Creating Value, not Wasting Resources: Sustainable Innovation Strategies

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It is well-accepted in academic and public debate that society has overused natural resources. Business managers in consequence face a normative framework where products need to become more 'sustainable'. The paper characterises the mechanisms and logic that make '[environmentally] sustainable innovation strategies'. Those mechanisms highlight multiple value creation and sustaining value beyond the original new product lifecycle. They yield as much utility as possible from the embedded natural resources. And they avoid creating waste. 'Multiple value creation' asks managers to revaluate the attrite product or to make customers change their use patterns. The paper then demonstrates how to extend the 'old' logic of innovation with a phase of revaluation: a phase promoting further use of the product and/or material. Our concept is empirically illustrated by two industry case examples. Namely, the copier industry and the emerging automotive lithium-ion batteries industry. We provide a patent analysis in order to demonstrate the assessment of extended life cycles, for the case of 'recovery of raw materials from disposed products'.

Keywords: value creation; resource efficiency; business model innovation; sustainability

Introduction

Academic and public debate suggest that society has overused natural resources (WWF 2012). Natural resources are depleting, resulting in undesirable consequences (Meadows et al. 2004). This puts normative, societal pressure on business managers to make products become more '[environmentally] sustainable'. *Inter alia* this requires less resource consumption. This paper contributes to the display of how firms profit from innovation within that particular normative framework. We argue that 'sustainable innovation strategies' are characterised by multiple value creation, and by sustaining value beyond the single new product lifecycle. Well-established economic theory regards innovation as a process of destruction and one-point-in-time value creation, followed by depreciation. Companies usually pursue creating value from product novelty; with each new vintage, they advance their product lines both in terms of new technology and new functionality. In the long run, the newly produced products are used up, depreciated and finally turn into waste.

The very principle of ‘sustainable innovation strategies’ is to avoid creating that waste. It is about creating value multiple times and for the same material. A more sustainable, green and clean pattern of innovation is again, just as the conventional pattern would be, characterised by creative destruction, value creation and depreciation. However, in contrast, first consumption must be extended by a phase of revaluation that facilitates and promotes second and further use phases of a product or material. We argue for a prolongation of product lifetime as a means to a more sustainable industry. Furthermore, new business opportunities arise. Some companies may specialise in second-use business models or in process technologies for sustaining the product or material within a new use context. This paper outlines a novel principle of ‘sustainable innovation’ where value creation takes place multiple times and where several different lifecycles overlap.

The structure of this paper is as follows: Section two “The old, conventional pattern of new product innovation and technological change” elaborates how product development traditionally follows a linear, pipeline approach. Section three “Towards a new pattern of sustainable innovation beyond efficiency” develops a paradigm of prolonged value cre- ation. The section underpins the conceptual development in this paper. Thereafter, section four “Multiple value creation in practice” explains and operationalises the concept of pro- longed value creation. It does so by looking at two case study examples. It becomes clear that process technology plays a major role in sustainability strategy’s implementation. This applies at least where closing-the-loop is concerned. Thus, section five is dedicated to the “Mapping [of] recovery and recycling industry to product segments and companies”. Section six “Discussion: does industry yet close the loop?” critiques the contrast of theory and sustainable innovation strategy practice. Finally, section seven, the “Conclusions”, closes the paper. We ask, if a new industry sector of reduction and re-use business is emerging. The paper tracks the technology landscape by a patent analysis based on intellectual property classification (IPC) of technology-industry concordances.

The paper displays the different logic layers of a sustainable strategy, if pursued within the circular economy context (see Figure 1). The logic of ‘loop closing’ and likewise of ‘multiple use’ are naturally opposed to a classical new product pipeline-centric view. Multiple use implies new business models beyond the sales of factory output. Examples are refurbishing; material collection and recovery services; or sharing economies. In an industrial context, recycling and materials recovery processes pose technological challenges, triggering process innovation. Examples are new processes that reduce costs, such as, facilitating less energy input or efficiency gain. In a nutshell, innovation logic, business model and process technology cannot be thought as separate. It is their combination that shapes strategy. The three levels also touch different disciplines: first, the nature of innovation itself is from a management, economics or social sciences perspective. Similarly, the business model layer which translates innovation into economic practice also bundles the underlying technology and resources to a value proposition. However, these layers must also be informed by engineering sciences and technology management. The third layer specifically addresses underlying process technology. This is pure engineering science and comes with its own vocabulary, for example, for the topic of a circular economy. Our paper covers all these layers and aims to help a holistic understanding of the techno-conceptual issues in implementing environmentally sustainable strategies.

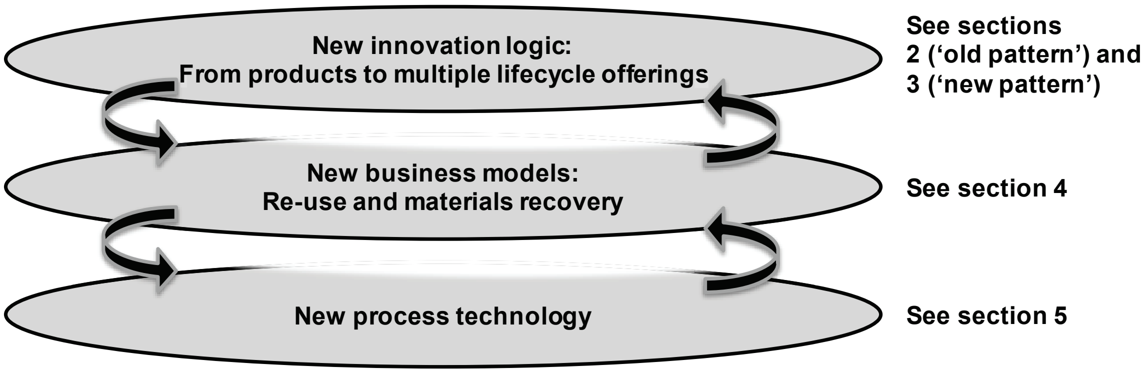

Figure 1: Environmentally sustainable strategy as a multi-layered concept

We present two cases of electr(on)ic products: first, the case of copier machine refurbishing shall illustrate the link between new innovation logic and business models for remanufacturing in the same use case context. Second, the case of automotive batteries shall display the link between an innovation logic of shifting to another than the original/first use case.

To manifest the technology case that underpins closed-loop business models, we conduct a patents count analysis. Similarly, Hagelüken (2015) stresses the crucial role of special and precious metals, labelled as scarce, for a number of clean technologies and high-tech electr(on)ic products. For product recovery, the occurrence of process technology is vital. In our paper, this technology innovation is assessed via patent analysis. For electronics, the untapped potential of closing the loop is currently a hot topic of debate. For instance, take the recovery of neodymium from hard drive recycling (see Sprecher et al. 2014). Consequently, the technology case analysis equips the study with a strategic appraisal of loop closing opportunities and concepts in the technological realm.

Note that our paper primarily considers the economic and ecological aspects of sustainability. The focus lies in innovative measures for pushing ‘sustainability’ and in particular, resource efficiency.

