A model for organizing and analyzing integration of environmental concerns in product design and re-design

Jørgensen, Michael Søgaard

Published in:
ASME 2014 12th Biennial Conference on Engineering Systems Design and Analysis

DOI (link to publication from Publisher):
10.1115/ESDA2014-20211

Publication date:
2014

Document Version
Accepted author manuscript, peer reviewed version

Proceedings of the ASME 2014 12th Biennial Conference on Engineering Systems Design and Analysis
ESDA2014
June 25-27, 2014, Copenhagen, Denmark

ESDA2014-20211

A MODEL FOR ORGANIZING AND ANALYZING INTEGRATION OF ENVIRONMENTAL CONCERNS IN PRODUCT DESIGN AND RE-DESIGN

Michael Søgaard Jørgensen
Center for
Design, Innovation and Sustainable Transition,
Aalborg University
Copenhagen, Denmark

ABSTRACT

Based on examples from research and innovation within nanotechnology, housing, bioenergy, and clothing the complexity of environmental innovation is discussed. A model for a more holistic approach to environmental innovation, which can be used both as part of innovation processes and for analyses of previous innovation processes, is developed. The approach is based on: 1) A scenario perspective on environmental aspects and impacts which implies a focus on the future roles of a product, its users and the surrounding society as imagined by the designers in their considerations about the problems addressed by the product and the solution it is offering. 2) A system's perspective which implies a focus on the system, which a product is part of, including the need for supporting infrastructures like stakeholder training, waste management etc. 3) A lifecycle perspective to environmental aspects and impacts in order not only to capture environmental aspects from cradle to grave, e.g. related to material extraction and refining, chemical exposure during manufacturing, use and waste handling. 4) A governance perspective on management of environmental aspects and impacts, both in relation to the legitimacy of the environmental problems addressed and the solutions 'offered' by the product.

Key words: environment, innovation, scenario, system's perspective, life cycle, governance.

INTRODUCTION

Today, the world is facing large social and environmental challenges due to the environmental problems related to the large resource consumption in the industrialized countries, but also due to the many economic, social and environmental promises expressed in relation to so-called high technology like nano-, bio- and ICT-technology (information and communication technology). Some of the challenges result from a rather linear and simplistic understanding of innovation. A linear understanding of technological change, where research is seen as the most important base for technological development and the abatement and prevention of social and environmental problems, does not explain the dynamics of technological change and the interaction between research, development and application of technologies [1,2]. Some examples of integration of environmental concerns into innovation processes that have shown environmental innovation as complex and controversial are:

- Eco-labelling of a few clothes in clothing companies' product assortment not being accepted by the imagined female users because these consumers do not accept restrictions to the wide range of choices they have from the present clothing assortment [3]
- Difficulties achieving the expected low energy consumption in so-called eco-houses due to lack of involvement of the users in the design and lack of dialogue between producer and user about the users' experiences [4]
- Bioenergy as controversial climate solutions due to disagreements about how to assess the climate aspects of bioenergy in general and how to assess specific initiatives. This makes it impossible to agree about the climate mitigation potentials from bioenergy [5]
- Nanotechnology as a complex technology area with very different environmental aspects and impacts which makes it impossible to justify that nanotechnology is a 'green' technology [6,7]

The examples mentioned above show that environmental aspects and impacts cannot be assigned as properties to materials or processes per se, but are outcomes shaped during activities of research, innovation and application. Seemingly rather identical technologies can be applied and handled in very different ways and contexts resulting in very different environmental impacts.

In the paper I argue that a more holistic model for environmental innovation from businesses, researchers and governments could help developing products and technologies with higher legitimacy and acceptance among potential users and among civil society actors, both in terms of the environmental aspects and impacts and in terms of the wider social impacts of these products and technologies. The paper presents a model for integration of environmental concerns into design and re-design of products and services as part of environmental innovation, based on analyses of the earlier mentioned examples. The model can be used for design and re-design activities, and for analyses of the shaping and the impacts of products and services developed in previous design and re-design activities.

