Towards Sustainability-driven Innovation through Product-Service Systems

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Abstract

Many current sustainability considerations in industry constrain design space by emphasizing reduced material and energy flows across product life cycles. However, there are also opportunities for sustainability awareness to extend design space and drive innovation. Product-service systems (PSS) in particular can be a vehicle through which sustainability-driven innovation occurs. A framework for strategic sustainable development, including a backcasting approach, provides the basis for understanding sustainability in this work and provides insight into how incremental and radical approaches could be aligned within product innovation. This work explores how sustainability considerations can be better integrated into existing product innovation working environments, with an emphasis on opportunities that occur as sustainability knowledge leads to innovation through a product-service system approach. It is demonstrated and ideas are discussed around how sustainability can be used to *drive* innovation processes through product-service systems that companies rely upon, while also supporting global society's movement toward sustainability.

Keywords:

Sustainable product innovation, sustainable product development, strategic sustainable development, ecodesign, product service systems (PSS)

1 INTRODUCTION

Most people that work with product innovation – both product designers and business managers – are in the dominant paradigm that puts short-term profit forward as the primary goal. However, these people are also quickly awakening to the need to more directly include both environmental and social issues in their daily decisions [1]. This is happening for many reasons: customer demand, an expanding regulatory environment, global resource constraints, and perceived opportunities for cost savings to name just a few.

One reason product developers have left sustainability essentially outside of their focus is that there is general confusion in the world around the topic of sustainability [2]. There is general agreement in the scientific community that things need to change [3], and this is often discussed under the term "sustainability." This paper builds upon the foundation that has been developed over the past 20 years into a framework for strategic sustainable development (FSSD) [4]. This FSSD provides an operational definition of sustainability and initial set of strategic guidelines that can be used to provide guidance to decision-makers, e.g. people working with product innovation.

With regard to products, there are two obvious things that can be changed. First, the physical artifacts themselves can be changed, and second, the way that products are managed (including how they are used) over their life cycles can be changed. For the former, more efficiency can be pursued, e.g. material reduction and energy optimization. These are generally good, though alone are not sufficient from a sustainability perspective. They also risk leading to the "rebound effect," which is the idea that improvements on a per-unit basis can lead to greater overall impacts due to increased volume that is enabled by, e.g., reduced cost that stems from the improved efficiency, see, e.g., [5]. While product innovation has traditionally focused on the former with occasional glances toward the latter [6], the movement in industry is now toward the design of artifacts and services together – often referred to as product-service systems (PSS) – and presents an opportunity for these two opportunities to be considered and improved in tandem [6, 7].

1.1 Aim and Scope

This paper endeavors to contribute to answering the following question: *How can sustainability considerations be better integrated into existing product innovation working environments, especially with regards to pursuing a product-service system approach?*

1.2 Method

This paper presents ideas that have been collected through several research projects. As such, it draws from research that included the following methods and techniques:

- A broad survey of literature has provided an opportunity to explore the related topics and specifically focus on the intersection between these key topics, in order to better understand the past and present thinking within the research field.
- Interviews and interaction with people working within the area of product innovation were conducted in order to better understand and describe the state of practice in industry.
- Participation in and facilitation of workshops with development teams with companies involved in these research projects have provided insights in how to aid companies in including sustainability in their thinking around product innovation.

This paper is based on the idea that research into design processes cannot be re-created or tested with a control group. In practical research terms, every design project is unique because of a unique set of needs in an ever-changing global context being addressed by a single design group. Furthermore, there is no "correct" or even "best" solution, as this will change from user to user or context to context. This is the essence of the idea of "wicked problems" introduced by Rittel and Webber relating to planning with regard to social problems, where they see "social processes as the links tying open systems into large and interconnected networks of systems… it has become less apparent where problem centers lie, and less apparent where and how we should intervene even if we do happen to know what aims we seek" [8]. In this regard, case study research is valuable because it allows for research topics to be defined broadly while potentially considering multiple variables and relying on multiple sources of evidence [9]. In recognition of the need for a new approach to this type of research, Blessing and Chakrabarti put forth a Design Research Methodology (DRM) [10]. The DRM and its methods provide guidance for planning and implementing design research, thus providing a more rigorous approach to research.

