Benefits of a Product Service System Approach for Long-life Products: The Case of Light Tubes

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Abstract

Products designed for long-life often have significant potential for better sustainability performance than standard products due to less material and energy usage for a given service provided, which usually also results in a lower total cost. These benefits are not always obvious or appealing to customers, who often focus on price. Long-life products are therefore at an inherent disadvantage: due to lower volume of sales that results from the products' longer-life, the margins (price) often need to be higher. In this paper, we demonstrate that when the revenue base is shifted to be the service of light (instead of the sales of light tubes), there is an opportunity for a "win-win-win" for the light user, the long-life light provider and society. Through a product-service system approach, resulting in a well-communicated total offer, the full array of benefits becomes clearer to the customer, including that they avoid the high initial cost.

Keywords

sustainability performance, long-life products, product-service system, value chain, modeling

1 INTRODUCTION

This study has come about through a partnership between researchers at BTH and Aura Light International AB (Aura) which produces long-life fluorescent light-tubes with a life-length that is three times longer than the industry average. Like many firms, Aura Light is increasingly aware of the opportunities and risks being presented by an increasingly sustainability-driven market [1-2]. The Sustainability Assessments research team at BTH has specific competence with strategic sustainable development (SSD) [3-4] and application of SSD in the context of product development [5-6]. Due to the long-life nature of Aura's product, there are challenges when competing with producers of "standard" life-length light-tubes, i.e. Aura has 1/4 as many opportunities to generate revenue from the sales of a physical product as its competitors. From a sustainability perspective, the long-life product is obviously worth exploring since it reduces material flows by approximately one-fourth.

The concept of product-service systems (PSS) has been defined as a system joining products and services in order to meet customer needs. It emphasizes a shift in the focus from selling physical product to selling the function provided by this combination of products and services. Definitions of PSS typically include reference to increased competitiveness of PSS providers. Some definitions do not explicitly include reference to reduced environmental impacts e.g. [7-8]. However, PSS definitions frequently also include reference to reduced negative environmental impacts, e.g. [9-11].

Tukker has articulated two concrete questions that he suggests are often overlooked when analyzing PSS: First, "which factors determine whether a PSS business model is the best way to create value added?" and second, "which factors determine whether a PSS business model per se generates less material flows and emissions than the competing product oriented models, and thus provides incentives for sustainable behavior?" [12]. These two questions (creating added value and reduced material flows and emissions) make a PSS approach for Aura Light an interesting consideration.

This paper explores the concept of product-service systems as a potential way of overcoming this contradiction between reduced number of revenue-generating opportunities, desire for increased revenue, and demand for less negative sustainability impacts. Through the example, this paper will demonstrate the potential for a company with an existing long-life product (a physical product designed for a significantly longer average useful life than a "regular" product) to consider if it can have a competitive PSS-offer.

2 METHODS

Two approaches to selling the service of light are compared: the first a producer of standard-life light-tubes, and the second a producer of long-life light-tubes. For each approach, the economics of the approach are considered from the perspective of the user and the primary provider. The socio-ecological sustainability implications (i.e. broader society) are also considered. Thus, this paper considers four scenarios from three different perspectives.

Four scenarios:

- Standard-life light tube sold as a physical product
- Standard-life light tube sold as a PSS offer
- Long-life light tube sold as a physical product
- Long-life light tube sold as a PSS offer

Three perspectives:

- Customer (economic - cost of light)
- Producer (economic - profit)
- Society (socio-ecological sustainability)

The prices and costs here are provided for illustrative purposes and are not actual figures from a company. The researchers were "kept in the dark" in order to not compromise sensitive information, and thus these figures come from a survey of the lighting industry. The following assumptions are made for this analysis:

- Long-life light-tubes lasts 4x longer than standard-life light-tubes (12 yrs vs. 3 yrs at 4000 h/yr)

- Sales price is 4x higher for long-life light-tubes (10 € vs. 2,50 €)
- Cost to replace a light-tube (including labor, disposal fee, and downtime) is 5 €
- Light fixtures are pre-existing (so not included here)
- Both light-tubes use them same amount of electricity
- Both light-tubes provide the same amount of light
- Electricity cost is 0,10 €/kWh
- Annual discount rate of 3%
- No "rebound effect" will occur because of a shift from product to PSS offer

2.1 Customer (economic) perspective

To answer Tukker's first question from the customer's perspective, a simple life-cycle cost model considers the economic aspects of the four scenarios from the customer (light-user) perspective. Here the cost to the customer for light-tubes (as either a purchased product or a PSS) and replacement of the light tubes are considered for providing 4000 hours of light per year for a period of 12 years. A discount rate is included due to the long time period considered. Pricing alternatives are not optimized in any way; the prices used are only to demonstrate the way in which long-life products are able to capture and re-direct value to the producer and user.

