain a variable to show in the result what lifetime hast to be achieved in order for the PSS to generate profit. For the determination of customer demand and sale events, data from the Federal Statistical Office of Germany about hotel occupancy is used. This data is shown in table 2 per month and as the occupancy percentage. The occupancy percentage is then multiplied by the number of days in any given month and divided by two to reflect the fact that most conference are longer than a single day.

Table 2. *Anual customer demand*

Month	Occupancy	Sales Events
1	49,5%	8
2	55,6%	8
3	58,1%	9
4	61,1%	9
5	62,8%	10
6	69,6%	10
7	67,3%	10
8	67,2%	10
9	73,1%	11
10	67,3%	10
11	61,2%	9
12	55,0%	9

The minimum revenue necessary for the PSS to cover its opex even in the slower months of January and February would amount to approximately 49 € per sale. But since also the capex needs to be covered and the goal is to make a profit a margin of 40% is used resulting in a sale price of 68,6 €.

Phase three requires the estimation of the risk that any given sale does not take place as originally assumed. As with the determination of the PSS lifetime there are many different factors known and unknown that might impact the sale of the product or service, for example a global

pandemic would severely impact the sales of the PSS. Therefore the same approach as with the PSS lifetime is taken here and the probability is taken as variable when determining the profit.

With this the profit for the conventional product can be determined and displayed as a plane illustrating where the risk would be acceptable in comparison to the revenue generated. Also the assumption is made that after five years of use the customer will probably buy a new coffee machine resulting in an additional sale. The resulting graph is shown in figure 4 with a distinct jump after 60 months due to the additional sale. But this only has a positive impact if the probability for both sales is high enough (approximately 80%) otherwise the additional costs to manufacture the additional product

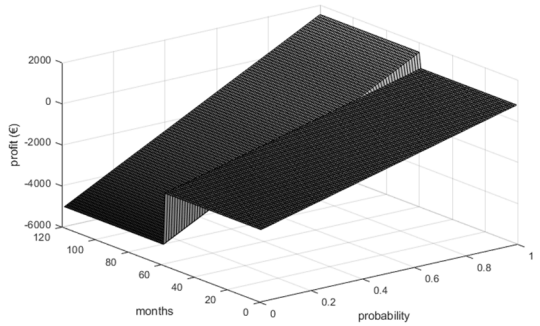

Fig. 4. *Conventional product profit*

For generating the profit data for the PSS it is advisable to first determine the profit per monthly sale and disregarding the fixed capex costs and cyclic costs for ease of calculation. Therefore only calculating the two inner most brackets of formula (7). Resulting in a profit that only takes in to consideration the variable costs in relation to the revenue which in this case would only be positive, since the variable cost only occur when the revenue does. This makes it very important to combine those results with the cyclic cost and the capex of the PSS to give a realistic representation of the profit, resulting in the plane visible in figure 5.

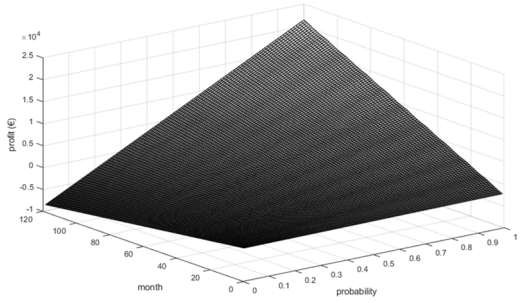

Fig. 5. *PSS profit*

The results in figure 5 behave as expected and show that for low sale probabilities the PSS generates increasing losses over time while performing its best over long time with high probabilities of sale.

This leaves only the final phase of comparing the results to determine the better business model for this case. For this the constructed planes can be overlapped to show where the PSS business model is better than the conventional product business model. The result is shown in figure 6. with negative values indicating that the conventional product is better and positive values indicating the PSS is better.

