STRATEGIES OF WASTE PREVENTION – A NEW PREVENTION HIERARCHY

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Abstract

The constitution of waste already starts with the manufacture of a product. Sustainable production requires waste prevention to the greatest both technically and economically feasible extent. In this paper the notion 'waste prevention' is further examined by defining and using a material product lifecycle. Thereby a five-level hierarchy of waste prevention is developed as a concept. Then waste prevention strategies are categorized and their approaches mapped on the product lifecycle. This clarifies possibilities and barriers for appropriation of the returns for companies pursuing different waste prevention strategies.

Keywords: waste prevention, product lifecycle, appropriability regime, industrial ecology

1. ECOSPHERE, SOCIETY AND WASTE – A KEY ISSUE FOR A SUSTAINABLE ECONOMY

On principle, every physical good will become waste, once it was produced. Therefore after the point of production it is too late for real waste prevention. There is no mean to prevent that the product becomes waste, as a whole or in parts is inessential. Re-use or recycling approaches also reach their limits in this point, because they only add further cascading utilizations of products or materials and thereby only delay constitution of waste. The only mean of real waste prevention is not to produce a good.

For many products this can be understood intuitively: Products which have only a short lifespan as products before they become waste such as plastic cans or packaging (like plastic films). But also products with longer product lifetimes such as vehicles, airplanes, buildings or even monuments finally will become waste.

These examples shall clarify: There is no waste free society. People need 'things' (physical products) which become waste. The total prevention of waste would hence mark the end of society and not the beginning of an environmentally friendly époque of society. The fundamental issue is not how to develop into a waste-free society, but how much waste is inevitably needed to enable society.

Beside this aspect – that society is basing on waste generation -, the existence of society itself is not independent of other external influences. Moreover, society is a part of a superordinate system and dependent on the functioning of this system. This system is the ecosphere and all human activities – also the producing industrial subsystem – are embedded in. The ecosphere consists of different subsystems, as well natural as man-made, which interact, are interrelated and interdependent [1]. All natural resources are extracted from this ecosphere and waste is disposed back into it. The ecosphere renders services which an industrialized society still needs to sustain. Without a sufficiently intact ecosphere, there is no society permanently able to exist and it would collapse [2,3].

Waste uses the function of the ecosphere as a sink, while production is the initial source. The sink function is limited in its absorptive capacity. Consequently, the following key issue for sustainable production arises: Society needs a sufficiently intact ecosphere and inevitably generates waste. This waste burdens ecosphere and thereby negatively effects the livelihoods of society. If society produces too much material goods and thereby generates too much waste, the ecosphere is deteriorated and renders lesser or worse services for society. These lesser services are at least partly compensated by producing even more goods when trying to reach the former utility level again. This causes even more waste and the negative cycle continues turning... Figure 1 illustrates this.

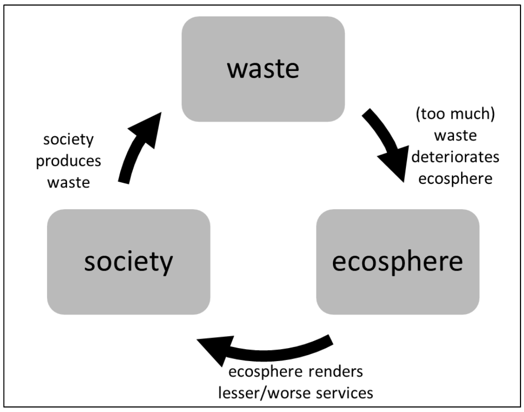

Figure 1 – Negative back coupling society-waste-ecosphere

A steady balance between the use of ecosphere and the demands of society (as consumers) is to achieve. From the derived necessity of waste for a society and with the inclusion of an intact ecosphere, the part of waste is to prevent which is not necessarily essential for maintaining the existence of society. Sustainable[1] economies imply to keep ecosphere intact by limiting the generation of waste to the extent that is needed for the preservation of a society. The benefits for society from pursuing waste prevention strategies are as follows: By reducing the amount of waste, the natural functions of ecosphere are preserved and it can render better/more services for society. Then, a waste prevention hierarchy can help to integrate these strategies into a conceptual framework and facilitate implementation by identifying their starting points.