2 RELATED AREAS

Concepts in this paper draw upon three broad topics: (1) sustainability, (2) product innovation, and (3) product-service systems. This section presents briefly each of these, as well as an additional area that is emerging as a combination of them: sustainable product innovation.

2.1 Sustainability

In recent decades, numerous reports, studies, theses, articles and books have been published documenting impacts and opportunities, e.g., species loss [3], resource constraints [11], and the business opportunities for those aware of sustainability issues [12]. The Brundtland definition of sustainable development [13] puts forth an attractive vision, but leaves a significant gap for the business need to be operational. This has lead to many attempts to clarify the concept of sustainability; one of which is a framework for strategic sustainable development (FSSD) based upon a five-level model that can be used to plan in any complex system. When it is used to provide guidance toward a sustainable human society (i.e. "human society within the biosphere"), it is referred to as the framework for strategic sustainable development [4].

Three key aspects of the FSSD make it well-suited for use in both strategic and operational contexts.

- Five level structure, clearly distinguishing between the system, the definition of success, strategic guidelines, actions, and tools
- Unique definition of success in basic principles for sustainability
- Backcasting from a desired future (contrasted with forecasting current trends only)

Combining backcasting with this unique definition of success results in "backcasting from sustainability principles" allowing for strategic decision making that promotes flexibility, movement toward a sustainable future, and appropriate allocation of resources.

The term "sustainability" in this paper, then, refers to global socio-ecological sustainability. It does not, unless specifically stated, refer to the sustainability of some other (sub-) system, e.g., a company.

2.2 Innovation

Innovation, generally, refers to new products, processes or ideas that are put into use in the world. "Innovation" differs from "invention" which is the creation of those new products or processes, in that innovation implies inventions that are put into practice. Schumpeter lists five types of innovation: new products, new methods of production, new sources of supply, exploitation of new markets, and new ways to organize business [14]. In this paper, the term "product" is in line with the ISO definition and refers to "what is sold" and thus not only the physical artifact:

> *A product is an output that results from a process. Products can be tangible or intangible, a thing or an idea, hardware or software, information or knowledge, a process or procedure, a service or function, or a concept or creation.*

Innovation literature frequently comes from the social sciences with roots originating with, e.g., Schumpeter. Innovation references also originate from within the field of engineering, e.g., [15, 16]. One related observation is presented by Kline and Rosenberg:

> *Economists have, by and large, analyzed technological innovation as a "black box" – a system containing unknown components and processes. They have attempted to identify and measure the main inputs that enter that black box, and they have, with much greater difficulty, attempted to identify and measure the output emanating from that box. However, they have devoted very little attention to what actually goes on inside the box; they have largely neglected the highly complex process through which certain inputs are transformed into certain outputs.*
>
> *Technologists, on the other hand, have been largely preoccupied with the technical processes that occur inside that box. They have too often neglected, or even ignored, both the market forces with which the product must operate and the institutional effects required to create the requisite adjustments to innovation. [17]*

It is often challenging to arrive at a shared vocabulary between these different perspectives. This paper attempts to draw on literature from social science and engineering perspectives.

2.3 Product Service Systems

The concept of product-service systems (PSS) emphasizes a shift in focus from selling only a physical artifact or service to selling the result of a combination of the two. Definitions of PSS typically include reference to increased competitiveness of PSS providers and often refer to reduced environmental impacts.