The old, conventional pattern of new product innovation and technological change

Following Schumpeter, we define ‘innovation’ as establishing new combinations of production resources with regards to production factors. Schumpeter (1934, 66; 1935, 100 f.) distinguishes five kinds of innovations: manufacturing of a novel kind or category/quality of product, using a new way of production method (process innovation), entering a new market, exploring a new raw material source, or establishing a new kind of business organisation. Therefore, innovation is considered as a destructive force but also a learning process. Firms can either invest in exploring new knowledge or in utilising current knowledge (Schumpeter, 1934). In that context, innovative organisations or state agencies are taken for change-agents who fulfil an entrepreneurial function (Hagedoorn 1996). March (1991, 71) describes a trade-off between exploration and exploitation where ‘exploration includes things captured by terms such as search, variation, risk taking, experimentation, flexibility, discovery, and innovation’.

It is therefore the purpose of strategic management to find a long-term profitable balance between exploration and exploitation. This balancing process is discussed under the term ambidexterity (e.g. Andriopoulos and Lewis 2009). System boundaries, however, constrain the utilisation of knowledge both mentally and technically:

> Firms exploit by search for knowledge within the organizational boundary and knowledge that is local to their existing knowledge base and explore by searching distant knowledge that is unfamiliar (Li et al. 2008, 119 f.).

More recently, literature has discussed how firms can better access external knowledge but also commercialise internal knowledge beyond the boundary of their own business system. More specifically, knowledge can be derived from various sources as well as exploited over various 'channels to the markets'. The term 'open innovation' (Chesbrough 2003, 2006; Chesbrough et al. 2006; Gassmann 2006) represents the many options of collaboration, markets for technology and joint commercialisation with business partners.

Put simply, the old pattern of innovation is about novelty from technology or technique. Over time, mass consumer markets lead to a dominant pattern of new product technology-pull. Multinational firms nowadays focus on more and more frequent new product launches. This more and more often implies rigorously streamlined product development processes and secondly, the employment of advanced manufacturing technologies (Jovane et al. 2009). Additionally, firms in consumer markets shorten their product lifecycles. Society and industry have thus adopted to some extent a throwaway mentality, a disposal economy.

Indeed, the strictly linear process model has been criticised as being far away from the modern, more circular practice of new product and knowledge generation (Buijs 2003). Notwithstanding, innovation in big companies often still follows a linear new product development process, guided by an end-of-line thinking. If innovation is taken for a sequential, linear product generation process, then technological change is primarily rooted in new product design, not in its modified use. Firms are more likely to generate new features or new technology than they would new business models; they compete via their 'new product pipeline'; and they serve one-time-consumption.

The next sections outline how [environmentally] sustainable innovation strategies can also be economically viable, assumed that firms systematically prolong and interconnect lifecycles, second use/re-use, and loop closing along the value chain. Consequently, novelty in products and production processes are not the only path to sustainability. Nonetheless, some cornerstones of the traditional industrialised product generation process remain important, in particular: (a) the creation of economies of scale, (b) network effects. Economies of scale as well as cost cutting are crucial in order to create mass markets for novel (green) technology.

Towards a new pattern of sustainable innovation beyond efficiency

The 'old' pattern of innovation focused on new product vintages, latest technology and new product features. It implied a one-point-in-time value creation which continuously delivers new products, followed by depreciation of the new product. Materials are used up after first use and the replaced product finally becomes 'waste'. Such new product innovation is technology-pushed or market-pulled, but not primarily and necessarily driven by resource efficiency along the value chain. Notwithstanding, the term 'efficiency' itself remains ambiguous. Within this study, we refer to the economic and organisational aspects, not to the social dimensions of sustainable innovation. It does not mean we would disregard the latter dimensions.

The principle of 'sustainable', 'green' or 'eco-innovation' takes a resource-centric view and assuming rational firm behaviour. 'Sustainable', 'green' products or services shall be defined as products or services that either conserve resources or that reduce pollution or waste (US Department of Commerce 2010). However, there is no trade-off between developing green products and being competitive (Porter and van der Linde 1995). In general, eco-innovations are defined as follows:

> Eco-innovations are all measures of relevant actors […] which develop new ideas, behaviour, products and processes, apply or introduce them [but also] contribute to a reduction of environmental burdens or to ecologically specified sustainability targets (Rennings 2000, 325).

Eco-innovation can be technological, organisational, social or institutional (Rennings 2000). Implicitly, this research stream takes a more systemic view of loop closing value and consumption chains. Eco-innovation pursues saving natural resources in production, consumption and at the product's end of life. Eco-innovation likewise addresses both the production process as well as service innovation. Innovation practice, however, seems to be biased towards the concept of eco-innovation as favouring incremental innovation but neglecting more radical innovation approaches (Hellström 2007). Firms incrementally over time but not abruptly, improve the environmental friendliness of their next product generations. Management then benchmarks one product generation's eco-friendliness against its predecessors. The previously discussed, traditional innovation processes remain 'one point in time' value creation practices.

A novel pattern of sustainable innovation beyond eco-efficiency needs to look at other aspects than solely the product features. We argue that it is necessary to take a multiple lifecycle perspective: natural resources could also be saved though prolongation of lifecycles and extended product life. Firms pursuing this new principle of sustainable innovation then need to change their logics of utility and they need to rethink the product's intended use. However, they would profit from sustainability gains in terms of new business opportunities or new quality of products. Sustainable innovation means the yielding of the most possible utility from natural resources, as soon as they are brought into the industrial system. It does not matter if they are incorporated in a product, component or just embedded as materials (Krikke 2011).

It is not one-point-in-time value creation but revaluation of goods, products and materials which becomes crucial for new patterns of innovation of sustainability. We recognise that the approach intersects with the ‘design for sustainability’ approach. The latter also stresses the environmental impact of different phases in a product’s lifecycle (UNEP and TU Delft 2006). Products can be ‘designed for’ better closing the loop and recycling (see UNEP 2013). Companies can ‘conserve’ resources by either using up fewer resources when manufacturing new products; by designing products that are resource-efficient in their use phase; or they can facilitate or re-use new products after a first use phase. The companies may furthermore recover resources from disposed products. Saying that, we oppose the old pattern of innovation where innovativeness is often primarily measured in terms of new product rate; efficiency gains; and number of produced outputs productivity. The proposed new principle of sustainable innovation saves resources, it is inclusive and lifecycle-orientated. The novel pattern covers new ways to combine product development with product re-use revaluation. Manufacturers and vendors prolong the economic life of a new product when they place it in a new use context or recover components and raw materials. At the end of various use phases (i.e. first and second use industries) high-priced raw materials are recovered. The lifecycles of product materials and even markets overlap; and the value chain is finally closed in a loop.

The ‘art of’ the sustainable innovation strategy we propose is a sequence of value creation and revaluation. It is not a substitute but complements the logics of resource saving, energy efficiency and eco-efficiency. The innovation of ‘sustainable’, prolonged use consists of creative destruction, of value creation and of depreciation. The companies would extend conventional practice by (at least) a second phase of revaluation.

That sequence of value creation and revaluation avoids creating waste. Rather, companies create value multiple times from re-use. Innovation then concerns either the detachment of re-usable components or the creation of novel use contexts for the attrite product.