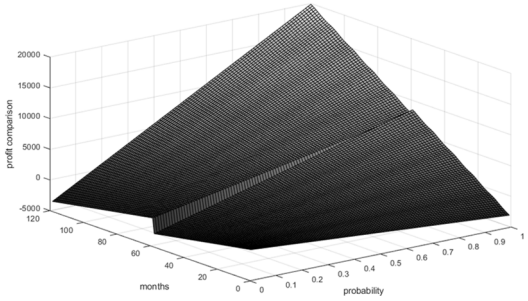

Fig. 6. *Profit advantage*

This shows that conventional products excel in cases where the longevity of the product used in the PSS is comparatively low or when the sale of the service to the customer is very uncertain. The advantage in this example is very pronounced which is most likely due to the difference in profit margins between PSS and conventional product. To investigate this assumption an additional calculation is performed with the profit margin of the PSS reduced to 30%. This then results in the plane shown in figure 7. which has a much smaller area in which the PSS is more profitable.

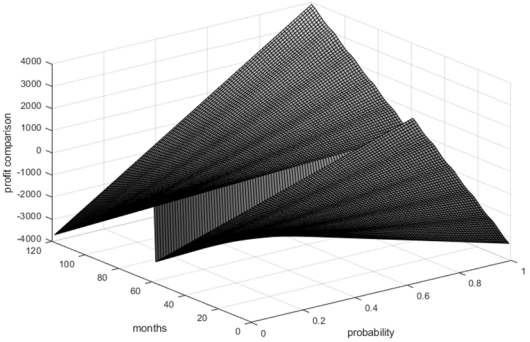

Fig. 7. *Profit advantage for identical profit margin*

This is confirming the overall assumption that PSS have to be operated for a longer time and with a sufficient number of sales that actually occur to generate more profit than a conventional product. But especially noticeable is also the fact that given a long enough timeframe the PSS can be profitable with substantially lower sale probabilities than the conventional product, which needs the aforementioned ~80% to be profitable. In contrast a PSS operated for 10 years with the same margin only needs slightly more than a 60% sale probability to be profitable. But it hast to be kept in mind that in this case it would take 10 years for the PSS to turn a profit, which is not desirable.Furthermore it should be mentioned that additional analysis would be possible by varying other parameters of the product and PSS in order to determine their impact on the comparison.

5. DISCUSSION

Overall there the assumption that PSS can be environmentally more beneficial because they are used over a longer period of time can be supported by economic

benefits. This means that PSS have an intrinsic incentive to be designed to have a long lifetime which will result in lager profits than a comparable sale of a conventional product. Furthermore the certainty that any given sale event take place can be lower for PSS and they still will be profitable because there are many chances to sell the service again and again during its lifetime. This is a further incentive to utilize a product with a long lifetime in the PSS because that way individual sale events can be of higher uncertainty without making the PSS unprofitable. But there also some problems that need further consideration since the method only compares overall profit of PSS against the profit of conventional product the time that is required for the PSS to generate a return on investment is not taken into explicit calculation. It can be found in the planes shown in the previous chapter by looking for a month when the profit turns positive under a given sale probability. Though this is not all that is impacted by the shift of cash flow form a single sale event once to many sale events over a longer period of time. While usually a steady cash flow is preferred, due to the fact that cash has to be available to pay running cost, there are arguments to be made that a single lump sum payment would be preferable. Because in the PSS case there is a need for cash that has to be full filled but won't be because the individual sale profit is much smaller than in the case of the conventional product. This is also supported by discounted cash flow methods which show that the value of money being available immediately is greater than money being available in the future.

Additionally in the case of a PSS the risk that the product might become unusable remains with the PSS operator instead of getting transferred to the customer. In these cases the lifetime of the product would get cut short and result in the PSS not being as profitable as anticipated. The change in profit from this can be seen in the figures by looking at the point on which the product would fail. But this does not consider the probabilities with which this would happen. This risk is difficult to quantify before implementing the PSS, a possible solution to mitigate this would be to increase the profit margin to shift the point where PSS has generating an overall profit to an earlier point in time in which case the product being lost would not be as bad. Another possible solution to mitigate this risk would be to utilize a fleet of products so that the lifetime of an individual product being cut short does not have such a large impact on the overall profit of the PSS. This of course would necessitate the fact that the PSS offering is not just sold to one customer but instead a large number of different customers. This would also mean that one product being sold to multiple customers increasing the number of sale events in a given timeframe and an increased probability that these sale events will actually occur. This would be representing the increase in workload until an individual product reaches its maximum workload and a second product is necessary to supply the service to the customer. But it does not simulate the impact that simultaneous customer demand would have on if it can be supplied or not and how that would impact potential future sales.