Tukker presents eight types of PSS, divided into three categories: product-oriented, use-oriented, and result-oriented [18]. Tukker, Tischner and Verkuijl have explored the opportunities for environmental improvement with regard to these eight types of PSS, suggesting that all eight types are usually, but not necessarily, associated with improved environmental performance [19]. Of the eight types, some are believed to have the opportunity for more significant environmental improvement than others, with the function-oriented type having the most significant opportunities. This eighth type, functional result-oriented PSS, leads into the idea of "functional product development" described by [6] as having the objective of "developing the solution (i.e. any combination of hardware, software, services, etc.) to customer needs that create value for the customer."

2.4 Sustainable Product Innovation

There is significant research in a variety of areas closely relating to sustainability in product innovation. Recently, work was done at Imperial College focusing on Sustainable Product and Service Development (SPSD) that reviewed many approaches to sustainability in product development and resulted in an approach emphasizing functional and systems thinking [7]. Ecodesign emphasizes bringing ecological issues into the product innovation process; see [20] for an introduction, as well as closely-related concepts like Design for Environment (DfE). The present work differs from those by utilizing the framework for strategic sustainable development mentioned in 2.1, thus providing a different perspective with regard to the sustainability component with potentially different results.

There are various approaches to design (more broadly than product development) that also bring in sustainability-related thinking, e.g., Cradle-to-Cradle or Biomimicry. Here, emphasis is placed on radical innovation through outside inspiration. Cradle-to-Cradle, with the mantra "waste equals food," emphasizes the need for technical systems to operate in cycles, and highlights the concept that "eco-efficiency only works to make the old, destructive systems a bit less so" [21]. Biomimicry suggests that nature has been innovating for millions of years, and that there is a huge amount of inspiration to be explored by human designers [22]. These two examples are mentioned because they strongly relate to the idea of using sustainability thinking to drive innovation.

3 TOWARDS SUSTAINABILITY-DRIVEN INNOVATION THROUGH PRODUCT-SERVICE SYSTEMS

Section 3.1 presents views on how sustainability considerations are currently included in product innovation processes. Section 3.2 develops the case for using, and then presents ideas for how to work towards, sustainability-driven innovation through product-service systems.

3.1 Observations on Sustainability in Swedish Product Innovation

This section first reflects on some motivations for companies wanting to include sustainability in their product innovation processes, followed by some ways that they are including sustainability in those processes and some of the justifications they provide for doing so.

Motivations for Including Sustainability

Companies include sustainability criteria in their product innovation processes primarily for one of these reasons: 1) legislation, 2) cost reduction (e.g. resource efficiency), or 3) employee interest in "doing good."

Certainly the Swedish companies involved in this work include sustainability aspects at least to the extent that they must in order to comply with legislation. Sustainability criteria that overlap with cost savings (e.g. efficiency of resource use or energy) are also very likely to be considered. Other sustainability criteria that do not have direct effects on cost are much less likely to be considered; though aspects that can have indirect impacts on company success, e.g., through the company's image are being considered with greater frequency.

The origination of sustainability from legal requirements or employee interest often leads to sustainability considerations being perceived as an extra expense, i.e. one more requirement that competes for resources.

In both business-to-consumer (B2C) and business-to-business (B2B) situations, customers are increasingly demanding sustainability be considered. In B2C it is often in the form of eco-labels or other identifying factors that provide peace of mind to the consumer, while in B2B situations it frequently relates to procurement demands by the purchasing company to reduce risks, e.g., of not being in compliance with environmental legislation.

Ways of Including Sustainability

In response to the way sustainability aspects are beginning to be required of companies, sustainability aspects are being added into product requirements, e.g., compliance with materials lists that say certain substances are not to be used in a product itself or the manufacturing processes for the product; carbon emissions over the life of the product must be estimated and held at or below a certain level; or the working conditions of suppliers must meet certain requirements. Some of these have been around for decades (e.g. material lists), while others are more recent (e.g. social aspects at suppliers).