While the duration of the first use phase depends on the economic end of life, the technical end of life of products or included components may exceed that life span. Therefore, the very purpose of sustainable use is to maximise the economic lifetime of products and their materials. First use shall be defined as the use of a new manufactured product without it being linked to a previous marketed product. Or, the new product at least includes a significant improvement of a previous product’s features. Innovation strategies of sustainable materials’/products’/services’ usage creates and seizes opportunities for second and subsequent use after or instead of a new product’s disposal. We hereafter denominate such strategies as ‘revaluation’.

The paper argues for two different patterns of revaluation.

First, industry may create value from re-use of components or processed materials. Modified new products may integrate already-used components; for example, for basic functions. Such innovation would then be limited to economically sound technical options of recovering the component. Innovation would be rather incremental: materials and production effort inherent in the components were preserved, but flew into a new product. Modular product design is a prerequisite in order to achieve this approach. The pattern can be considered a type of modular innovation (Henderson and Clark 1990).

Secondly, value created can be rooted in a socio-technical use context or in new business models which prolong the materials’ economic lifecycle. Specialised firms may introduce and establish novel use contexts attaching a second or third use phase to a merely technologically unmodified product. Such a new use context or business model for a prolonged economic life can span different product lifecycles and even several application domains stretching across industry sectors. This kind of innovation is rather a business and organisational innovation than a new kind of product. Success factors for innovators differ especially in that regard: firms need to be capable of adapting the new product development in order to apply the re-use logic or they need to be capable of implementing new business models. These are two dynamic capabilities. The first is a matter of technology; the second is an organisational and managerial ability of exploring, creating and unlocking new markets (Geroski 2003).

The multiple sequences of value creation and revaluation are closed by the final step of raw materials recovery. At that process stage, the used product cannot be revaluated regarding its functional components or as a whole, and all economically viable options for re-use have been realised. Therefore, the product’s raw materials have to be recovered by recycling processes. In this very case, value can only be created from the extraction of raw materials from the fully depreciated products. The opportunities in recycling are both determined economically (raw materials prices) and technologically (process technologies, materials in a state of high entropy). In industrial context, the relevant innovations for this value chain step are merely new technological processes and new practices in service distribution networks or take-back systems. Figure 2 provides an overview of the new sustainable pattern of innovation and it displays the overlapping lifecycles.

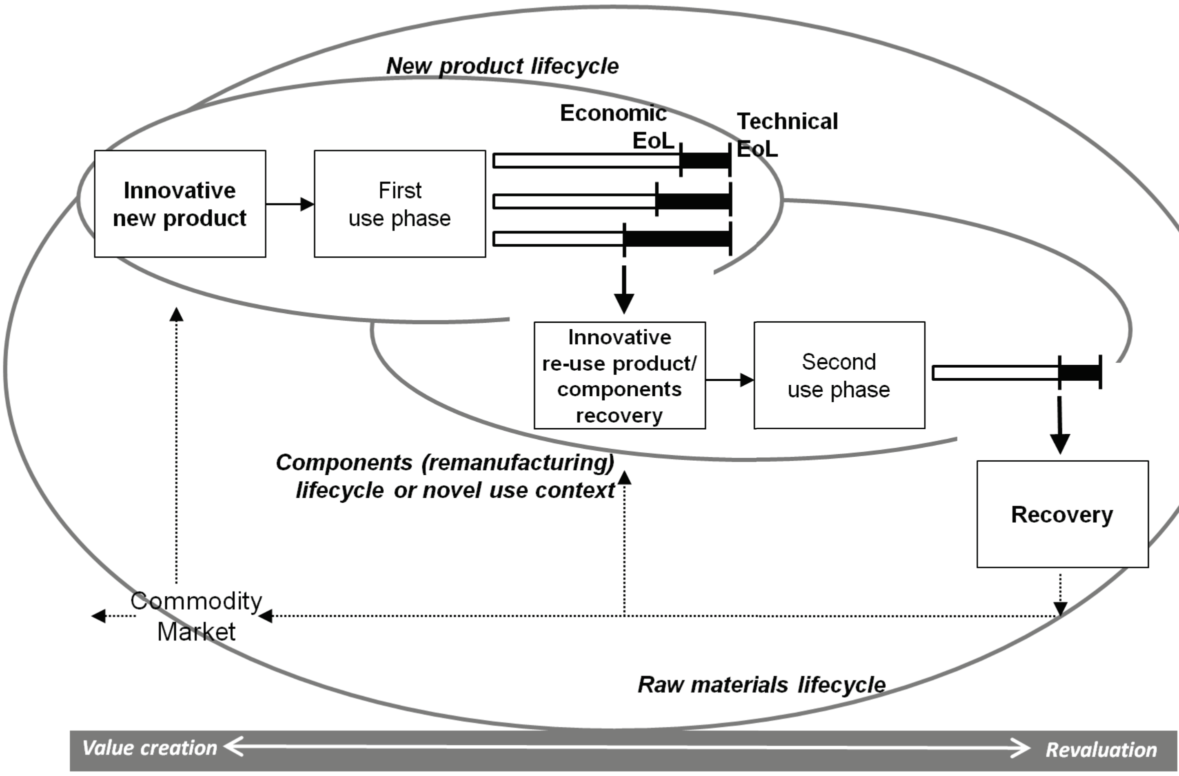

Figure 2: Conceptualisation of the Sustainable Pattern of Innovation

The old pattern of new product innovation is driven by creating value from new features and new technology. In contrast, sustainable innovation strategies are about seizing new opportunities of (re-)use. They follow a logic ‘from material to new product to second use products’ etc. First use and subsequent secondary use phases then create a chain of overlapping lifecycles. The product is used up incrementally over lifecycle by lifecycle; either from higher to lower requirements in novelty and quality within the same industry, or just within different use contexts and possibly, different industries. At the end of the aggregated economic lifetime of the different lifecycles, high-priced raw materials will be recovered and the residual product turns into waste. The clever industry leader will anticipate second use when developing and distributing a new product. The aforementioned product’s second or third use – and so on – must be profitable for the original manufacturer, who is taking it back, or for the consumer, if the latter owns the product. Manufacturers and dealers can re-use components or processed materials. Industry first needs to be enabled to create a market environment where the customers are in principle willing to buy used products or materials.

Generalised, it is environmentally ‘sustainable’ to exceed product life by second and third use, and so on, if such subsequent use does substitute the purchasing of new products.[1] Furthermore, the preserved utility from re-use or refurbishment must exceed the costs of revaluation. Costs can arise from assembly and remanufacture; technical modification; functional and quality testing and repair. They can also occur for certification; increased warranty; cannibalising the own new product; or marketing.

The technical end of life represents the maximum lifespan a processed material (in the form of a component or product) can be used up prior to recovery. We propose that suppliers should ask the following questions when developing new products: which components can be re-used by our company? How can we design and develop a new product attractive for second use? Given that revaluation comes with costs, is there a viable business case for second use? If there is: which industries can reprocess the materials or components best? What is the best suited business model, in terms of aggregated lifecycle costs and of utility across lifecycles?

Note that a product’s use may also end due to a lack of energy efficiency (e.g. no longer up to standards due to high electricity use) or end due to technological obsolescence compared to the features of a brand new product. The attrite product might although still function. Moreover, there must be a viable market for second or third use (VDI 2012). Therefore, industry makes an economic decision about when to end a use case’s

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[1] Environmental benefit is case-specific. It depends on use patterns and on potential gain of efficiency-in-use of its subsequent conventional new product generations.

lifespan in favour of another use case or to facilitate the components' re-use. The argument is illustrated in Figure 2.