6. CONCLUSION

The overall goal of this paper has been achieved presenting a method that can be used to determine the economic viability of a PSS in comparison to a conventional product. Also the profitability requirements of the product in the case study align very well with the requirements generally associated with an environmentally friendly PSS. To be certain that this is not just coincidental further case studies have to be performed with the method proposed in this pare. Additionally it is necessary to perform further research into the impact the cash flow over time, the use of multiple products in a PSS and multiple customers have on the results in the case study. Also whether the proposed method can has to be adjusted for these cases or if it can still be used unchanged.

7. REFERENCES

[1] INTERNATIONAL TRADE CENTRE, *The European Union Market for Sustainable Products: The retail perspective on sourcing policies and consumer demand*. ITC, Geneva, 2019

[2] H. Heinrichs, *Sharing Economy: A Potential New Pathway to Sustainability*. *GAIA - Ecological Perspectives for Science and Society*, vol. 22, no. 4, pp. 228–231, 2013.

[3] J. Hamari, M. Sjöklint and A. Ukkonen, *The sharing economy: Why people participate in collaborative consumption*. *Journal of the Association for Information Science and Technology*, vol. 67, no. 9, pp. 2047–2059, 2016.

[4] Z. Mi and D.'M. Coffman, *The sharing economy promotes sustainable societies*. *Nature communications*, vol. 10, no. 1, pp. 1214, 2019.

[5] M. Geissdoerfer, P. Savaget, N. M.P. Bocken and E. J. Hultink, *The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production*, vol. 143, pp. 757–768, 2017.

[6] M. S. Andersen, *An introductory note on the environmental economics of the circular economy*. *Sustainability Science*, vol. 2, no. 1, pp. 133–140, 2007.

[7] M. A. Ülkü and J. Hsuan, *Towards sustainable consumption and production: Competitive pricing of modular products for green consumers*. *Journal of Cleaner Production*, vol. 142, pp. 4230–4242, 2017.

[8] M. Ilić and M. Nikolić, *Drivers for development of circular economy – A case study of Serbia*. *Habitat International*, vol. 56, pp. 191–200, 2016.

[9] A. Tukker, *Product services for a resource-efficient and circular economy – a review*. *Journal of Cleaner Production*, vol. 97, pp. 76–91, 2015.

[10] M. P. P. Pieroni, T. C. McAloone and D. C. A. Pigosso, *Configuring New Business Models for Circular Economy through Product–Service Systems*. *Sustainability*, vol. 11, no. 13, pp. 3727, 2019.

[11] L. Hüer, S. Hagen, O. Thomas and H.-J. Pfisterer, *Impacts of Product-Service Systems on Sustainability – A structured Literature Review*. *Procedia CIRP*, vol. 73, pp. 228–234, 2018.

[12] P. C. Gembarski, D. Schreiber, T. Schoormann, R. Knackstedt and R. Lachmayer, "Are we talking about the same thing?" Analyzing Effects of Mass

Customization and Product-Service Systems on Sustainability, Bd. 2018. In: *Proceedings of the 8th International Conference on Mass Customization and Personalization – Community of Europe (MCP - CE 2018)*,

[13] D. C. A. Pigosso and T. C. McAloone, *Supporting the Development of Environmentally Sustainable PSS by Means of the Ecodesign Maturity Model*. *Procedia CIRP*, vol. 30, pp. 173–178, 2015.

[14] C. Vezzoli, F. Ceschin, J. C. Diehl and C. Kohtala, *Why have 'Sustainable Product-Service Systems' not been widely implemented? Journal of Cleaner Production*, vol. 35, pp. 288–290, 2012.

[15] M. Goedkoop, C.J.G. Halen, H.R.M. Riele and P.J.M. Rommens, *Product service systems, ecological and economic basics. Econ. Aff.*, vol. 36, 1999.

[16] T. C. McAloone, K. Mougaard, L. M. Neugebauer, T. A. Nielsen and N. Bey, Orthogonal views on product/service-system design in an entire industry branch," In: CULLEY, Steve J. (Hrsg.). *Product and systems design*. Glasgow : Design Society, 2011 (DS / Design Society, 68). pp. 77–87,

[17] A. Tukker, *Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet*. *Business Strategy and the Environment*, vol. 13, no. 4, pp. 246–260, 2004.