Innovation processes must then take these additional requirements into consideration. This further limits (e.g. beyond technical limitations) the design space in which product developers are able to create solutions, and may draw resources away from other types of improvements that could be made. This adds to the cost of the innovation project, putting additional constraints on the already stretched allocation of resources.

Justification for Including Sustainability

These approaches typically lead to attempts to show how sustainability efforts reduce costs or increase revenues, and to argue that when fully considered sustainability aspects do not increase overall costs for the company. Theoretically, this is done at a product level through, e.g., life-cycle costing (LCC), total-cost accounting (TCA), or full-cost accounting (FCA); see, e.g., [23, 24]. Willard has written on the effects of sustainability at the firm level, and suggests that there are significant economic impacts on a company's bottom line from incorporating sustainability aspects that relate to, e.g., staff retention, attraction of the best talent, etc. [12]. Many companies that have been involved in these research projects are aware of these approaches, but do not appear to have them integrated into standard procedures.

Summary of Observations

The chain of thought presented in this section suggests that companies include sustainability considerations either because they are required by legislation, out of some sense of greater good, or in order to attract or retain customers and staff. All of these are fine reasons to include sustainability considerations, and likely contribute to a company's success. However, this chain of thought does not get directly to the main motivation for industry: profitability. Rather, there is an indirect journey that leads back to profitability. As with the FSSD referred to in section 2.1, "sustainability" is at the "success" level. However, for companies, "success" is not "global socio-ecological sustainability," but rather "profitability." Awareness of sustainability issues and the strategic use of them can certainly support a company's efforts to be profitable.

Innovation is a significant factor in profitability: the ability to identify and successfully take to market new products, to find new and better ways to produce physical artifacts and to deliver services, etc. directly support competitiveness and profitability for firms. And, innovation that supports development of society towards a future that 'can be' (i.e. a sustainable society) should have an inherent overall advantage over innovation towards a future that 'cannot be'. Assuming this is true, there is an opportunity for sustainability to drive innovation processes in companies that leads to profitability. What is missing, then, is the competence to use sustainability, and especially a strategic sustainability perspective, to guide and accelerate innovation processes.

3.2 Sustainability as Driver of Innovation

The Case for Sustainability as Driver

Sustainability as described in section 2.1 asks what is necessary in order for human society to not systematically degrade the social and ecological systems that it depends upon, and suggests that society ought not to do things that potentially risk long-term existence. This way of thinking about sustainability can be used to drive innovation by guiding incremental and radical innovations in either products or processes (e.g. reduced material or energy use by a product or increased efficiency in production processes). This thinking can also drive incremental and radical innovations in business models, market conditions and societal institutions which opens up for the meeting of human needs in ways that mean significantly reduced negative environmental or social impacts.

Sustainability-driven innovation is different than "innovation for sustainability," which implies that the innovators are interested in pursuing sustainability as an end goal. This is not typically the way companies do, or even legally can, define success. Rather, knowing about sustainability issues can help companies to be more successful on an increasingly sustainability-driven market.

Using a product-service system approach provides an opportunity for companies to reconsider how their artifacts, services, and combinations of these create value and generate revenue. Pursuing a PSS does not necessarily explicitly demand a sustainability focus or even awareness, and it does not necessarily imply an improved sustainability profile. Rather, a PSS-approach opens up to new ways of thinking which are inherently in less contradiction to a sustainable society than more traditional approaches focused only on generating revenue from the sales of physical artifacts. This is because a PSS-approach opens the possibilities to generating revenue based on the provision of specific functions that meet needs rather than generating revenue based on the sales of those physical artifacts. Revenue based on function is further enhanced through sustainability-related initiatives such as dematerialization, consideration of closed-loop product life cycles, minimization of operating costs that are often indicative of negative environmental or social impacts, etc.