The elements in the holistic model for design and re-design as part of environmental innovation are:

- A *scenario perspective* on an innovation and the related environmental aspects and impacts implies a focus on the future roles of the innovation, the expected users and the surrounding society as they are imagined by researchers and designers in their considerations about the problems to be addressed by for example a product or service and the solution offered by the product or service.

- A *system's perspective* on an innovation implies a focus on the system, which a product or service is part of, including the need for supporting infrastructures like supply of water and energy or other resources, user information, waste management, etc.

- A *lifecycle perspective* on the environmental aspects and impacts of an innovation is necessary in order not only to assess partial environmental aspects and impacts, but environmental aspects from cradle to grave, e.g. related to material extraction and refining, and to chemical exposure during manufacturing, use, and waste handling.

- A *governance perspective* focuses on how the design process is organized: who is involved when and how, and what aspects are seen as legitimate to address. This implies a focus on the possibilities of shaping environmental aspects and impacts during research and innovation and the possibilities to prevent negative environmental impacts and support the realization of positive environmental impacts.

The following sections discuss the elements of the model in more details and how the elements of the model interact with each other.

A SCENARIO PERSPECTIVE ON ENVIRONMENTAL INNOVATION

A scenario perspective on environmental innovation implies a focus on the problems that is addressed and the solutions that are developed in environmentally oriented innovation processes. Ornetzeder and Rohracher [8] understand the linking of researchers, designers and users in innovation processes through a number of processes and relations:

- References to discourses orienting and restricting the actors' expectations and actions
- Technologies as part of wider sociotechnical regimes, which include expectations, practices and norms
- Intermediate actors translating and mediating between different stakeholders' interests

Carroll [9] distinguishes in his discussion of design between an engineering approach and a scenario-based approach to design. Carroll claims that most engineering methods belong to the methodological tradition that seeks to control the complexity and fluidity of design through techniques that filter the information considered and decomposes the problems to be solved. Contrary to this Carroll characterizes a scenario-based design approach as belonging to a tradition that seeks to exploit the complexity and fluidity of design by trying to learn more about the structure and dynamics of the problem domain. Carroll (2000) [9] characterizes scenarios in the following way:

- Scenarios are stories about people and their activities
- Scenarios presuppose a setting
- Scenarios include various actors with goals and objectives
- Scenarios have a plot by including a sequence of actions and events

Based on Ornetzeder & Rohracher [8] and Carroll [9], the starting point in environmental innovation processes and in analyses of previous innovation processes assessment should be taken in the scenario consciously or unconsciously built into the innovation processes in terms of the problems, which a certain product or service, according to its 'promoters', is supposed to solve and how the solution is supposed to solve the addressed problem. The overall questions to address are:

- By whom are the addressed problems recognized as problems?

- By whom is the suggested product/service recognized as an acceptable solution?
- What are the environmental aspects and the potential environmental impacts related to the product/service?
- How are the potential environmental impacts compared to present ways of solving the problem in focus?

These questions enable, ideally, assessments of the environmental aspects of a product or a service as part of and innovation. This is not to say that research and innovation always are organised as researchers' or designers' simple search for solutions to well-defined problems. Maybe the contrary is the case: the problems addressed by researchers and designers are shaped parallel to the development of solutions, when certain achievements are reached in research and innovation. This implies that the 'solutions' sometimes are found first and afterwards the researchers and developers try to identify 'societal problems', which they think could be solved by these solutions. This implies that what is legitimate as parameters, problems etc. within a researcher's or designer's understanding and what is outside an understanding is shaped at the same time [1]. The discourses around genetically modified (GM) food and plants show examples of what could be called 'reverse search processes'. GM researchers and companies pointed initially to pesticide resistant plants as an efficient agricultural strategy [1]. Only after critique from environmental organisations of the risk of pesticide pollution of ground water, the industry included arguments about the GM-plants as elements in an environmental strategy by referring to a claimed potential for reduced pesticide consumption [6].