Waste prevention is regarded as a strategy contributing to sustainable production. It has to be applied 'in doses', because society is basing on waste creation. The goal of this article is to develop a product-oriented concept of waste prevention. It considers the ideas of a real waste prevention and defines several degrees of waste prevention.

2. LIFE CYCLE CONSIDERATIONS FOR A WASTE PREVENTION HIERARCHY

2.1 Material Product Lifecycle and Environmental Impacts

Physical products proceed different phases during their lifecycle with environmental impacts. For the clarification of the dependencies a simplified concept of a material product lifecycle with four different phases is introduced. The separation in different phases is effective for identifying possible starting points for waste prevention. This 'material product lifecycle' -depicted in the following Figure 2- includes the complete product creation (development and production), the use phase, the recovery phase and at its end the product finally becomes waste.

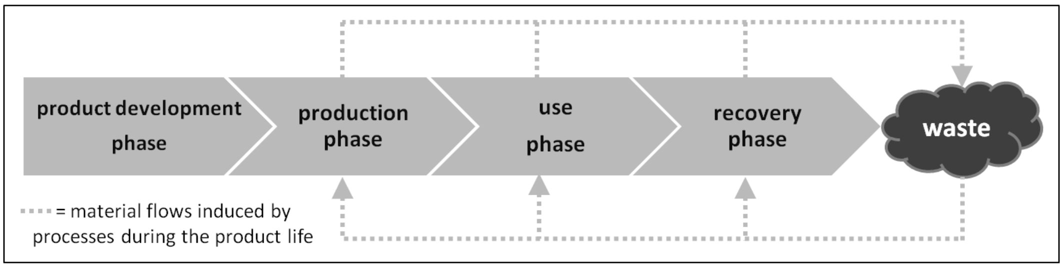

Figure 2 – Material product life cycle with four phases[2]

[1] The authors' understanding of the notion 'sustainable' corresponds to the following definition: "A sustainable path for the future is one that is able to reproduce its own requirements to exist and to at least prevent larger system collapses in the most important 'support systems' (i.e. ecological, social and economic subsystems) of future societies. In this way future generations will have open to them decision-making options, which are as varied and as wide ranging as possible, not least with regard to the use and/ or substitution of (non-renewable) resources." [4]

[2] Also see [5] for a similar design of the lifecycle of technical products.

This lifecycle covers all phases of a product life in which environmental impacts are determined or generated. Because this is a product-oriented examination, the process-induced material flows -depicted in Figure 2- serve only as clarification that waste is not only generated at the end of the life cycle, but also during the most other phases. As well, recycling processes for waste which accumulates from production, use and recovery, feed back raw materials into the production phase. This is also possible by the extraction of raw materials from disposal sites. For the following examination of the starting points of waste prevention these process-induced material flows are not further observed for reducing complexity. They are accounted to the product which induces them.

The material product life starts with product development phase. In this phase the properties and functionalities of a future product are decided on. Existing technologies are configured and/or combined in order to form a marketable product. All aspects regarding the product design are part of this phase. The largest part of the environmental impact of a product is determined in the development phase. Thus, the importance of this phase for the characteristics of the further product lifecycle is to emphasize [5,6]. This phase is the earliest possible starting point for waste prevention.

In the production phase the physical creation of a product takes place. This involves all manufacturing steps or processes directly supporting them. Waste which is generated by manufacturing processes is accounted to the material goods conducting them.

The use phase follows. The consumer has obtained a product and uses it. This phase ends when the consumer does not want to use a product anymore and disposes it. Many products continuously generate additional waste. For example products which need maintenance or equipment which becomes waste. This can lead to the situation that a product does not only become waste itself but generates even more waste through its use ('waste muliplicator'). For example, an automobile becomes waste and generates further waste in its use phase such as old tires, defect parts or other equipment (oil, brake fluid) etc.