Making Sustainability the Driver

Section 3.1 presents observations of the day-in and day-out of sustainability aspects in product innovation in some Swedish companies: there exists a core product, there is a desire to improve the product both in terms of meeting evolving customer needs and in terms of profitability, and there is an interest or a need to maintain or improve sustainability performance. With that in mind, and also keeping in mind Section 2.4, which briefly introduced other existing innovation-based design approaches (with Cradle-to-Cradle and Biomimicry as specific examples), the following are thoughts on how innovation processes can become more sustainability-driven.

Backcasting when Developing Support

The challenge when developing support for innovation processes is that with regard to sustainability, there is a sense of needing the radical changes that can be inspired by more radical concepts. On the other hand, the challenge of integrating support into existing product innovation working environments is that there are established routines and tight timeframes for innovation projects; asking for a radical re-thinking of how a product should or could function is simply not possible given limited resources. Product developers ask for a simple tool that guides them to the right material choice; e.g. aluminum requires more energy to produce than steel, so steel should be used. This, of course, is a gross over-simplification of the life cycle impacts of the different materials, and is precisely why simple, well-intentioned guidance is problematic: the questions seldom have simple answers. People understand this: aluminum is lighter than steel, so using aluminum instead of steel in some applications will recover the extra energy used in production, eventually having a better overall performance with regard to energy use. However, the best design may depend significantly upon user behavior, thus an apparently simple question becomes a wicked problem as described in section 1.2.

Support concepts must acknowledge the reality of the present product innovation working environment, including resource (e.g. time) constraints as well as product performance obligations. This naturally tends towards an incremental approach to improving the sustainability performance of products. At the same time, there is an urgency to provide support that is capable of meeting the ever-higher demands of the global context. In light of this, there is an opportunity to use a backcasting approach when developing support tools and methods. This would entail developing support that considers both the immediate decisions that product developers are being asked to make, and also using that support to lead the product developer's thinking into new areas.

The short-term steps involve providing support tools and methods that companies need to continue exploring a PSS mindset may not result immediately in function-based innovation (since function-oriented products are only one type of PSS). The long-term is about working toward function-based innovation so that revenue streams can evolve to be based on sales of function – with its associated potential benefits for global socio-ecological systems.

Here the suggestion is that the backcasting approach should be used by researchers to develop support methods and tools. Furthermore, based on the assumption that pursuing function-based products is a very attractive opportunity that combines society's need to pursue sustainability with the business need to be profitable, the suggestion is that the vision that is backcast from should be a product innovation working environment that is focused on functional product innovation.

Expand from Sustainability Constraints to Sustainability-driven Innovation

As described in 3.1, sustainability is often incorporated into product innovation working environments as an "add on," e.g., through product or process requirements that serve as filters to reduce the number of ideas or concepts until only the "more sustainable" (i.e. the options with the fewest known environmental impacts) remain.

To a greater or lesser extent, adding sustainability-based design requirements and incorporating methods and tools to existing product innovation processes are ways of comfortably introducing sustainability into those environments. However, as the easy opportunities for improvement with regard to sustainability are implemented (i.e. the "low-hanging fruit" are "harvested"), continued improvement with regard to sustainability aspects is more difficult. After the easy opportunities are exhausted, then there is a need/opportunity for sustainability to proactively drive innovation.

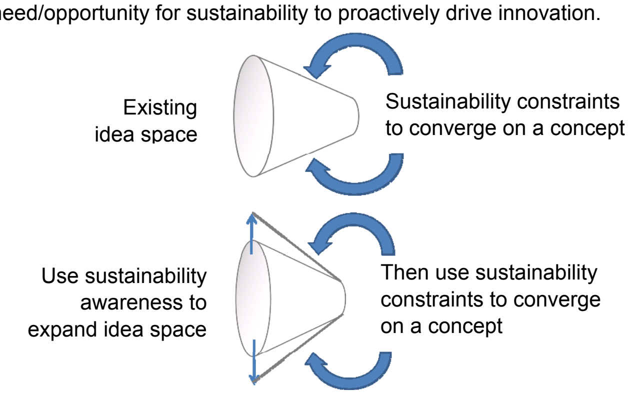

Figure 1: Using sustainability knowledge to expand idea space prior to using sustainability knowledge to constrain selections.