Analyses of the recent development of eco-friendly housing in Denmark show how the environmental focus in design processes within a product area may change over time [4]. Sustainable buildings have often been niche products, but in recent years a new approach has emerged in Denmark aimed at mainstreaming and normalizing eco-friendly houses in order to attract ordinary Danes. The aim has been to present an conceptualization of sustainable buildings which is less radical than some eco-communities' visions and try to engage traditional building companies in the innovation processes. The new concept has implied a narrower approach to sustainability and a lack of social sustainability measures. While earlier paradigms of sustainable buildings emphasized themes such as community building, self-provisioning, local empowerment, and shared facilities, such objectives are largely absent in the new types of sustainable buildings [4].

An analytical concept which can be used as part of the scenario perspective is 'script'. Several authors within the Actor-Network Theory approach, including Akrich [10] uses the concept of 'script' as a way of describing future roles ascribed to a product, its users, the societal infrastructures, etc. In an innovation approach the concept of 'script' can be seen as characterising those intentions which a designer builds ('inscribes') into a technology, product, service, etc. through its material shape, its functions, the user guidelines etc. This includes the future roles, which technologies, user, surrounding infrastructures, etc. are supposed to have. The word 'script' refers to the understanding of the result from innovation as a (manu)script made by the designer for example for a technology and its future use. Whether the script afterwards is accepted by the imagined users through their so-called de-scription and a stable practice is developing, depends on the script, the type of technology, the alternatives and the societal context. Akrich [10] talks about 'negotiations' between the inscribed possibilities and limitations the script gives the user. These negotiations take place in interaction with the economic, knowledge, technical etc. resources which the user has access to when shaping the practice with the technology. A product is said to be 'hard' if the users cannot change the practice with the product, even if they feel restricted in the shaping of their practice. On the other hand, the technology is said to be 'soft' if the users can shape their own practice. The so-called 'prescription' refers to the room for action, which the script allows.

The earlier mentioned analyses of experiences from eco-housing [4] shows that the assumptions about the interactions between the house, the technical installations, and the future user practices, which are included in the script, not always is able to ensure such a low energy consumption as expected. Sometimes the users of the house are not well enough informed about energy efficient operations of the installations in the houses (ventilation, central heating, etc.) and sometimes the interactions between the physical design of the house and different installations are not analysed carefully enough and the assumptions are not made visible.

In a discussion of the problems addressed and the solutions proposed or offered by researchers and developers it is therefore important to discuss the logic of the scenarios, as described by Carroll [9]: the claims about future possibilities, including the background and consistency of the claims and the roles the scenarios give to different human and non-human elements, like the users, their practices, and the surrounding society.

An example of a scenario identified in a Danish green technology foresight project about nano-, bio- and ICT-technology [2, 6] was the development and use of nanosensors for environmental purposes. Such sensors are said to become so small and so cheap in the future that they can enable much more measurements of chemicals etc. in the environment, in wastewater etc. Besides the environmental impact from the sensors themselves and the potentials for better environmental management from better data, there could, however, be an indirect environmental impact of the nanosensors, if the

development of these sensors makes authorities and industry believe that environmental impacts anytime and anywhere can be detected with such sensors. Such an understanding could imply an environmental strategy, which downplays the role of prevention of pollution and focuses more on early detection of pollution. In the discussion of such a scenario and its elements it is important to discuss the logic of the scenario. This means for example discussing whether it hitherto actually has been the lack of environmental data that limited governmental environmental regulation or corporate environmental management, or it more has been a question about the level of environmental regulation and management, which industry and other stakeholders have been willing to accept. If the latter is the case, the development of nanosensors might not imply more concern for the environment but on the contrary imply less focus on prevention and thereby higher environmental risks because focus then moves towards early detection and clean-up activities [2,5].