The last phase of the material product life cycle is the recovery phase. It starts with the disposal of a product by its former user, and the product is assigned by logistic processes to a waste management/recycling firm. This firm technically processes the disposed products in order to handle them economically advantageous and in compliance to the legal requirements. This includes all measures for making raw materials re-utilizable or reduction and removal. In this phase potential waste is prepared for subsequent use if possible. At the end of these processes, a former product has become waste.

2.2 The Waste Prevention Hierarchy

It is important to mention at this point that there are already legal efforts which aim to minimize waste as the legacy of society. For example, the German 'Closed Substance Cycle and Waste Management Act' (KrW-/AbfG) [7] is to mention. As a principle, it gives priority to prevention before recovery before removal. Similarly, in the EU Directive on Waste a five-level waste hierarchy is stated. Priority is given downwards to prevention, preparing for re-use, recycling, other recovery (e.g. energy recovery) and disposal [8]. Accounting for the material product life cycle, the shortcoming of these approaches is to tackle the waste and thereby only late in the material product life cycle. A main thesis of this article is that it is too late for real waste prevention as soon as a product is produced. There is no real prevention of waste, but only of products (also see [9] for "the sustainability gap in waste management"). Thus, prevention hierarchy is to develop for waste (but NOT starting from waste), which covers the whole product lifecycle. Hence, the product development, the production and the use phase are incorporated explicitly in strategies of waste prevention.

Basing on the material product life cycle, a categorization of waste prevention is suggested. Thereby the starting points in the life cycle for each category of waste prevention are identified. This categorization leads to the establishment of a waste prevention hierarchy subdivided in several degrees. Every degree is regarded as strategy of waste prevention. Criterion for this categorization is the extent of the final (in terms of 'real') prevention of waste.

Waste prevention of first degree ('real waste prevention'):
Waste prevention of first degree is defined in this context as the abandonment of the production of material goods. The manufacturing of products or of components of a product is prevented entirely. This includes the abandonment of the production of substitutes. The production phase itself is not a starting point. By definition of this first degree it is disqualified because in this phase the physical production takes place. Two

different approaches for the waste prevention of first degree can be identified by mapping this prevention on the life cycle:

- Abandonment of components of a product which are not necessary or generate only small utility for the customer. The starting point in this case is at the beginning of the material product lifecycle in the product development phase in which the product design is determined. This means to apply design principles which focus on creating material-efficiently/effectively utility for the user. It also includes the construction of products which need lesser raw materials but have the same functionality and durability as before. The raised (natural) resource efficiency is only related to the material use per product and not to production processes. Examples are tooth paste without the paperboard package (the package as waste is prevented and the main utility of tooth paste is still available), the design of an automotive gear box with lesser weight and same durability (material for the manufacture of the product is saved and thereby the saved amount of material is prevented to become waste at the end of life).
- The better, parallel use of a product from several users during one use phase by using it simultaneous/ sharing its use. By a better use of products the same utility for the users can be generated and a lesser overall number of products is needed. Thereby lesser products have to be produced for a given utility. The usage behavior is not in the producers' direct sphere of influence because the product is out of the producers' effective control (the product has been sold to the user). Although producers cannot directly influence the usage behavior, they can indirectly affect it by appropriate business models (selling the utility rather than a product, leasing, rent, etc.) or variations in product designs (flexibility in use). Examples: New car-sharing business models (Car2Go from Daimler AG [10]; customers share cars and not every customer has to buy a car of his own which lowers the overall need of cars) or the use of a building as a cinema and a church (without parallel use two buildings have to be built instead of one. This prevents the waste of one building in this example).

Waste prevention of second degree ('real waste prevention under the use of auxiliary products'):
In this category the production of a material product is prevented under the use of auxiliary products which finally will become waste theirselves. The auxiliary products are a kind of substitute for the prevented product. It is to emphasize that considering the whole lifecycle more material products are prevented than waste is generated by the auxiliary products. Starting points for this degree of waste prevention are both in the product development phase by the producers and in the use phase by the consumers. The producer has to design products which enable this prevention, while the consumer has to be willing to alter his usage behavior and to substitute former products by these auxiliary products. The digitalization is exemplifying this. Electronic storage and reproduction of content prevents products which have been physical products formerly. The technological progress is the enabler for dematerialization. No longer is a main product manufactured but an utility. Special emphasis in this case is on possible rebound effects which may decrease the original ecological gains by an increased consumption [11]. Examples for the waste prevention of second degree are: a movie downloaded from the internet (no use of a DVD as material product which later would become waste, the movie is an electronic file; auxiliary products: electronic equipment such as a notebook), e-papers and e-books (no use of a printed book or newspaper as material products which later would become waste, content as an electronic file; auxiliary products: electronic equipment such as a tablet computer).