Here it is suggested that sustainability can drive innovation by opening up the idea space during idea generation, i.e. contributing to the "divergence" that occurs in earlier stages, before sustainability aspects are used as a filter to "converge" into a final product. An example of this is provided by Ny et al. through a waterjet cutting machine, where they describe a way in how to do this by modeling a current system and then looking at it in an anticipated future in which the market is increasingly sustainability-driven.

Create value by optimizing at a broader system level

Expanding the peripheral perspective of people working with innovation can lead to opportunities for capturing value that is otherwise outside of their scope. This is because there is frequently an emphasis on the optimization of sub-systems, while higher level systems remain sub-optimized: focus is on tweaking the details of lower-level systems, while opportunities for significant higher-level system improvement are missed. This is in line with what Bey and McAloone [25] suggest when discussing the role of ecodesign and LCA in PSS development: that a PSS approach inherently promotes thinking at a higher system level.

A waterjet cutting optimization project illustrates this: the first efforts in the project related to building detailed technical models of the machines and machines parts, which were used to better optimize the weight of the parts, and thus improving the energy efficiency of the machine, e.g., an opportunity to reduce the weight of moving parts by 30 percent lead to overall system improvement [26].

Additionally, outside of the scope of those early technical improvements, was the opportunity to optimize the broader system with regard to use of sand as an abrasive in the process. The weight optimization of machine parts is at a more focused system level, thus involving a smaller number of actors, and thus easier to modify. The opportunity to optimize the abrasive was out of the scope of the initial focus, and when explored, involved a significantly larger number of actors. There is, however, economic value to be captured and environmental improvement to be made specifically by reducing transportation related to the sand. One can assume the current situation happens as it does today because it optimizes the economics at a certain level. However, as the market becomes increasingly sustainability-driven (e.g. increased transportation costs due to energy price increases, carbon-related taxes, etc.) opportunities to optimize at a higher system level will become more economically rational.

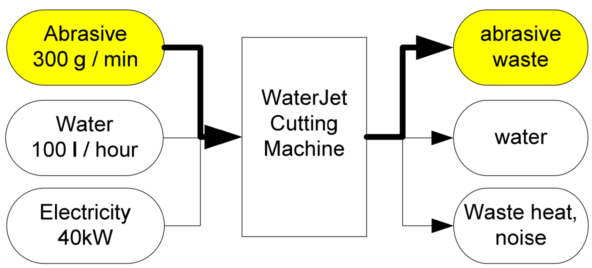

Figure 2. Expanding the view of the Waterjet Cutting Machine to include other required energy and material flows in the cutting process. The abrasive is highlighted due to having the greater environmental impacts.

This example is provided as an illustration of how broadening system boundaries can lead to improvement: first the machine itself was optimized. Then this example broadened system boundaries to consider how to optimize consumables related to the machine, The next opportunity to broaden system boundaries involves a move toward a PSS based offer (selling the function of cutting, instead of selling machines) by further extending system boundaries, e.g., to better consider how users interact with the waterjet cutting machine and the specific contexts of how the machine is used.

Capturing the value created by optimizing at higher system levels is challenging, particularly with business models focused on the sales of physical artifacts. However, Thompson et al. present an example that appears poised for capturing value at this higher level: long-life light tubes that reduce total cost of ownership by eliminating operating costs associated with changing the light tubes at the end of their useful life [27]. This value is not typically considered in the development of physical artifacts, and communicating it to customers is also challenging. The PSS approach, however, opens possibilities for win-win-win situations for the light-tube providers, users and (because of improved sustainability-performance) society.