SYSTEM'S AND LIFE CYCLE PERSPECTIVES ON ENVIRONMENTAL INNOVATION

A *system's approach* to environmental innovation implies that focus is not only on single properties or features of a product, for example the tiny dimensions of the earlier mentioned nanosensors, but on the whole product-system, which the sensor is part of, including the need for supporting infrastructures like quality standards, waste management systems, the roles expected to be taken by the future actors in these systems etc. (for example a specific practice during use or waste handling [6]. In order to make environmental assessments of an environmental innovation it is important to know whether these system elements exist, are emerging or need to emerge, so relevant value chains and life cycles and social and environmental aspects can be identified. A systems approach works well together with the Actor-Network Theory. The theory argues that a technology is not just working through a technical artefact, but as an emerging and increasingly stabilised network of associations between diverse material and non-material elements – artefacts, humans, texts, symbols, concepts etc.

A *life cycle* based approach to integration of environmental concerns in product development, like presented by Olesen et al [11], fits with a system's approach to products, since it allows an assessment of the interactions between a product, the user and the surrounding society from an environmental perspective. Olesen et al [11] define the term 'the meetings of a product' as: 'the action taking place, when a product, a product life system and an actor interact and this implies effects, whereof some are environmental'. As product life systems are mentioned manufacturing, assembly, packaging, use, service and waste management. This understanding works well within an Actor-Network Theory approach, since a designer's intentions about the future of a technology, product or service contained in a script can be seen as a way of describing possible future 'meetings' between technologies, different actors, and different types of supporting infrastructure systems.

Olesen et al [11] talks about 'disposition' as the way a designer during the product development activities defines and influences the character and the effectiveness of the meetings of products. This understanding fits also well with the earlier mentioned terms inscription and prescription from Actor-Network Theory. The disposition takes place through the shaping of the product or through 'negotiations' with other actors about the future of the product, for example which materials the manufacturers will use, how product take-back might be organised, etc. This shaping takes place as 'negotiations' among different actors during the innovation processes, during the planning of manufacturing, during the later use of the product etc. Olsen et al [11] describe how disposition thinking can develop an overview of the future meetings of the product so that the future life (cycle) of the product more likely is developing as planned.

The concepts of scripts and disposition in a system's and life cycle perspective can be used to assess the environmental pressure a product or a service might put on the environment if realised and assess the prerequisites or inscribed roles of the user and the surrounding society, which the designer – consciously or unconsciously - defines for the future in order to handle or prevent environmental pressures. Improvements in environmental performance (reduction of potential negative impacts) can be obtained through changes in one or more of the elements in each of the meetings during the life cycle: actor, product and product life system. It is important to try to relate potential environmental impacts in one of the life cycle phases back to the script. For example: high quality demands for carbon nanotubes for a badminton racket (might) imply that chlorinated organic solvents need to be used during the manufacturing stage in the production of the carbon nanotubes. Such a pressure might be managed through lower quality demands to the racket, substitution of the solvents with less hazardous solvents or cleaning of the air emissions with filters [6].

Experiences from an analysis of women's clothing practices [3] and of the interaction between production and consumption of clothing [12] show the importance of a systems' perspective in analyses of the role of environmental aspects in design and in the potential (imagined) users' uptake of a product or a service. A combination of statistical analysis of Danish clothing consumption, an ethnographic study and an analysis of strategies in the clothing sector developed an understanding of the system of production and consumption of clothes among women. The analyses show that the increasing clothing consumption is influenced by interactions between low price strategies on clothing from the increased outsourcing of clothing production to low-income countries, fast fashion

business strategies, and concerns about increasing social expectations among colleagues and friends about frequent changes in clothing. These analyses also show that those corporate strategies, which address *all* products and not only a limited part of a company's product portfolio, are more likely to reach consumers since even educated groups of consumers do not want eco-labelling of just a few products to limit their possibilities for choosing among a big variety of different clothes when shopping [3,12].

During research and innovation a life-cycle screening of possible future applications, based on the MECO-concept (Materials, Energy, Chemicals, Others) from the so-called EDIP-methodology (Environmental friendly Development of Industrial Products) is a possible framework for identification, description and assessment of environmental aspects and impacts related to a product or a service in its life cycle [13]. The MECO-screening focuses on a qualitative and semi-quantitative description and assessment of

- M: Materials, including the use of scarce and non-renewable materials
- E: Energy, including whether the energy sources are fossil or renewable
- C: Chemicals, including aspects of human toxicology (e.g. risks of carcinogen, reproductive, allergic and neuro-toxic impact) and eco-toxicology (e.g. risks related to persistence and bio-accumulation)
- O: Other aspects, like land use, biodiversity, work environment, etc.