When re-using a product in a new use case context, the innovator implicitly switches to a new market with another market lifecycle. An innovator has to switch between these lifecycles at the right time in order to create value or revaluate products and approximate the economic optimum of product materials' life. From an ecological stance, this 'not only one point-in-time value creation' is a means for using resources more efficiently. More efficiently by keeping them as long as possible in the industrial cycle, by avoiding their unnecessary early depreciation. The decision regarding what sustainable innovation has to tackle the end of the first use phase is based on how to connect the several overlapping lifecycles illustrated in Figure 2. The lifecycles are material product lifecycles. They include each and every lifecycle phase that could determine or generate ecological impact (for a detailed description see Regenfelder and Ebelt 2012; VDI 2012). Making this decision can include deciding whether to explore novel business models or to switch to other industries and, to novel application domains for the processed materials.

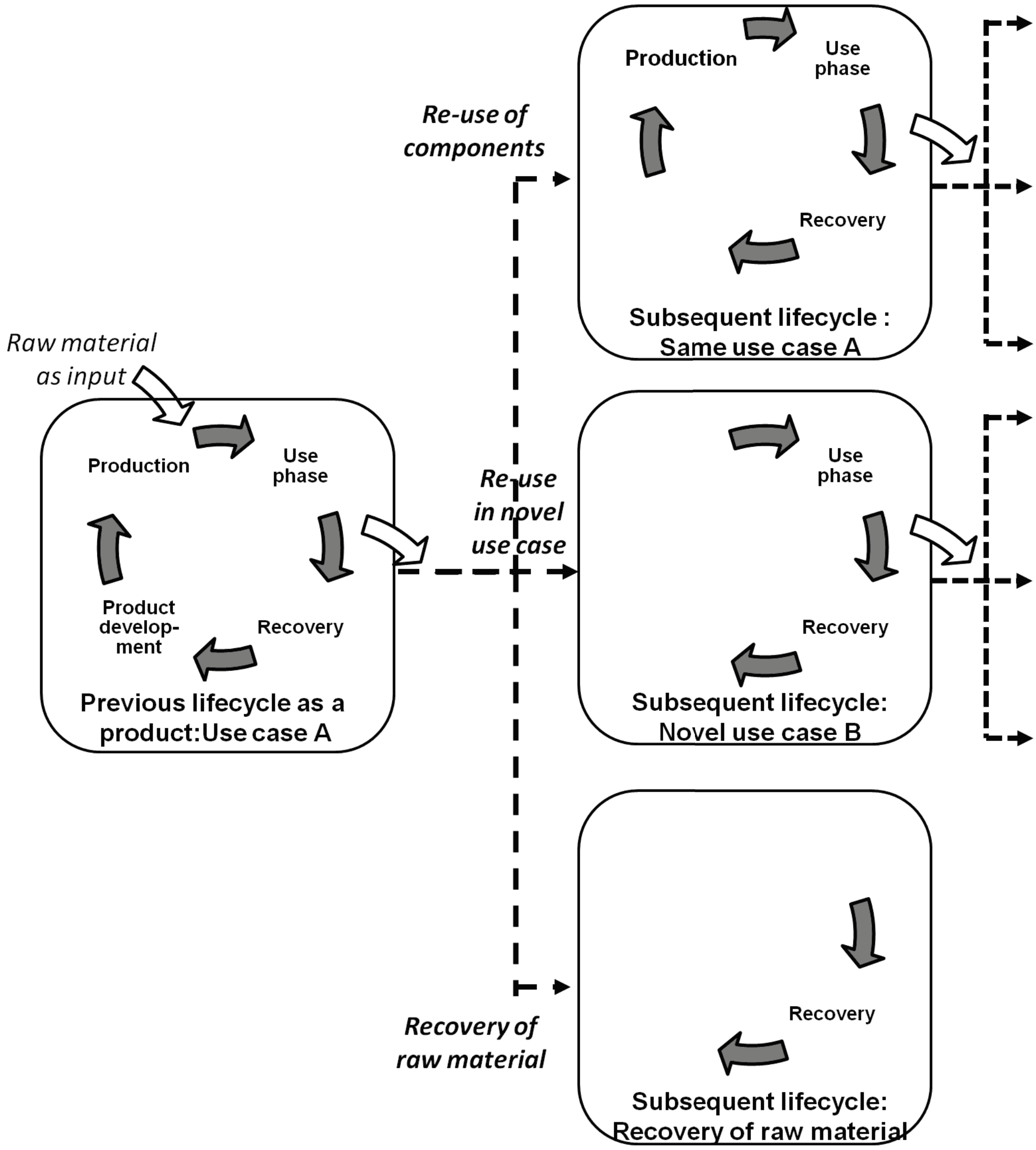

Figure 3: Options for Innovators to Create Value after First Use Phase

A manufacturer's sustainable innovation strategy would evaluate whether to re-use components (for the same use, use case A in Figure 3), whether to re-use products in a new use case (use case B) or whether to recover material (no second, third etc. use). In a sustainability-driven market regime, waste disposal also creates costs for the firm. Revaluation and recovery of particularly high-priced raw materials therefore may be paths to follow to cut costs. The right market regimes may offer new business opportunities to firms specialised in reduction and waste management. Note that Figures 2 and especially 3 illustrate how different value creation cycles interfere (use cases A, B and recovery).

Multiple value creation in practice

This section provides two qualitative case examples of business models for the first two steps of the proposed strategy pattern of sustainable innovation.

Components re-use: The case of the copier industry

The current copier industry's business model emerged in the 1960s: customers began leasing their copiers from manufacturers, including leasing of service and support. Payment was then as per fixed monthly fee and per page. This means, the manufacturer always stayed in control of the appliances (Chesbrough and Rosenbloom 2002). In 1960 Xerox pioneered the recovery of used appliances. The company developed a remanufacturing system and business strategy from the re-use of components in the late 1980s to the early 1990s (Kerr and Ryan 2001). Other leading copier manufacturers such as Canon, Océ and others then quickly adopted the same business model.

Innovation in the copier industry relates to new features and functionalities, whereas the original core components of the products became commoditised and are now only changed incrementally. Competition is based on price and services. The radical innovation took place in the late 1950s at Xerox when a new technological way of making photocopies was developed. Electrophotography, printing and electronics technology were combined into a new product type. Today Xerox develops new product designs where about 60% of all components are based on previous models. Product architecture is modularised, based on platforms with a standardised set of core components. The 40% innovation of a new appliance consists of new technology pursuing a more durable, energy-saving or a more functional product (Xerox 2010).

In this example, revaluation consists of remanufacturing and the re-use of components. Copiers are leased to industrial customers and old copiers are to some extent disassembled and the then remanufactured components are inbuilt into new products. This mentioned product modularisation is a precondition to this specific business model (Kimura et al. 2001). At the same time, product innovation derives from product adaption: new functions have to be developed in a way that they remain compatible with the used components for functioning in a technical system. The business model (lease of appliances and pay per copy) remains unchanged even though the leasing product now spans potentially different technology vintages.