Two criteria are considered for the customer: cost in the first year, and total cost for light over 12 years. Twelve years is used because it is the lifetime of one long-life light tube.

A price for the annual service of using a light-tube is set to 1 €. This rate was obtained by setting the net present value of the revenue generated by a long-life light-tube that is provided as a PSS-offer for 12 years equal to the net present value of the revenue generated by selling one light-tube that has an expected life of 12 years.

2.2 Producer's (economic) perspective

For a PSS-offer to be possible, it must also be profitable for the offer provider in addition to being attractive to the customer. In this case, the long-life light tube producer is trying to lower total cost to the customer while capturing for itself enough of the value realized through that cost savings to be competitive with the producers of standard-life light-tubes. This is represented by exploring if the customer savings is significant enough to compensate for the reduced number of light-tubes the customer must use to meet its need for light. All of the costs incurred by the customer are mapped, the costs that can be reduced by the long-life offer are noted, and a decision is made regarding whether or not the PSS-approach is profitable. Note that company data is not able to be published, so illustrations are used to demonstrate the concept.

2.3 Society's (sustainability) perspective

As a prelude to answering Tukker's second question regarding reduced material use and emissions, an approach is taken that incorporates a strategic sustainability perspective in order to not only quantify material and emission reductions, but also to be sure that the scenario is not causing other sustainability issues. This is done by using an approach called "backcasting from sustainability principles" that states there are four basic principles that will be met by a society that is sustainable [3; 13; 14-15]. These basic principles state that in a sustainable society, nature is not subject to systematically increasing:

1 concentrations of substances extracted from the earth's crust;

2 concentrations of substances produced by society;

3 degradation by physical means, and

4 in that society, people are not subject to conditions that systematically undermine their capacity to meet their needs.

Since these are principles for sustainability of global human society, we assume that companies, products, or PSS that comply with these conditions (and thus do not contribute to society's sustainability problems) will have a competitive advantage compared to those that do not meet these principles.

For the sustainability assessment, a strategic life cycle management (SLCM) approach is used to consider how the scenarios comply with basic principles for global socio-ecological sustainability during each of the life cycle stages [15]. This approach is used in order to first take a strategic overview of the sustainability implications before attempting to provide a quantitative response to Tukker's second question regarding energy and material flows; this allows a full sustainability perspective so that as some challenges are addressed (e.g. material and energy reduction), other sustainability challenges are not created unintentionally. The SLCM approach is implemented by using a strategic life cycle matrix to identify any differences between the offers being considered.

The columns in the matrix refer to those basic principles for a sustainable society. The rows in the matrix refer to life cycle stages of the product or PSS. This allows for the identification of any current or future sustainability challenges related to the life cycle of the product. The matrix is shown in Figure 1.

	Principle 1	Principle 2	Principle 3	Principle 4
Materials	*List of aspects of the offer that are not in compliance for each life cycle stage and sustainability principle*			
Production				
Packaging & distribution				
Use				
End of Life				

Figure 1: Strategic Life Cycle Management Matrix

One matrix is completed for each product or PSS being considered, and if differences are identified, then a more in-depth assessment can be conducted to consider the trade-offs. This step is in realization that "sustainable behavior" is not only about reducing material flows and emissions, and that by focusing only on these two items there is a significant risk of sub-optimization of sustainability performance.

After obtaining a strategic overview from the matrix, there is an opportunity to go into more detail to allow for the quantification of relative environmental impacts. Life Cycle Assessment (LCA) [16] is a tool suited for such a quantitative analysis, and has been referred to as a complementary tool in PSS development in other places [17]. The LCA software tool Simapro, utilizing EcoInvent [18] data, along with some assumptions with regard to transportation and energy, is used to obtain some order-of-magnitude estimates regarding environmental impacts due to reduced material use from the long-life product over the product's life cycle. While this is not an ISO 14040-certifiable LCA (that process requires a much more rigorous process for goal setting and scoping, data collection and verification, and impact assessment), this can be performed in a few hours to obtain an approximation of the improvement across the product's life cycle.