Waste prevention of third degree ('delay of waste constitution'):
Waste prevention of third degree means all approaches which retard the new production of further products of similar nature and delays the constitution of waste. This implies to prolong the lifecycle of a product with a longer use phase or to enable additional lifecycles (in terms of further use phases for the consumer). The focus is on the product circulating as high-qualitative as possible (versus unnecessary degradation) in a cascading utilization. The product with its physical form and/or functionality is conserved. Attention has to be paid on products with large negative ecological impacts during their use phase. If the use of a product effects too much negative impacts and new products do not (if technological progress leads to more efficient products), a (too) long lifecycle and the delay of waste constitution is not desirable from an ecological point of view. There are several starting points for the delay of waste constitution:

- Durability of products prolongs the initial use phase and delays both the end of life and the production of replacement products. The prolongation of the use phase has to be criterion for the product design in the product development phase. An example for this long-life products are returnable bottles made of stable plastics instead of one-way plastic/glass bottles which become faster obsolete and thereby waste.
- Extension of lifecycle through repair and upgrading means to conserve the utility of a product (repair in case of defects) or to extend the functionality of a product (upgrading) during the use phase in order to reach a

similar utility compared to new products. A premature end of the use phase is avoided or the use phase is extended. The user stays the same. Users' access to repair and upgrading services is prerequisite.

- Re-use intends to enable a second (further) use phase for a product. At the end of a use phase (at the interface to the recovery phase) – when a user does not want to further use a product -, a user gives away the product and abandons the control/the property right of it. The lifecycle then consists of one product development phase, one production phase, several use phases and one recovery phase. Thereby the lifecycle is prolonged. If a product is re-used, its functionalities can remain unmodified (inspection and refurbishment) or they are extended (upgrading). In both cases a product is re-transferred by a re-use firm (refurbisher, remanufacturer) for some, few process steps into production phase. Quality assurance is an important issue for this approach. The Berlin-based ReUse-Computer-Network is exemplifying this approach. Members of this network check, refurbish, if necessary, upgrade used ICT- (information and communication technology) products, and incorporate quality testing in their ReUse-production-process. The products are marketed using an own ReUse-Computer check-sign as a label for signalling product quality to the customers. [12].

Waste prevention of fourth degree ('waste substitution'):
Waste prevention of fourth degree is the substitution of the types of waste: Waste with a given environmental burden is substituted by waste with a lesser environmental burden. This burden can be assessed both quantitatively and qualitatively. This approach aims to connect requirements of recovery with the product development phase. This includes all actions which achieve a better recyclability of waste (design for recycling) or facilitate reduction measures. As a follow up of the previous product life, waste is reduced in the recovery phase. E.g., the avoidance of composite materials in the product development or the development of products, which are easy to disassemble and recycle, enables waste substitution. This can be implemented for example in a high-pressure cleaner whose housing consists only of one type of plastics instead of two and is easy to disassemble.

Waste prevention of fifth degree ('reduction of waste multiplicators')
The 'waste multplicator effect' occurs if a product generates a large amount of additional waste during its use phase. The reduction of the multiplicator effect aims to prevent this additional waste. Products have to be designed efficiently regarding their waste generation in use. This reduction usually leads to a raise in efficiency of consumption and consequently a reduction of cost. Therefore waste prevention of fifth degree reduces the costs for the user in the use phase. From a macro-economic point of view, efficiency strategies are questionable: Because of rebound effects they often raise the overall consumption of a product and in this context the overall waste. That is why efficiency strategies on their own are of minor importance for sustainable manufacturing [13]. This degree can be exemplified in a maintenance friendly machinery which needs lesser services and therefore also needs lesser auxiliary operating materials such as spare parts (which otherwise would become waste).