The component re-use approach omits production steps. It accordingly saves on input for the manufacture of components. Conversely, it needs recovery/reverse logistics and components remanufacture. Economically speaking, the remanufacturing requires less effort than new production and therefore is advantageous. Xerox states that this approach saves several hundred million dollars of costs per annum (Xerox 2012). So value is created and appropriated from revaluation. This finding becomes even more obvious when considering the ecological material–product lifecycle impact. Studies on the resource intensity of the product system conclude that remanufacturing of whole copiers raises resource efficiency. For example, take the re-use of components for Xerox model DC265 (seven removable modules; modules can be shared between product lines): over its lifecycle the model saves 49% weight of materials; saves 68% of energy consumption and avoids 47% of waste. It needs to be stressed that savings are higher if products are designed for disassembly and remanufacturing (Kerr and Ryan

2001).[2] In general, the re-use of copier components equals significant CO_2 savings. Note that these savings are also dependent on the recovery network configuration (Krikke 2011). Xerox, for example, is able to remanufacture and re-use 70–90% of components (% concerning weight) that meet specifications as if they were new. The percentages are facilitated by a 'design for' disassembly and remanufacturing. Such design already considers multiple lifecycles of components in product development. The re-use and remanufacturing programme includes re-use of complete products. It covers the remanufacturing and conversion to an upgraded product; and re-use of major modules or subcomponents as parts in manufacturing. In 2011, Xerox prevented 77,000 tons of waste with this approach (Xerox 2012).

What is obvious in this case example is the strong connection between the first value creation and the subsequent revaluation:

> Xerox also designs product families around modular product architectures and a common set of core components. These advances offer us many options for breathing new life into old equipment. A returned machine can be rebuilt as the same model through remanufacture, converted to a new model within the same product family or used as a source of parts for next-generation models (Xerox 2010, 12).

Different lifecycles of products, components, raw materials and even of future product platforms are considered and overlap. However, a number of components or products are still just recycled when they have reached their technical end of life: they end up as electronics or plastics waste, materials can then be recovered with advanced recycling technologies for loop closing.

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2 Savings are case specific as a result of specifics such as logistics, packaging, network configuration and others.

Second use of new technology: The case of automotive lithium-ion batteries

The first electric car lithium-ion battery for mass production was shipped in 2010–2011. The primary use of the battery (new car) is expected to be about six to eight years. Then the battery is degraded to only 70–80% of its initial capacity and is no longer usable for the automotive use case (Neubauer and Pesaran 2010). A market for secondary use is emerging and industry is planning a future of multiple use, then better maximising value from the batteries' lifetime. That is, from the the planning phase of their e-mobility business models. Large lithium-ion batteries are not yet mature technology; a dominant design has not yet emerged. The first use phase is shaped by the choice of the business model and the product placement purpose of the original equipment manufacturer (OEM). Questions of the purpose are: should the battery be leased or sold? Should the car serve low-safety requirements in low-cost markets, or should it serve a high-quality segment in a market with strict safety regulations? There has also been a debate on the various potential ownership models. Should the OEM sell the battery in a bundle with the new car; share its batteries within a pool (of OEMs); or lease out the batteries directly to the end user? Industry is currently searching for the appropriate business models which can prolong economic life of batteries or decrease first use's battery costs in other fashions. The configuration of business models such as, battery leasing; mobility solutions (combining vehicle, battery and maintenance); or car sharing also implies setting up new terms of usage. Previous, OEMs need to determine economic battery life (Slowak 2012, ch. 3).

Anderson (2009) provides a detailed cost structure analysis of automotive lithium-ion batteries. The cell level takes in sum about 85% of the total battery pack materials' costs. Material costs account for approximately 75% of the battery pack costs. Cost degression from economies of scale will not let cell product prices decrease to 150–250

US Dollar/kWh before years 2020–2025.

Re-use of battery cells' respective modules in applications with low-quality requirements can help spread significant costs among different use phases of various industries. Such low-end applications for second use may be heating or storage of renewable energy sources (area regulation, grid support, electric power service quality, etc., see Neubauer and Pesaran 2010, 2011; Neubauer et al. 2012; Wolfs 2010). The lifespan of the second, third – and so on – use is determined by quality, reliability and safety requirements, consumer perception of value impairment. It is also determined by the requirements of the secondary, subsequent use cases.

Mainly unchanged, the product can be 'switched over' to another use case so that the aggregated lifespan of the battery is prolonged and so that the processed material costs are spread across a larger user base. Thus, initial battery costs are expected to decrease by 11% by 2015 through implementing revenue gains from re-use of manufactured batteries.[3] Revenue potential from re-used batteries is expected to be between 500 and 2000 $/kWh of battery's power capacity in a 10-year period of secondary use (Neubauer and Pesaran 2011). Battery leasing rates in the primary use case could be reduced by 22%, if the product is revaluated, making use of the residual value (calculated for Chevrolet Volt, cf. Williams 2011). Ecologically speaking, a prolonged use phase omits nearly any remanufacturing steps and re-use enables other eco-efficient applications with respect to renewable energies. Figure 4 shows the prolonged lifecycle from re-using or revaluating a new battery.

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[3] Economies of scale and scope assumed.