3 RESULTS OF ECONOMIC ASSESSMENT

The boundaries of this study with regard to the value chain focus foremost on the producer of the light-tube and the light user. Because it requires four standard-life light tubes and the associated activities throughout their life cycles to match the useful life of one long-life light tube, the costs throughout the value chain recur four times for the standard-life light tube for every one time in the long-life light tube's life cycle. This is illustrated in Figure 2.

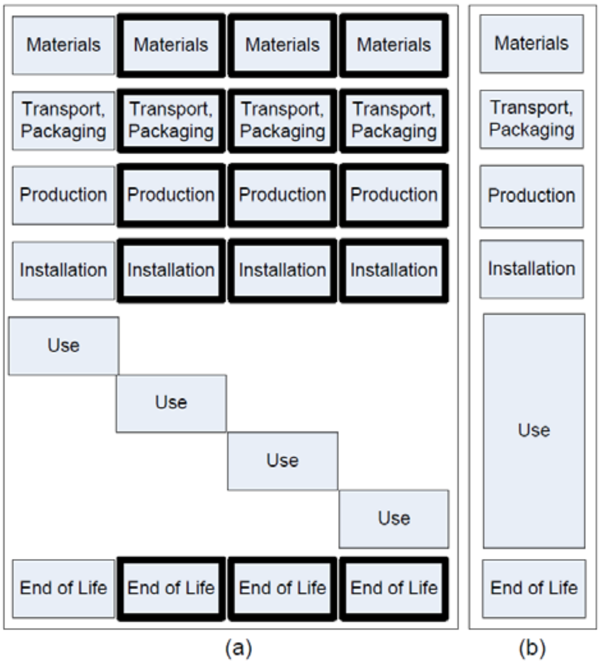

Figure 2: Activities where costs are incurred over the light tube life cycle when providing 48 000 hours of light with standard-life light-tubes (a) compared to 1 long-life light tube (b). Bold boxes show costs incurred in (a) only.

Light Customer Perspective

Economic considerations for the light user are presented in Table 1. Regarding initial cost, the long-life light tube sold as a product has a significantly higher cost than the other scenarios: 15 € (10 € for the light-tube in addition to the 5 € cost of tube installation) compared to either 7.50 € or 6 €.

Users of light have lower costs by using the long-life tubes, either by purchasing them outright or by accessing the light tubes through a PSS-offer. In this example, the 15 € difference between the total for standard-life and the total for long-life is simply the three installations (5 € each) that are not required with the long-life option. This difference remains significant when the net present value is considered, so here it seems that either of the long-life scenarios would be preferred by the customer.

Considering both the initial cost and the full costs over 12 years, the long-life light tube offered as a PSS appears most attractive to the customer.

Light Producer Perspective

The long-life light-tube producer's challenge is to do two things at the same time: first, to lower costs to the customer in order to make the long-life offer attractive, and second to increase the revenue that the customer is paying for the light-tubes (again remembering that the long-life producer is selling one-fourth as many tubes as a standard-life light-tube producer). Actual numbers from the company are confidential, but this concept is illustrated in Figure 3. Electricity costs are also included in the diagram in order to show the total life cycle costs of the customer (i.e. electricity is greater than 90% of the customer's cost).

Table 1: Customer costs of light-tubes and light in € over 12 years (48 000 hours of light).

Customer Perspective: Costs

	Standard life		Long life	
Year	Product	PSS	Product	PSS
2010	7,50	6,00	15,00	6,00
2011	0,00	1,00	0,00	1,00
2012	0,00	1,00	0,00	1,00
2013	7,50	6,00	0,00	1,00
2014	0,00	1,00	0,00	1,00
2015	0,00	1,00	0,00	1,00
2016	7,50	6,00	0,00	1,00
2017	0,00	1,00	0,00	1,00
2018	0,00	1,00	0,00	1,00
2019	7,50	6,00	0,00	1,00
2020	0,00	1,00	0,00	1,00
2021	0,00	1,00	0,00	1,00
Total	**30**	**32**	**15**	**17**
Net Present Value	**24,39**	**25,64**	**14,42**	**14,19**

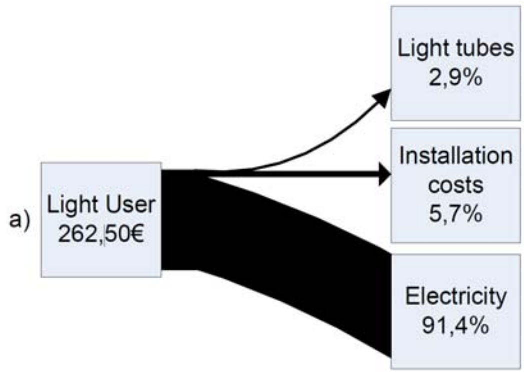

Figure 3a: Total customer costs for light during 12 year with a standard-life light tube sold as a product