It is important to work from a *dialogue-based understanding of 'environment'*, which not only focuses on quantifiable environmental aspects like wastes and emissions, but for example also the impact on land use or the impact on our understanding of the need for precaution. This approach to environmental assessments has been inspired by the approach of 'participatory life cycle assessment' as described by Bras-Klapwijk [14], where the focus of the life cycle assessment is discussed among concerned and involved actors when planning and carrying out the assessment in order to increase the legitimacy of the assessment among the actors afterwards.

Not least the controversies about the climate aspects of bioenergy globally and in Denmark [5] show the need for stakeholder dialogues and development of a common understanding about the environmental aspects and impacts.

A more elaborated life cycle assessment (LCA) builds upon an object of assessment, namely the functional unit, i.e. all impacts etc. are related to a certain 'amount' of a specific service or function in the society. In a LCA context, the assessment of emerging technologies like nanotechnology is challenging due to a number of knowledge gaps. It may not be known exactly what the function (or functional unit) is or what the technology may substitute, and the production may still be at an experimental level, raising questions about technology and material choices. To illustrate the MECO concept a screening is presented for a consumer product containing nanoparticles [6].

Buckyballs for a badminton racket is produced via a combustion process in which toluene and oxygen is combusted in a closed system low pressure chamber forming fullerenic soot. Buckyballs are extracted from the soot using solvent like chlorobenzene and purified to C60 and C70 by high-pressure liquid chromatography. The residual soot contains low percentage of fullerenes having a commercial value. The fullerenes produced are incorporated into an epoxy resin. For processing carbon fibres and an epoxy resin into a composite material, the resin is put into a curing oven where it melts on the substrate (in this case the carbon fibres); then it solidifies to form an insoluble plastic composite material, which does not melt again. The hardened resinous waste contains buckyballs. During the use phase of the racket no impacts are expected. When finally disposed off the racket will presumably be disposed off as municipal solid waste and be either incinerated or landfilled. A MECO screening of the racket is shown in Table 1.

Table1: Presentation of the Materials, Energy, Chemicals and Others matrix for the different life cycle stages of a "nanospeed" badminton racket [6]

Nanospeed racket	**Raw material extraction**	**Production**	**Use**	**Disposal**
Materials	Fossil fuels	Waste resin		
Energy	Vacuum pump	Melting and curing		
Chemicals	Chlorina-ted and other solvents			Nanoparticles released from waste?
Other aspects, including occupational health and safety		Occupational handling of nanoparticles		

GOVERNANCE OF ENVIRONMENTAL INNOVATION

A governance perspective on environmental aspects and impacts related to innovation of products and services is necessary as part of discussing the possibilities of influencing the life cycle of the product or service. This includes an assessment of the possibilities of obtaining environmental benefits from a product or a service. Such an assessment is also necessary as part of an assessment of the legitimacy of the social and environmental problems addressed, which are addressed and the solutions 'offered' by for example a product.

When assessing environmental aspects of a product or a service two perspectives should be considered: the potential environmental aspects related to production, use and disposal (an 'attributional' perspective), and the potential (changes in) impacts from interaction with other parts of the economy, including different types of rebound effects (a 'consequential' perspective).

Table 2 illustrates this methodology applied on identification of environmental aspects of a product/service through the case of nanosensors [6].

The case shows that a designer has a significant influence on the environmental impacts during a product's life cycle through the choices (s)he makes, e.g. that chlorobenzene will be used for the extraction of fullerenes for the badminton racket due to high quality demands for the nanotubes. The users may have similar influence through the demands they put on products. However, in both cases the influence may be of indirect character since the designer may not be in dialogue with the manufacturers and discuss the choice of materials and probably not the environmental impacts from the manufacturing of the materials. The users most probably get no information about the environmental aspects and impacts of the racket, most probably only information about the improved quality due to lower weight and higher strength of the product. Lack of dialogue about the environmental aspects of up- and downstream processes could lead to negative environmental impacts in the life cycle of the products.