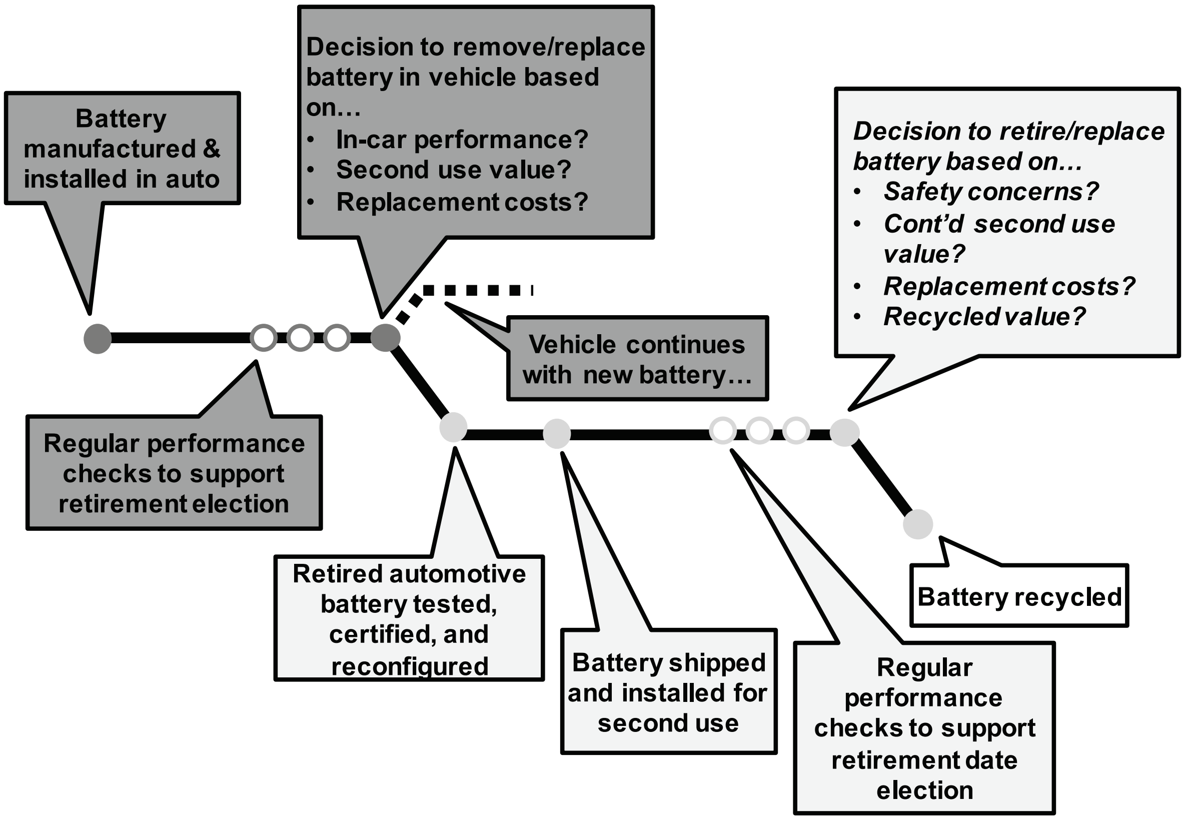

Figure 4: Timeline of an Automotive Battery with Re-use for another Use case

(Neubauer and Pesaran 2010, 21, adapted presentation)

A new product lifecycle begins with product development. Success criteria, among others, are latest technology, functional equivalence, design-to-cost, time-to-market or lead user-driven product design. The second use lifecycle then begins with the re-use of the cell in a new battery pack. It addresses stationary low-end requirement markets. Innovation here is about the value transition between different industries. Likewise, for the copier industry, materials recovery closes the loop and product lifecycles overlap.

At this stage, the revaluation of the materials is driven by process innovation. The higher the price increase of lithium in the course of time, the more materials recovery becomes profitable.

Mapping recovery and recycling industry to product segments and companies

Subsequent patent count analysis mirrors the rise of new process technology available in the electronics industry. We investigate two case examples of recovery processes, related to lifecycle prolongation of products. The paper asks if there is an 'innovation loop closing'. It is important for policy makers, consultants and industry managers to judge informedly about what technologies can close the loop and who owns the knowledge and ownership rights of the available approaches and techniques. Patents are a well-accepted proxy or indicator of technology output (De Rassenfosse 2013; Lee 2015; Pavitt 1985). Patent data has been used to map technological competition in various industries and to track the trajectory of specific technologies (Gao et al., 2013; for examples, Verspagen 2007; Park 2014). Nonetheless, the different patenting practices and patent scopes, among other factors differing across firms and industries, mean that patent data has some limitations. It has to be considered with caution to the case particulars and detail (see Gittelman 2008; Giuri et al. 2007).

Does industry create technology to enable the sustainable pattern of innovation we have previously outlined? The depicted data may be limited to the field of electronics; given that keywords characterise the recovery of resources needed for high-tech products in principle, not for a specific metal's study in particular. Amongst these resources are many labelled as 'strategic': in terms of economic importance and scarcity. Whereas some metals such as 'platinum group' metals already show high end-of-life recovery rates, others such as from the 'rare earths' cluster show quite low recovery rates (European Commission 2010; European Commission 2014a; European Commission 2014b; Graedel et al. 2011; USGS 2013). Their commercial recovery has just started in recent years. For instance, recovered from energy saving lamps (LANUV 2012).

Therefore, this paper assesses whether there is a rise in patenting over time which were related to recycling and recovery technology. We defined loop-closing innovation earlier in this paper. The following provides a patent analysis in order to exemplify ‘which kind of firms are closing the loop’. Would we observe OEMs or rather specialised recycling firms as those developing the underlying technology? If OEMs, it implies that OEMs already include revaluation within their innovation logic.

This patent count uses a keyword search combined with IPC concordances in order to isolate the relevant technology domain (see Table 1). For further details on methodology see Appendix 1. Patent raw data are retrieved from the EPO PATSTAT database. The database particularly covers US, European and Japanese patents. Our concordances for counting the recovery process-related patents refer to selected ‘environmental sound technologies’, specifically listed in OECD (2009) and WIPO (2012) concordances. For product-related patents we isolate electronics technology IPC classes from the Schmoch (2008) IPC concordance.

One term out of
disassembl%, recover%, recycl%, re-cycl%, refurbish%,remanufactur%, reuse, re-use
in combination with at least one term of
high-power magnets, high power magnets, lithium, neodymium, rare earth, platinum group metals, % pgm %, electronic%

Table 1: Applied keywords
Chosen keywords characterise the technology used in materials recovery processes as well as rare earth materials, excluding software patents. Here the term ‘re-use’ would be misleading.

The paper selected four five-year periods. For example, beginning on 1 January 1991 to 31 December 1995. We only count non-PCT (Patent Cooperation Treaty) patent applications of companies and being priority patents within their patent family.

The analysis' results are illustrated in Table 2, including the absolute number as well as relative changes in the growth of the number of patent applications to preceding periods, for each given period. The figure 'adjusted change to preceding period' is calculated from 'change to the preceding period'; it is decreased for the overall change of patenting throughout the entire database within the same periods. This enables us to evaluate if recovery and re-use technology patent applications outperform cyclical dependent patenting growth. Simplified, we want to conceptually demonstrate how policy makers can track available loop closing technology and their leading development firms for a certain sustainable innovation strategy.

Time period t:		**1:1991–1995**	**2:1996–2000**	**3:2001–2005**	**4:2006–2010**	**Period 4 compared to period 1**
Recovery process-related patent count		222	377	399	785	785 vs.222
	Change to preceding period		+69.82%	+5.84%	+96.74%	+253.60%
	Adj. change to prec. period		**+55.83%**	**−21.67%**	**+73.68%**	**+174.74%**
Product-related patent count		519	844	1060	1726	1726 vs. 519
	Change to preceding period		+62.62%	+25.59%	+62.83%	+232.56%
	Adj. change to prec. period		**+48.63%**	**−1.92%**	**+39.77%**	**+153,70%**
Overall patent count		3,541,534	4,036,934	5,147,293	6,334,265	6,334,265 vs. 3,541,534
	Change to preceding period		+13.99%	+27.51%	+23.06%	+78,86%

Table 2: Patent count results. Data from PATSTAT, version October 2012.

Figures for recovery- and process-related patent applications have developed in a similar pattern over time. The 'adjusted change to the preceding period' does strongly increase when compared to the last to the first observed period. However, in single five-year periods, the patterns of increase differ from the overall picture. There is a significant growth in the years 1996–2000, but an adjusted decrease in the following period. For the period 2006–2010, previous strong growth is resumed, especially for recovery process-related patents. We conclude that there are tendencies of loop closing when considering the 20-year period from 1991 to 2010. The absolute number of patents is continuously increasing over time. This applies to all observed five-year periods.

In a next step, the paper analyses which are the main applicant firms behind the figures given in Table 2. Do we see a separate recovery industry emerging or do the same manufacturers and vendors provide the technology? Table 3 displays the top 10 applicants for each period.[4] Note that the adjusted number of patent applications per applicant, which is used to determine the ranking, accounts for co-patents. For example, a patent with two applicants would enter the sum with 0.5 share for each applicant.