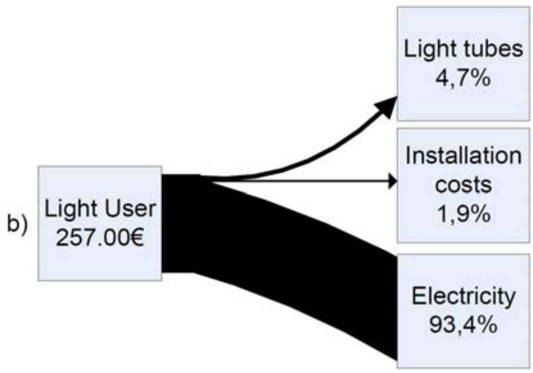

Figure 3b: Total customer costs for light during 12 year with a long-life light tube sold as a PSS

For the light consumer and the light-tube producer, there is an opportunity for the long-life light-tube to be mutually beneficial because it captures value that is otherwise distributed throughout other actors in the value chain. In this example, the captured value includes:

1 Savings by cost reduction due to changing tubes 1/4 as often (savings include e.g. the expense of manual labor and disruption to operations), and
2 Increased efficiency of light provided per material/energy input (1/4 as much material required and 1/4 as much energy for production, transport, etc. excluding the use phase)

4 RESULTS OF SUSTAINABILITY ASSESSMENT

Strategic Life Cycle Management Matrix

Due its focus on a qualitative overview to identify all potential sustainability concerns, the SLCM approach provides no distinction between the standard-life and long-life light tubes. This is because the life-cycles of both light-tubes contain the same sustainability concerns from a strategic overview perspective. See an example of a partially completed SLCM matrix for light tubes in Table 2.

Table 2: Example of an SLCM Matrix for light-tubes.

	SP1	SP2	SP3	SP4
Materials	Mercury Copper Lead	Solvents in marking ink	Land change due to mining	Worker safety
Production	Lead	Flame retardants Cleaning chemicals		
Packaging Distribution	Use of fossil-based plastics		Land use for transport	
Use	Use of fossil energy			Ballast noise
End of Life			Land change used for landfill	

Based on this conclusion, one can then say that probably the scenario that has less energy and material flows is the "more sustainable" alternative. With the long-life product reducing the raw materials, manufacturing, maintenance (e.g. light-tube replacement) and end-of-life phases of the light-tube's life cycle by three-quarters, it clearly has environmental benefits over the standard-life light-tube (assuming that energy use for illumination is the same for both light-tubes).

Quantification of Environmental Impacts

Estimates are made using EcoInvent data in the life cycle assessment software tool Simapro. To make some quick estimates, these values were assumed:

- 150 kg-km of transport for light-tube components
- 100 kg-km transport of light-tube to customer
- 2400 kWh of electricity from the Swedish grid
- IPCC GWP 100a as the impact assessment method

This resulted in electricity during the use phase being about 94% of the environmental impact.

Then the electricity source was changed to the US grid, which resulted in the impacts due to electricity use being on the order of 99%. This assessment is sufficient for us to say that the global warming potential (using IPCC GWP 100- year) of using the long-life tubes with "dirty" electricity is about 3% less than standard tubes, and on the order of 17% less on a "clean" grid. In this scenario, the GWP is reduced on the order of 10%, even though material use is reduced by a factor of 4.

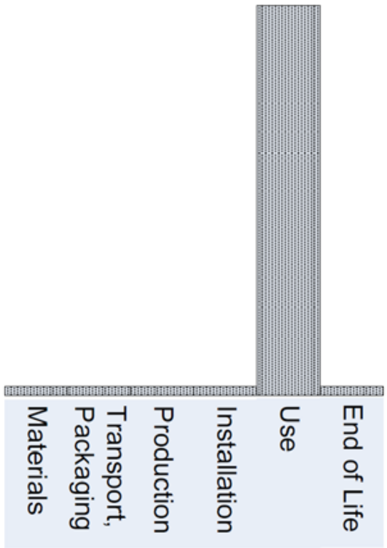

Figure 4: Approximate environmental impacts per life cycle stage of a long-life light-tube showing relative high impact during use phase.