Figure 3 assigns the degrees of waste prevention to the phases of the material product life cycle. This overview of the waste prevention hierarchy clarifies the phases affected the most by the introduced approaches.

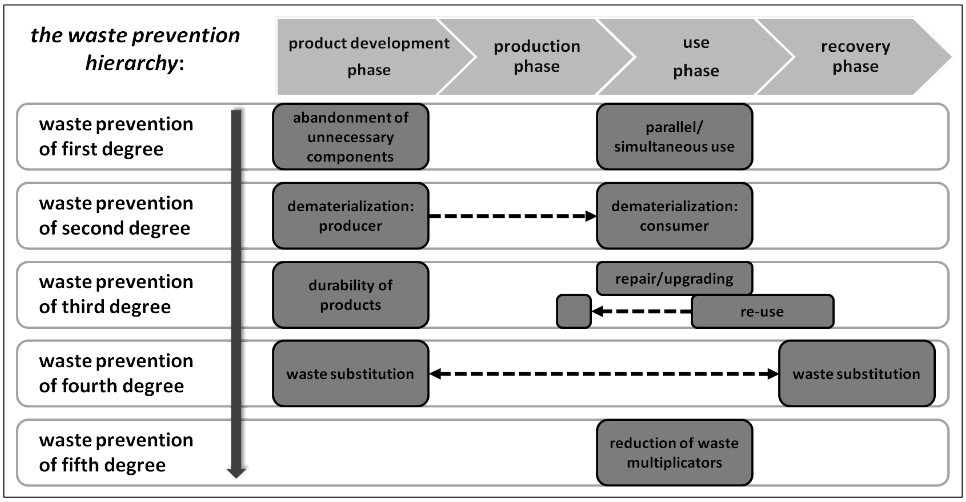

Figure 3 – Overview of the waste prevention hierarchy mapped on the material product life cycle

3. DISCUSSION OF THE APPROACHES AND CONCLUSION

So what is the matter for implementation of the approaches of the waste prevention hierarchy in practice?

For a possible implementation of the approaches of waste prevention the economic incentive systems are crucial. Incentive systems describe how companies appropriate the utility (in terms of revenues) of their economic activities. It is an important part of economic analysis which actors appropriate the utility of economic activities: If a company cannot appropriate utility from its own activities, it generally abandons them.[3] Expenses for economic activities may yield their utility time-lagged, also in later phases of the product lifecycle. For this examination it is useful to transfer the concept of appropriability regimes from technology and innovation management[4] to the material product lifecycle. Derived from this, the notion weak appropriability regime is used in the following, if the economic subject, which executes an activity, is only able to appropriate its utility to a low extent or in rare cases. A strong appropriability regime is available, if this appropriation can be assured to a large extent. [14,15,16,17,18]

Introducing the material product life cycle to this issue, it becomes clear that different actors have the power of control/the property rights during the lifecycle of a product. The actor ,whose property a product is, has the direct power of appropriation to it. Figure 4 shows the different actors which possess a product during its lifecycle. Involved actors –simplified- are manufacturing companies, customers/consumers/users and recyclers/waste management firms. These actors may be completed with leasing firms and refurbishers/remanufacturers.

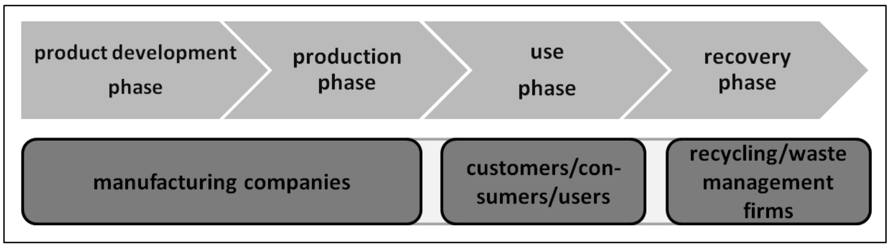

Figure 4 – Actors with property rights on a product during its material product lifecycle