1991–1995	**1996–2000**	**2001–2005**	**2006–2010**
MATSUSHITA ELECTRIC IND CO LTD ***(36.00)***	MATSUSHITA ELECTRIC IND CO LTD ***(68.50)***	MATSUSHITA ELECTRIC IND CO LTD ***(37.50)***	INVENTEC CORP ***(27.00)***
HITACHI LTD ***(17.20)***	HITACHI LTD ***(25.60)***	CANON KK ***(30.00)***	HON HAI PREC IND CO LTD [Foxconn] ***(25,50)***
NEC CORP ***(11.70)***	SONY CORP ***(20.50)***	SEIKO EPSON CORP ***(20 .00)***	UNIV CENTRAL SOUTH ***(21.00)***
FUJITSU LTD ***(10.70)***	RICOH KK ***(12.00)***	INVENTEC CORP ***(19.00)***	TOYOTA MOTOR CORP ***(20.00)***
CANON KK ***(9 .00)***	CANON KK ***(11 .00)***	HONGFUJIN PREC IND [Foxconn] ***(14 .00)***	BYD CO LTD ***(15,25)***
SONY CORP ***(9 .00)***	KONISHIROKU PHOTO IND [Konika] ***(11 .00)***	RICOH KK ***(14.00)***	GEN ELECTRIC ***(12.00)***
DOWA MINING CO ***(7.67)***	CASIO COMPUTER CO LTD ***(8 .00)***	FUJI PHOTO FILM CO LTD ***(12 .00)***	HITACHI LTD ***(12.00)***
SANYO ELECTRIC CO ***(7.00)***	IBM ***(8 .00)***	SUMITOMO METAL MINING CO ***(12.00)***	HONGFUJIN PREC IND SHENZHEN [Foxconn] ***(12.00)***
US ARMY ***(7 .00)***	NEC CORP ***(7.50)***	DENSO CORP ***(11.33)***	WISTRON CORP ***(11.00)***
SUMITOMO METAL MINING CO ***(6.50)***	SANYO ELECTRIC CO ***(7.50)***	IND TECH RES INST ***(11.00)***	UNIV TSINGHUA ***(10.50)***

Table 3: Top 10 applicants (adjusted patent share)

The main industry which is patenting recovery and re-use technology is the consumer electronics (OEMs) industry, then followed by metal mining. In recent years, we also see Asian automotive companies such as Denso, BYD and Toyota entering the scene.

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4 This analysis uses PATSTAT harmonised applicant names (‘doc_std_name’), without further aggregation. Inconsistencies in the original dataset are eliminated.

Large chemical companies such as Asahi Chemical, Bayer and Toray are only among the top 30. Firms from Japan, China and Taiwan dominate the top 10 list, as illustrated in Table 3. We also find two Chinese universities in 2006–2010's top 10 ranking.

Discussion: Does industry yet close the loop?

In the case example of the copier industry, modularisation is a precondition for re-use and thus revaluation. But in order to re-use components, modularisation serves another function as well. Some core modules are stabilised and turned into commodities; they can then be re-used in next product generations. In the case of the automotive lithium-ion battery, business model innovation is essential in order to achieve revaluation. The battery must be replaced before its technical end of life. This is, when it no more fulfils the high safety and comfort requirements. For the purpose of revaluation, the battery should be set into a new, preferably less technically demanding use context. Stationary applications within other industries might provide such a business case.

Revaluation, economic rationale and its barriers need to be assessed on a case-by-case basis for each industry. Our provided case examples demonstrated how products and their incorporated resources can yield utility by not being depreciated or turned into waste too early. Economic and ecological benefits then complement each other. High prices of certain raw materials and rising legislative regulation (European Union 2012; Lifset and Lindhqvist 2008) may also make recovery a profitable business.

Sustainability beyond efficiency unfolds specifically from loop closing and systems innovation: a new recovery industry has to emerge and/or its process steps have to be included into existing industry. In systemic innovation, existing technologies are recombined. Likewise, communication between different industries is crucial to establish such a system (Jaspers 2009). The outlined approach might much better to promote value transformation, that is, firms revaluing across industries and switching products over between lifecycles. Our paper has highlighted why companies and society could think strategically of a new loop closing innovation logic. Likewise, Schenkel et al. (2015)'s review of closing the loop of supply chains shed light on more than just the environmental value of loop closing. It has economic benefits for the supplier as well as benefits in terms of consumer satisfaction. Companies could also pull information about customer behaviour from operating loop closing lifecycles and business models.

The circular economy aims at decoupling environmental pressure from economic growth. It thus receives increasing support from multiple stakeholders. And, their support might increase the more they become concerned with the negative externalities of (rapid) growth and excessive consumption (Ghisellini et al. 2016). Policy pressure might also arise when society becomes aware of economic and intangible value extracted from sustaining natural resources (Comberti et al. 2015). Based on year 2005 data, Haas et al. (2015) assumes a low degree of circular economy flow in the global economy. Despite the conceptual progress in the domain of circular economy theory and its conceptions, there are a lack of practices which to date are available and are yet economically viable. Furthermore, the necessary interplay of developing a new innovation logic; industry investments; and the technology base are often neglected. One might refer to the case of renewables (i.e. India, see Kumar and Sinha 2014). The aforementioned, sustainability transitions are complex socio-technical processes that require multiple stakeholders and action on multiple levels. The unique contribution of our paper was to conceptually outline those levels and their interplay.

It depends on collection schemes; product characteristics; market specific structure; practices and attitudes; and products' legislative environment, whether a recycling sector can emerge for an industry or whether it can not. It is the interplay of the different above pillars that allows the collection scheme, the recycling process chain, refurbishment, remanufacturing or remarketing to be effective.

Generally speaking, for collection to be effective, users' attitudes are decisive. For instance, existing take-back systems infrastructures determine convenience and accessibility of collection points; (financial) incentives; and the ways of information provision. For several elec(tron)ic products data safety concerns may also hamper users from returning their appliances (Quariguasi Frota Neto and van Wassenhove 2013; Ongondo and Williams 2011; Regenfelder 2015).

Concerning refurbishment or likewise, remanufacturing, the essential first precondition is that technical end-of-life needs to stretch beyond the typical or possible product life for a first user. Modularity of products is an issue as well. In the case of materials recycling one requires appropriate treatment technology (which is, sorting, disassembly, preparation). It is also crucial that a market demand for the refurbished or remanufactured products exists, not only demand for newly manufactured products. Products may have become obsolete; then only material recycling is viable for loop-closing. The market determines demand as well as feasible pricing for the refurbished or remanufactured product and recycled materials. Companies need to assess whether revenues from loop-closing are higher than the process costs the same requires. Costs stem from collection, recycling, refurbishment and remanufacturing. The cost comparison should additionally consider disposal cost of products that have not recycled for previous lifecycles (see VDI 2012).

Where recycling, refurbishment or remanufacturing cannot generate economic benefit, legislation can still make it mandatory or provide policy incentives. Examples are the European Union's End-of-Life Vehicles Directive (European Union 2000; 95% of cars' weight have re-usable or recoverable); the European Union's Waste Electrical and

Electronic Equipment Directive (European Union 2012); or the Waste Framework Directive (European Union 2008, note: includes a waste hierarchy in favour of the proposed new pattern of innovation). The European Union's Waste Electrical and Electronic Equipment Directive (European Union 2012) implementation has been led by German retail firms creating the mandatory take-back systems for several old appliances.