[18] D. Schreiber, P. C. Gembarski and R. Lachmayer, Modeling and configuration for Product-Service Systems: State of the art and future research," In: *19 th International Configuration Workshop*, 2017, pp. 72,

[19] ADRIAN TAN, TIMOTHY CHARLES MCALOONE, Characteristics of Strategies in Product/Service-System Development," In: *Proceedings of the DESIGN 2006 9th International Conference on Design*, pp. 1435–1442,

[20] L. G. Damha, A. H. Trevisan, D. G. Costa and J. M. H. Costa, How are End-of-Life Strategies Adopted in Product-Service Systems? A Systematic Review of General Cases and Cases of Medical Devices Industry, Bd. 1. In: *Proc. Int. Conf. Eng. Des. (Proceedings of the Design Society: International Conference on Engineering Design)*, pp. 3061–3070,

[21] G. H. Brundtland, *Global Change and Our Common Future*. *Environment: Science and Policy for Sustainable Development*, vol. 31, no. 5, pp. 16–43, 1989.

[22] J. Pope, D. Annandale and A. Morrison-Saunders, *Conceptualising sustainability assessment*. *Environmental Impact Assessment Review*, vol. 24, no. 6, pp. 595–616, 2004.

[23] J. Huber, *Nachhaltige Entwicklung durch Suffizienz, Effizienz und Konsistenz*. Halle (Saale), Martin-Luther-Universität Halle-Wittenberg Institut für Soziologie, 1994,

[24] S. Schaltegger, F. Lüdeke-Freund and E. G. Hansen, *Business cases for sustainability : The role of business model innovation for corporate sustainability*. *International journal of innovation and sustainable development : IJISD*, vol. 6, no. 2, pp. 95–119, 2012.

[25] ISO 14044. 2006. *Environmental management – Life cycle assessment – Requirements and guidelines*

[26] L. L. Kjaer, D. C.A. Pigosso, T. C. McAloone and M. Birkved, *Guidelines for evaluating the environmental performance of Product/Service-Systems through life cycle assessment*. *Journal of Cleaner Production*, vol. 190, pp. 666–678, 2018.

[27] G. E. White and P. F. Ostwald, *Life cycle costing*. *Management accounting*, vol. 57, no. 7, pp. 39–42, 1976.

[28] Y. Asiedu and P. Gu, *Product life cycle cost analysis: State of the art review*. *International Journal of Production Research*, vol. 36, no. 4, pp. 883–908, 1998.

[29] F. Johannknecht, M. M. Gatzen and R. Lachmayer, *Life Cycle Cost Model for Considering Fleet Utilization in Early Conceptual Design Phases*. *Procedia CIRP*, vol. 48, pp. 68–72, 2016.

[30] W. Fabrycky and B. Blanchard, *Life Cycle Cost and Economic Analysis*. 1991.

[31] BULL, John W. (Hrsg.)*Life cycle costing for construction*. 1. ed. London, Blackie Academic & Professional, 1993,

[32] B. H. Goh and Y. Sun, *The development of life-cycle costing for buildings*. *Building Research & Information*, vol. 44, no. 3, pp. 319–333, 2016.

[33] O. Salem, S. AbouRizk and S. Ariaratnam, *Risk-based Life-cycle Costing of Infrastructure Rehabilitation and Construction Alternatives*. *Journal of Infrastructure Systems*, vol. 9, no. 1, pp. 6–15, 2003.

[34] F. Johannknecht, M. Herrmann and R. Lachmayer, *Kostenmanagement von Produkt-Service-Systemen : Managing Costs of Product-Service Systems*. *Die Konstruktion*, no. 6, 2019.

[35] F. Johannknecht, M. M. Gatzen, D. Hahn and R. Lachmayer, Holistic Life Cycle Costing Approach for Different Development Phases of Drilling Tools," In: *International Petroleum Technology Conference*, 2016,

[36] F. Johannknecht, *Lebenszyklusorientiertes Kostenmanagement für Produkt-Service Systeme : Dissertation*. Garbsen, PZH Verlag, 2018,

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