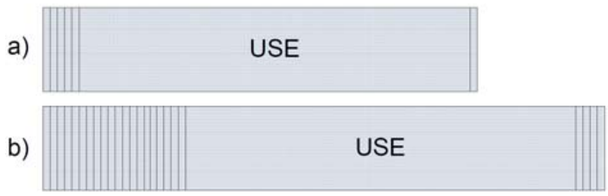

Figure 5: Environmental impact comparison between one long-life light tube (top) and three standard-life light-tubes (bottom). Vertical bars represent the life cycle stages in Figure 4. Top bar shows the long-life product, with 1/4 of impacts from stages other than use, compared to bottom bar that shows standard-life product. Impacts from use phase are the same for both.

5 SUMMARY OF RESULTS

The authors choose not to go into further detail with the LCA because this is not a trade-off situation: the long-life light tubes win from the producer's economic perspective, the consumer's economic perspective, and a broader societal perspective (from fewer negative sustainability implications) and there is no need to more exactly quantify the extent to which a long-life light tube is "less bad" than a standard-life light tube. Furthermore, on a sustainability-driven market where costs related to material and energy flows are expected to increase, the benefits from minimizing those flows are only expected to increase.

If, in line with current practice, revenue comes from the sales of light-tubes, then the long-life producer earns more profit than standard-life producer and the customer has a lower total-life cost, but the customer balks at the high initial cost. It is only when the long-life product is used as the basis for selling light that the long-life producer really wins: the long-life producer has a higher profit and the customer has both a lower total life cost and an initial price similar to what is offered by the standard-life product. The trade-off is that the producer must then front the capital costs for production.

Table 3: Summary of assessments

	Standard Life		Long Life	
	Product	PSS	Product	PSS
Consumer (Initial cost)	Prefer: lower initial cost	Prefer: lower initial cost		Prefer: lower initial cost
Consumer (total cost for 48 000 hours of light)			Prefer: lower total cost	Prefer: lower total cost
Producer				Prefer: because customer prefers
Society (full sustain-ability)	no differences identified			
Society (reduced materials and emissions)			Prefer: lower material and energy flows	Prefer: lower material and energy flows

6 DISCUSSION

This paper uses many of the same logical arguments in favor of a PSS approach that have been offered by early movers in this field. The contribution here comes from shifting the starting point of those arguments, particularly emphasizing that products designed for long-life gain competitive advantage through a PSS offer by capturing value that is otherwise distributed elsewhere in the value chain. Rather than having a regular product evolve into a PSS and then work toward longer-life, we start with a long-life product that gains competitive advantage by selling the function it provides: a different path to the same result.

6.1 Economics of Long-Life Products and PSS

Long-life products have the potential to capture value that can be shared between producers and consumers. However, consumers may hesitate at paying the price of the long-life tube that allows a long-life manufacturer to be competitive – remember that long-life producers have only a fourth as many products to sell, and thus must earn higher margins per light-tube to generate similar net incomes. Thus a PSS-approach based on offering the service of light is one possible approach for the long-life light-tube manufacturer. The example given here is only a limited PSS offer, and there is substantial more opportunity for a long-life light-tube provide to transition more toward the service-end of a PSS offer. This paper limits itself to a slight shift toward a PSS offer to make its point. The authors acknowledge that multitude of additional opportunities to shift even farther toward the service end of the PSS spectrum.

What needs to happen from a PSS-development perspective, then, are two things. First, to lower the cost to the customer, and second, to increase the revenue to the primary producer, So, the smaller the difference between these two (i.e. “primary producer revenue” – “user cost”), the more opportunity there is for the primary producer to make an offer that is attractive to the user. This is simply saying that PSS-developers need to look at broader life cycle costs of a PSS-offer, and not only the production costs within its own operation. Currently this idea that a long-life light-tube reduces life cycle costs is emphasized by Aura in its sales approach. Yet Aura still sells its light-tubes in a traditional way. This opens the opportunity to package both existing light-tube hardware and additional services into an offer to light users.

6.2 Assessing Sustainability

The methods used to assess the sustainability of concepts in this paper complement Tukker's implication that reduced energy and material flows leads toward more sustainable behavior. Tukker’s assumption is generally correct with one significant caveat: that the materials and energy sources have the same types of sustainability impacts. If, for example, the long-life product in our comparison contained substances that are not included in the standard-life product in order to give it the long-life property, then a more thorough assessment of the implications of the different materials would need to be conducted. This is certainly the case when comparing other lighting technologies ranging from the soon-to-be-banned incandescent bulb to LEDs, with the range of rare metals they often require. An SLCM matrix for these alternative lighting technologies demonstrates significantly different results.