The case particulars underlie the emergent patterns and they best explain why in some industries we see loop closing whilst in others we see not. Is there, for instance, a policy incentive, or has it to do with the traditional values of the industry? It is subject to the specific industry's market participants including non-market agents. They in interaction determine or negotiate what an 'effective' policy incentive may look like. It means, can the policy have impact in daily business practice and are its effects perceived as relevant?

Our patent analysis is a sound method to track technology advancement. As previously mentioned, several scholars have used patent data to track technology development and technology competition. Still it is only a proxy and has a number of limitations. Our paper thus does not draw firm individual, specific conclusions from the data. However, none of the published papers have to date in depth dealt with closing the loop or recycling industries and their technology. In that regard, our paper is highly innovative. Both recovery process-related and product-related patenting exceed the overall increase of patents. At the same time, we see fluctuation between the chosen five-year periods. Our applicant analysis indicates that there are rather complementary 'sustainable' activities in traditional industries than a rise of a recovery industry. We see evidence that electronics original equipment manufacturers themselves are providing new technology for revaluation. We conclude that loop closing is underway. Companies involved are merely multinational corporations and big electronics contract manufacturers such as Foxconn from Asia. For both case examples (copiers/electronics and automotive) there is strong patenting activity although automotive has only started recently.

Conclusions

Sustainability is rooted in profitable strategies maintaining, but also revaluating resources and products in the industrial sphere. Our study has provided a new concept of ‘revaluation’ and sustainable innovation strategies; it allows firms to exceed the pure paradigm of eco-efficiency.

Our case examples demonstrate how revaluation can be beneficial not only in ecological but also in economic terms. First, firms may re-use components. Secondly, lifecycles do overlap if different but sequential use cases of the same product can be assumed. Furthermore, thirdly, we could show that an in-depth patent analysis may map the broader landscape of the different re-use and recovery technologies as well as their actors. Nonetheless, our conclusions from the patent analysis are limited to the electronics industry sector. The addressed resources can be found in electronic products as well as for the automotive battery case. The automotive industry is experienced in setting up remanufacturing chains, e.g. for engines and parts (Lund and Hauser 2012; VDI 2002).

Sustainable innovation can utilise overlapping lifecycles in order to save processed materials and/or re-use components. Industry is already beginning to close the materials loop with innovative process technology and business models. It is necessary, however, to distinguish between economic and technical end of life. In consequence, systematic business model innovation and interlinked cross-segment value chains are promising themes for further management research.

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Appendix 1: Patent analysis approach, applied in Chapter 5

Formulas:

$$\triangle_t = \frac{n_t - n_{t-1}}{n_{t-1}}$$

$$\triangle_{adj.,t} = \frac{n_t - n_{t-1}}{n_{t-1}} - \triangle_{overall,t}$$

$$S_{adj.} = \sum_{1}^{q} \left(\frac{a_{1,\dots,m}}{m} \right)$$

n_t = Number of patent applications in period t

$\triangle_t$ = 'Change to preceding period' in period t

$\triangle_{adj.,t}$ = 'Adjusted change to preceding period' in period t

$\triangle_{overall,t}$ = 'Cange to preceding period' in period t for overall patent applications of the database

$S_{adj.}$ = 'Adjusted patent share' of an applicant, grouped by harmonised applicant names ('doc_std_name').

m = Number of applicants of one patent application.

q = Number of patent applications one applicant is involved in.

*Only priority applications within a patent family are counted. We do not distinguish whether a patent is finally granted or not.

Patent search strategy for Recovery and Re-use Industries – Keywords:
disassemble, disassembly, recover, recovery, recycle, recycling, re-cycle, re-cycling, refurbish, refurbishment, remanufacture, remanufacturing, reuse, re-use

+

with at least one term out of the following:
high-power magnets, high power magnets, lithium, neodymium, rare earth, platinum group metals, pgm, electronic, electronics, electric

only if in combination

in the following classes

Patent search strategy for Recovery and Re-use Industries		
Storage of electrical energy	B60K 6/28, B60W 10/26, H01M 10/44-10/46, H01G 9/155, H02J 3/28, 7/00, 15/00	WIPO (2012)
Recovery or working-up of waste materials	C08J 11/00-11/28, C09K 11/01, C11B 11/00, 13/00-13/04, C14C 3/32, C21B 3/04, C25C 1/00, D01F 13/00-13/04	WIPO (2012)
Disassembly of vehicles for recovery of salvageable parts	B62D 67/00	WIPO (2012)
Obtaining metals from scrap	C22B 7/00-7/04, 19/30, 25/06	WIPO (2012)
Reclaiming salvageable components or material from electric discharge tubes or lamps	H01J 9/50, 9/52	WIPO (2012)
Reclaiming serviceable parts of waste cells, batteries or accumulators	H01M 6/52, 10/54	WIPO (2012)
Preparing material; Recycling the material	B29B7/66	OECD (2009)
Stripping waste material from cores or formers, e.g. to permit their re-use	B65H73	OECD (2009)
Recovery or working-up of waste materials	C08J11	OECD (2009)
Working-up raw materials other than ores, e.g. scrap, to produce non-ferrous metals or compounds thereof	C22B7	OECD (2009)
Obtaining zinc or zinc oxide; From metallic residues or scraps	C22B19/30	OECD (2009)
Obtaining tin; From scrap, especially tin scrap	C22B25/06	OECD (2009)
Environmental technology	A62D, B01D-045, B01D-046, B01D-047, B01D-049, B01D-050, B01D-051, B01D-052, B01D-053, B09#, B65F, C02#, F01N, F23G, F23J, G01T, E01F-008, A62C	Schmoch (2008)

Patent search strategy matching Product Domains to Recovery and Re-use Industries		
Electrical machinery, apparatus, energy	F21#, H01B, H01C, H01F, H01G, H01H, H01J, H01K, H01M, H01R, H01T, H02#, H05B, H05C, H05F, H99Z	Schmoch (2008)
Audio-visual technology	G09F, G09G, G11B, H04N-003, H04N-005, H04N-009, H04N-013, H04N-015, H04N-017, H04R, H04S, H05K	Schmoch (2008)
Telecommunications	G08C, H01P, H01Q, H04B, H04H, H04J, H04K, H04M, H04N-001, H04N-007, H04N-011, H04Q	Schmoch (2008)
Digital communication	H04L	Schmoch (2008)
Basic communication processes	H03#	Schmoch (2008)
Computer technology	(G06# not G06Q), G11C, G10L	Schmoch (2008)
Semiconductors	H01L	Schmoch (2008)
Optics	G02#, G03B, G03C, G03D, G03F, G03G, G03H, H01S	Schmoch (2008)
Organic fine chemistry	(C07B, C07C, C07D, C07F, C07H, C07J, C40B) not A61K, A61K-008, A61Q	Schmoch (2008)
Materials, metallurgy	C01#, C03C, C04#, C21#, C22#, B22#	Schmoch (2008)