Innovate the offer, not the artifact

The case presented by Thompson et al. also shows that there is an opportunity to use an existing product to focus on a new approach to providing the function that customers want. In the case of long-life light tubes, the physical artifacts have a specific attribute (a working life several times longer than the average light tube) that (potentially) offers a significant sustainability advantage. This case suggests that in order for the sustainability advantage provided by the attribute of that product to also be made into an economic advantage, the business model around the product needs to shift toward a function-based offer of providing light, rather than remaining focused on selling the physical artifact.

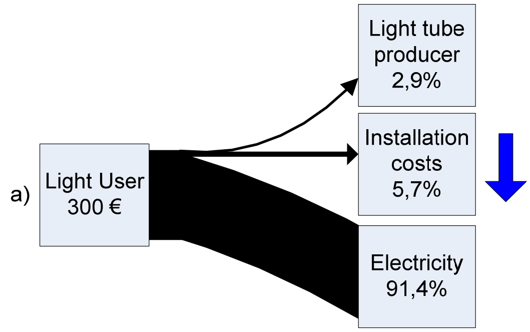

Figure 3a: Total customer costs for light during 12 years with 4 standard-life light tubes sold as the product.

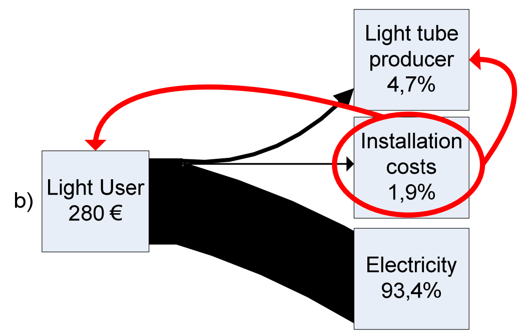

Figure 3b: Total customer costs for light during 12 years with one long-life light tube as the basis for a PSS-offer.

4 RESULTS AND CONCLUSION

This paper aims at supporting the inclusion of sustainability considerations in the product innovation process by articulating how sustainability can be a driver in the innovation process, specifically through a product-service system approach. This work contributes to understanding with regard to theory about how sustainability-driven innovation can occur through product-service systems within the broader research field, as well as how to apply that understanding to the state of practice in industry today in order to realize more sustainable PSSs.

There is an opportunity to improve sustainability performance of a PSS and increase customer value by broadening the scope in product innovation working environments to allow for increased consideration of opportunities in two areas highlighted in this paper. First, technical systems can be optimized at higher system levels, e.g., as in the case of abrasives with the waterjet cutting case. Second, business models can be modified to focus on communicating value through function, especially with regard to products that have sustainability attributes as demonstrated in the case of long-life light tubes. For those working in the area of sustainability, “sustainability” often becomes the primary motivating factor. While a business cannot be sustainable if it is part of an unsustainable society, the perspective is different from within the business world. Thus, companies are typically more interested in innovation than sustainability, for the ability to innovate is what allows the company to sustain itself: changing customers, offering new products/services, expanding into new markets, etc. In recognition of this, this paper has demonstrated and developed ideas around how sustainability can be used to drive those innovation processes through product-service systems that companies rely upon, while also supporting global society's movement toward sustainability.

5 FUTURE WORK

Future efforts building upon this work could include:

- Clarifying the argument for shifting inclusion of sustainability aspects from a "do less bad" approach that only emphasizes quantifying and reducing known negative environmental impacts, and moving toward a methodology where sustainability is driving innovation processes;
- Further reviewing and summarizing sustainability aspects of PSS, with a specific look at the FSSD's role in understanding and analyzing the value PSS can bring to global sustainability work;
- Continuing to support working toward sustainability-driven innovation through PSS by developing methods, tools and frameworks; and
- Exploring how socially oriented aspects, and in particular user interaction with the product, can be better considered during product innovation, specifically in the context of a PSS based offer, where user behavior has very significant implications for the economic viability and sustainability performance of the offer.

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