Table 2. Methodological framework for the identification of environmental aspects and assessment of potential environmental impacts of a product/service and its application

Perspective on environmental aspects	**The potential environmental impacts related to the different types of aspects** **Case: nanosensors**
Attributional perspective Aspects related directly to the technology and its infrastructure, and its use	Induced environmental impact and resource consumption from manufacturing, use and disposal from the nanosensor itself. Induced or avoided environmental impacts from the use of data from nanosensors.
Consequential perspective Aspects related to potential changes within sectors or areas of consumption	The influence on environmental pressure if environmental sensors are seen as a safeguard towards environmental impact and substitutes investments in preventive measures like less resource consuming technology or less polluting chemicals and materials

In the earlier mentioned case with (lack of) recognition of eco-labelled clothing as offering enough relevant choices for women, the attributional perspective of the products would suggest that the products are okay, but the consequential analysis of the interaction with the existing clothing practices of the women show problems for the eco-labelled products as relevant governance strategy.

Some of the controversies about the (lack of) climate mitigation from use of bioenergy relates to differences in trust in the ability of certification schemes to ensure real-life control of, not least, imported biomass [5].

According to Brown et al [15] an important element related to the governance of products and services and their environmental aspects is the quality of the promises and the methods for judging the robustness and pertinence of such expectations. An example: Genetic engineering has demonstrated how scientific research is informed by tacit visions and imaginaries of the social role of technology [16]. Although utopian, these visions form the basis on which research priorities are negotiated and planned. Furthermore, such visions are seldom subject to public discussion and debate, before the priorities for research and innovation are made [16]. Such visions need to be more articulated by their scientific authors and be subject to wider social deliberation, review and negotiation. Controversies about the environmental aspects and impact should be seen as necessary and productive from a societal perspective [16].

The role of *precaution* is an important principle to apply in environmental governance, and analyse the role in analyses of the integration of environmental concerns in product design and re-design. The suggested approach to precaution has among others been inspired by the approach in the European Environmental Agency's analysis of a number of case studies of so-called 'late lessons from early warnings' (developed by Harremoes et al [17]). This inspiration implies that the assessments as much as possible should include early warnings, account for real-world conditions and use different types of knowledge, including knowledge from environmental researchers, NGO's, governmental authorities, and businesses.

CONCLUDING REMARKS

A holistic approach to the environmental innovation has been developed based on controversies and complexities from recent examples of environmental innovation. The approach can be summarised in the following way:

- A product or a service should not be understood and assessed as single elements, like a chemical or material, but as

systems analysed in a life cycle perspective. The system need to be included in the identification and assessment of environmental aspects and impacts.

- Scripts and scenarios might be used to develop and describe the future roles of a product or a service, the expected users and the surrounding society and necessary infrastructures, which designers – consciously or unconsciously - imagine as part of their development of a product or a service.

- Societal problems and their solutions are not universal, but actor-specific and their legitimacy can be discussed. Furthermore, the legitimacy of different solutions to environmental problems might be compared. Such a comparison might go beyond the simple comparison of consumption of chemicals and resources, etc., and include the cultural impact, like the impact on the societal understanding of nature and the need to act in a preventive and precautious way.

- The environmental aspects of a product or a service are co-shaped during both design/re-design and application, which implies that governance concepts that involve the different affected types of stakeholders need to be applied.

- The governance perspective builds upon democratic legitimacy as concept, which includes possibilities and limitations to participation and democratic control.

REFERENCES

[1] Jørgensen, M.S., Jørgensen, U. and Clausen, C., 2009, "The Social Shaping Approach to Technology Foresight," FUTURES, 41(2), pp. 80-86.

[2] Jørgensen, M.S., and Jørgensen, U., 2009, "Green Technology Foresight of high Technology – a social Shaping of Technology Approach to the Analysis of Hopes and Hypes," Technology Analysis and Strategic Management, 21(3), pp. 363-381.