Measures for waste prevention in most parts trigger additional costs in certain phases of the lifecycle, while the utility is yielded in later phases. For some approaches the appropriation of utility is uncomplicated: they yield utility when the product is still in the property of the actor which paid the costs for the measure (before). E.g. the approach 'abandonment of unnecessary components of a product' can cause additional costs in the product development phase, but they can be compensated directly at the manufacturing companies by lesser material or assembly costs (if single production steps are eliminated). Similarly the cost savings of the approach 'parallel/simultaneous use of a product' (the consumers buy lesser products and can share costs) can be distributed among the users. The approach 'repair/upgrading' has to be paid by the user which also has the utility.

Even if the utility is yielded not directly to the actor which bears the cost, the actor can succeed in appropriating the utility through market mechanisms. For example, the approaches 'durability of products' and 'reduction of waste multiplicators' trigger costs in the product development phase and the utility is yielded in the use phase. The manufacturing companies which have to bear those costs can pass them to their customers (partly or wholly); prerequisite the users are willing to pay for the additional utility.

'Re-use' of complex products is enabled by specialized refurbishment companies. If re-use business models are economically advantageous, depends on product characteristics and market conditions. 'Dematerialization' is driven by a technology push. It opens up new markets for the companies and new applications for the users. Both actors, which are involved, profit from.

Approaches, which have a lack of direct or indirect power to appropriate, face difficulties in their practical implementation. The approach 'waste substitution' exemplifies this: For 'waste substitution' a design for recycling (or other design for environment, etc.) is needed. This raises costs in the product development

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[3] Except e.g. activities to comply with legal requirements.

[4] The notion appropriability regime is used in technology and innovation management for the distribution of revenues originating from innovative activities/intellectual property. Also in this case revenues occur time-lagged and cannot in all cases be appropriated by the actor, which paid the cost for initial investments.

phase and/or the production phase. The utility is yielded in the recovery phase and in most cases there are no mechanisms to pass the costs to recycling/waste management firms, which have the additional utility (no direct market interaction producer – recycler). For appropriating in this case, the producer would have to expand its business and also function as a recycling/waste management firm (very unusual in practice) or the beginning of the product life should be linked to the end of life by legal instruments such as the individual producer responsibility (in practice insufficient implementation at least in the European Union, see for examples [19,20]). In most cases producers have no incentive to support the approach waste substitution.

From the view of a single company the crucial issue for appropriation is the time lag from measures, which have to be taken at the beginning of the lifecycle, to the deployment of their utility in later phases. Moreover, a certain likelihood of appropriation (this also can be a financial compensation from another actor) is essential. If appropriation is to insecure, actors include this in their economic rationale and will not take measures in advance. The discussed approaches are characterized by different appropriability regimes. From approaches with strong appropriability regimes (abandonment of unnecessary components of a product; parallel/simultaneous use of a product; repair/upgrading), to moderate appropriability regimes (durability of products; reduction of waste multiplicators; re-use; dematerialization) and weak appropriability regimes (waste substitution).

This examination of waste prevention strategies first clarifies the relationship between waste, society and environment. The emphasis is on the awareness that it is too late for real waste prevention as soon as a physical product is manufactured. Therefore a product-oriented view for a waste prevention hierarchy is essential. Basing on the assumption that there is the requirement to reduce waste streams for approaching sustainable manufacturing, a material product lifecycle is defined in order to find starting points for approaches of waste prevention strategies. The waste prevention hierarchy categorizes the several strategies of waste prevention and describes their approaches. For the evaluation of the approaches another criteria besides the final prevention of waste is important: the appropriability regime. Only when a strong or at least moderate appropriability regime is combined with one of the higher degrees of waste prevention both ecological and economical demands can be satisfied. Thereby also society benefits from decreased environmental burdens. Approaches with weak appropriability regimes are only viable if firms make great efforts to overcome the barriers of appropriation. This could also include changes in their business models.