However, the two physical products (standard-life and long-life light tubes) compared in this example do not differ in any significant way with regard to the materials throughout the life cycle of the product. The same materials are used in each tube, only in different quantities. If instead, the comparison was between long-life fluorescent tubes, incandescent bulbs and LEDs, then the SLCM approach would have identified as a significant difference that fluorescent tubes use mercury, or that LEDs use other rare metals. Traditional approaches to only quantify the differences in material and energy flows may miss this point, or may unintentionally focus on energy reduction without awareness of sustainability trade-offs of doing so. The authors do not suggest that such a decision is a bad decision – rather only that it should indeed be a *decision*, and not an unintended consequence.

6.3 Value Chain Cooperation

A point to clarify is the difference between providing alternative financing methods (i.e. the long-life manufacturer providing financing options to eliminate the light consumer’s balking at high initial cost) and having a PSS offer. The former does not provide an opportunity for the light-tube producer to capture the value that comes from eliminating the cost of replacing the light-tubes; it rather passes all of that value directly to the light user. By not only considering, but rather outright claiming for itself that value – and being willing to share that value with the customer – the long-life producer has the opportunity to be competitive with standard-life light-tube producers.

It is important to note that other value chain actors – particularly material suppliers for the light-tube production and service-providers who change the light-tubes– are likely to lose value when the long-life light-tubes are used due to the reduced number of light-tubes that are used. While it is outside the scope of this paper to consider the impacts of this, the authors suggest that there could be an opportunity to engage those extended value chain partners in discussions of opportunities for new innovations in the value chain to better adapt the value chain to a PSS offer so that value chain partners are not left behind or otherwise preventing the transition to a PSS offer.

6.4 Full System Perspective

The long-life aspect of the light-tube reduces the need for changing light-tubes, and this consideration follows Mont's [19] suggestion that a PSS needs to take a full system perspective. Precisely by taking this full-system perspective,

the long-life product identifies opportunities in the value chain to add value to the customer, and thus addresses Tukker's first point about determining the value creation of the PSS business model. Tukker's second point regarding reduced material flows is clearly addressed through the nature of the long-life product – and importantly – is addressed in this particular case without significant concern of a rebound effect.

Continuing to take a full system perspective, we must also acknowledge that the majority of both cost and environmental impact are due to electricity use. Throughout this paper we have not taken into consideration what either the producer or user might do to reduce costs/impacts related to electricity use, but rather have only assumed that electricity use for either standard-life or long-life light-tubes are the same. As part of a PSS-offer, certainly there could be opportunities for a "provider of the service of light" to incorporate ways to reduce lighting needs and further share the cost savings between the provider and user.

Other concerns related to long-life products should not be overlooked in the practical consideration of sustainability issues. One such consideration is technology change: with a usable life of up to 12 years, it is quite likely that lighting technology will advance during that time and become more energy efficient. With the vast majority of energy use (and thus arguably the majority of negative sustainability impacts) coming from the use phase, it is possible that "locking into" a technology with such a long life would result in increased energy use. A further shift toward the service end of the PSS approach would also further shift this burden from the user to the producer – whether good or bad, this is something to be aware of.

7 CONCLUSION

This paper extends the same logical arguments in favor of a PSS approach that have been offered by early movers in this field by shifting the starting point of those arguments. Here the emphasis is that products designed for long-life gain competitive advantage through a PSS offer by capturing value that is otherwise distributed elsewhere in the value chain. Rather than having a regular product evolve into a PSS and then working toward longer-life, it is possible to start with a long-life product that gains competitive advantage by selling function: this is a different path to the same result.

Specifically, this paper shows how value can be captured through cost-savings and then re-distributed directly to the consumer or the producer. Estimates of life cycle costs are made, including acknowledgement of the need to consider discount factors in economic analysis of products designed for long-life. This economic assessment addresses the life cycle costs of acquiring the function of light from the user's perspective, and addresses in simple terms the economic viability of a PSS-offer from the light-tube producer's perspective.

The long-life manufacturer creates value by producing long-life products that reduce the need to replace light-tubes, and the challenge is to capture that value because it is not contained within the value offer with their current business model. The value the long-life manufacturer creates essentially lies in the hands of their customers who, of course, appreciate the value created since it reduces their lighting costs. However, those light consumers are not necessarily willing to share this value (savings from not needing to change light tubes) by paying a premium to the long-life producer. Therefore the producer must find opportunities to capture that value, and a PSS-approach provides such an opportunity.

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