[3] Jensen, C.L., and Jørgensen, M.S., 2013, "Young academic women's clothing practice: Interactions between fast fashion and social expectations in Denmark," Sustainability in Fashion and Textiles: Values, Design, Production and Consumption, In: M. A. Gardetti, and A.L, Torres, eds., Greenleaf Publishing, pp. 344-357.

[4] Jensen J., Jørgensen M.S., Elle M., and Lauridsen E., 2012, "Has social sustainability left the building? The recent conceptualization of "sustainability" in Danish buildings," Sustainability: Science, Practice, & Policy, 8(1), pp. 94-105.

[5] Jørgensen, M. S., and Andersen, B.H., 2012, "The controversies over bioenergy in Denmark: 'bio' is not the same as 'sustainable'," Env. Engineering and Management Journal, 11(11), pp. 2101-2119.

[6] Jørgensen, M.S., Andersen, M.M., Hansen, A.G., Wenzel, H., Pedersen, T.T., Jørgensen, U., Falch, M., Rasmussen, B., Olsen. S.I., and Willum, O., 2006, "Green Technology Foresight about environmentally friendly products and materials - The challenges from nanotechnology, biotechnology and ICT," Working Report No. 34, Danish Environmental Protection Agency.

[7] Jørgensen, M.S., Olsen, S.I., Franco, A., and Hansen, S.F., 2006, "An integrated design approach to the governance during research and innovation of environmental aspects related to nanotechnologies," Working paper, Department of Manufacturing Engineering, Technical University of Denmark.

[8] Ornetzeder, M., and Rohracher, H., 2006, "User-led innovations and participation processes: lessons from sustainable energy technologies," Energy Policy, 34, pp.138-150.

[9] Carroll, J.M., 2000, "Making Use: scenario-based design of human-computer interactions," The MIT Press.

[10] Akrich, M., 1992, "The De-scription of Technical Objects," Shaping Technology/Building Society: Studies in Sociotechnical Change, Bijker, W.E. and Law, J, eds., Cambridge, MA: MIT Press, pp.205-224.

[11] Olesen, J., Wenzel, H., Hein, L., and Andreasen, M.M., 1996, "Environmental friendly design" (In Danish: "Miljørigtig konstruktion"), Instituttet for Produktudvikling, Danmarks Tekniske Universitet, Miljø- og Energiministeriet, Miljøstyrelsen, Dansk Industri, Copenhagen.

[12] Jørgensen, M.S., and Jensen, C.L., 2012, "The shaping of environmental impacts from Danish production and consumption of clothing," International Journal of Ecological Economics, 83, pp. 164-173.

[13] Wenzel, H., Hauschild, M. and Rasmussen, E., 1996, "Environmental assessment of products" (In Danish: "Miljøvurdering af produkter"), Instituttet for Produktudvikling, Danmarks Tekniske Universitet, Miljø- og Energiministeriet, Miljøstyrelsen, Dansk Industri, Copenhagen.

[14] Bras-Klapwijk, B., 1998, "Adjusting Life Cycle Assessment Methodology for Use in Public Policy Discourse," Ph.D. thesis, Delft University of Technology.

[15] Brown, N., Rip, A,, and Van Lente, H., 2003, "Expectations In & About Science and Technology. A background paper for the 'expectations' workshop of 13-14 June 2003," Utrecht

http://www.york.ac.uk/org/satsu/expectations/Utrecht%202003/Background%20paper%20version%2014May03.pdf)

[16] Grove-White, R., Kearnes M., Miller, P., Macnaghten, P., Wilsdon, J., and Wynne B., 2004 "Bio-to-Nano? Learning the lessons, interrogating the comparison (Amended version)," Lancaster University and Demos.

[17] Harremoes, P., Gee, D., Mac Garvin, M., Stirling, A., Keys, J., Wynne, B., and Vaz, S.G., 2001, "Late lessons from early versions: the precautionary principle 1896-2000," Environmental Issue Report No. 22, European Environmental Agency, Luxembourg.