4. REFERENCES

[1] Bauer, J.: *Industrielle Ökologie : theoretische Annäherung an ein Konzept nachhaltiger Produktionsweisen*, dissertation, University of Stuttgart, Stuttgart, 2008

[2] Meadows, D. et al.: *Die Grenzen des Wachstums – Bericht des Club of Rome zur Lage der Menschheit*; Deutsche Verlags-Anstalt, Stuttgart, 1972.

[3] Meadows, D., et al.: *Limits to Growth – The 30-Year Update*, Chelsea Green Publishing Company, White River Junction, 2004.

[4] Gleich, A., et al.: *Sustainability Strategies in Field Trial – Results of the project 'Sustainable Metal Industry in Hamburg'*, Sustainable Metals Management – Securing Our Future – Steps Towards a Closed Loop Economy, Gleich, A. et al. (eds.), Springer, Dordrecht, 2006, 249-291

[5] Niemann, J. et al.: *Design of Sustainable Product Life Cycles*, Springer, Berlin, 2009.

[6] Rebitzer, G.: *Integrating life cycle costing and life cycle assessment for managing costs and environmental impacts in supply chains*, Cost management in supply chains, Seuring, S. et al. (eds.), Physica, Heidelberg, 2002, 128–146.

[7] German Federal Ministry of Justice: *Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Beseitigung von Abfällen (Kreislaufwirtschaftsgesetz – KrWG)*, Berlin, 1994 (2010), http://bundesrecht.juris.de/bundesrecht/krw-_abfg/gesamt.pdf, 2011-10-07

[8] European Union: *Richtline 2008/98/EG des Europäischen Parlaments und des Rates vom 19. November 2008 über Abfälle und zur Aufhebung bestimmter Richtlinien*, Amtsblatt der Europäischen Union, Brussels, 2008, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:DE:PDF, 2011-09-27

[9] Grooterhorst, A.: *Die Nachhaltigkeitslücke -oder- Kann Abfallwirtschaft nachhaltig sein?*, Müll und Abfall, 9 (2010), 440-448.

[10] Reichel, A. et al.: *Linking Sufficiency and Business: Utility Systems Engineering in Producer-Consumer-Networks*, Proceedings of the Academy of Management 2009 Annual Meeting: Green Management Matters, Chicago, August 2009.

[11] Binswanger, M: *Das Entropiegesetz als Grundlage einer ökologischen Ökonomie*, Zwischen Entropie und Selbstorganisation. Perspektiven einer ökologischen Ökonomie, Beckenbach, F. et al. (eds.), Metropolis, Marburg, 1994, 41-66.
[12] Ebelt, S.: *Darum Wiederverwendung! – Macht die Wiederverwendung einen Sinn oder sprechen alle von einer blendenden Farbe?,* ReUse-Computer – Ein Beitrag zur Entschleunigung der Ökonomie, Becker, F., et al.(eds.), oekom, München, 2005, 62-86.
[13] Huber, J.: *Industrielle Ökologie. Konsistenz, Effizienz und Suffizienz in zyklusanalytischer Betrachtung,* Global Change, Simonis, U. E. (ed.) Nomos, Baden-Baden, 2000.
[14] Chesbrough, H. et al.: *The Role of the Business Model in Capturing Value from Innovation: Evidence from Xerox Corporation's Technology Spinoff Companies*. 3 (2002), 529-555.
[15] Gerybadze, A.: T*echnologie- und Innovationsmanagement – Strategie, Organisation und Implementierung*, Vahlen, München, 2004.
[16] Nelson, R. et al.: *An Evolutionary Theory of Economic Change*, Belknap Press of Harvard University Press, Cambridge and London, 1982
[17] Teece, D.: *Profitting from Technological Innovation: Implications for Integration, Collaboration Licensing and Public Policy*, Research Policy, 1986, 285-305.
[18] Teece, D.: *Managing Intellectual Capital. Organization, Strategic and Policy Dimensions*, Oxford University Press, New York, 2000.
[19] Lifset, R et al.: *Producer Responsibility at a Turning Point?,* Journal of Industrial Ecology, 2 (2008),144-147.
[20] Mayers, K., et al: *Redesigning the Camel – The European WEEE Directive*, Journal of Industrial Ecology, 1(2011), 4-8.