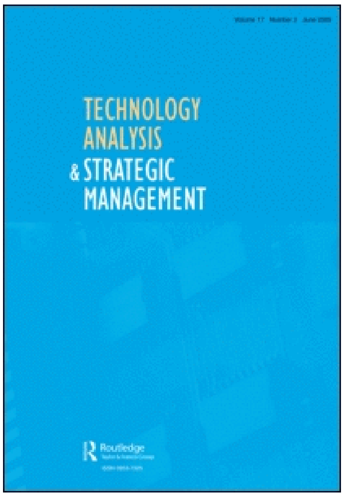

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Green technology foresight of high technology: a social shaping of technology approach to the analysis of hopes and hypes

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High tech visions play an important part in public technology policy and are often promoted through technology foresights. The article presents and analyses results from a green technology foresight of nano-, bio- and information- and communication technologies initiated by the Danish Environmental Protection Agency with the purpose of acquiring knowledge about the environmental potentials and risks related to the three areas of technology. The foresight was organised with a social shaping of technology (SST) approach to the field in order to cater for the complex relationship between societal demands, technology options, innovation dynamics and environmental impacts. The approach involved studying actor-networks, laboratory programmes and technology trajectories as well as deconstructing different stakeholders' high tech visions. The identified environmental potentials and risks related to the three areas of technology and recommendations for future governance of research, innovation and application areas are discussed.

Keywords: technology foresight; social shaping of technology; laboratory programmes; high tech visions; research and innovation policy

Introduction

The world is facing large societal challenges as a result of environmental problems stemming from the large resource consumption in the industrialised countries and the increasing consumption in the newly industrialised countries, partly based on outsourcing of manufacturing from the industrialised countries. In this context many expectations are assigned to so-called high-tech areas like nano-, bio-, and information- and communication technologies (ICT). These are, for example, supposed to contribute to solving environmental problems. However, these expectations often build on rather linear and simplistic understandings of the properties of these technologies and their ability to deliver solutions. Changing the view on technological change from a

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linear understanding to a social shaping of technology approach (SST) to technological change has profound theoretical implications for the way future technological change in technology foresight is conceived. Instead of taking technology as an (external) driver of change, limited only by the ingenuity of mankind, technology is seen simultaneously as a driver and as the object being assigned tasks by different actors to be a part in solving societal problems. Technological change is a continuous process, where technology and social and environmental aspects are co-shaped by the priorities and focus in research, in innovation and in the applications of technology. In this article we discuss the experiences of employing a social shaping of technology approach to a green technology foresight of nanotechnology, biotechnology and ICT we were engaged in during 2004–2006 as researchers at Technical University of Denmark (Jørgensen et al. 2006). 'Green' was understood as a foresight study with the main focus on environmental aspects and impacts. Although great expectations were assigned to these technologies from the outset, the questions raised in the green technology foresight initiated by the Danish Environmental Protection Agency were still open-ended concerning the environmental potentials and risks. This created an opportunity to develop ways to deconstruct guiding visions of researchers and companies, focus on the different levels of maturity concerning innovative potentials of the areas, and ask questions of the complementary technologies needed to implement the high-tech visions in societal applications. It also helped identifying spaces where emerging and existing technologies can be addressed for governance of their potentials and risks with respect to the environment.

After an introduction to the background of the green technology foresight project the research design is presented, including those SST approaches which were applied in the foresight activities. Furthermore, the results from the green technology foresight project are discussed: (a) the identified environmental potentials and risks related to the three areas of technology, and (b) the proposals for future governance of research, innovation and societal application areas, as a prerequisite to forefront environmental potentials and risks in the development of high tech areas.

The aim and background of the green technology foresight

The aim of the green technology foresight was to develop recommendations for Danish strategies for integrated environmental and innovation policies in relation to the three areas of technology in order to reduce and prevent the future risks to environment and ensure focus on the environmental potentials in research, innovation and applications, and obtain environmentally related competitive advantages (Jørgensen et al. 2006).

The foresight was funded by the Danish Environmental Protection Agency (EPA) and managed by the Department of Manufacturing Engineering and Management (now Department of Management Engineering) at the Technical University of Denmark (DTU) and the System Analysis Department at Risoe National Laboratory (now also part of DTU). The focus of the foresight was argued with reference to the expectation that hi-tech-based products and systems could provide more sustainable solutions, including reduced chemical exposure without changing technological regime, such as moving from conventional farming towards organic farming, or from private cars towards public transport. The choice of EPA reflected the central role these technologies are assigned in research and innovation policies almost all over the world, but reflected also the environmental potentials and risks often highlighted in relation to these technologies (Anon. 2003).

Research design: green technology foresight as discursive activity

This paragraph explains how the foresight study was organised as discursive activity with focus on the co-shaping of technological change and environmental aspects. The SST approach to technological change (Bijker 1995; Russell and Williams 2005) and historical studies of technological development (Hughes 1987) have demonstrated the mutual influence of science and society on technological development and the interdependencies of technologies. Technology is seen as a bricolage (Latour 1999), a mixture of different elements, and technological change as a continuous process, where technologies and their societal impacts are co-shaped by a series of actions taken in research, innovation and application.

The SST approach and its combined focus on production and consumption of technology implies 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. The following two examples of technologies analysed in the report from the green technology project illustrate this complexity of environmental impacts (Jørgensen et al. 2006). Few would probably disagree in the development and use of new systems of miniaturised sensors combining ICT and nanotechnology, organised as nets of sensors and providing possibilities for the measurement of concentrations of chemicals in nature. However, environmental NGOs and researchers emphasising cleaner technology would probably object if the sensors ended up being used for measurements of emissions for the purpose of maintaining the discharges just below a given emission level and thereby changing the focus away from prevention at the source. The use of organic material (biomass) for production of bioethanol might sound as an environmentally friendly strategy substituting hydrocarbons, but the actual environmental impact depends on the type of organic material (is it organic waste or plants grown especially for bioethanol) and the alternative use of organic material (e.g. maintaining the humus layer in soil or heating and electricity production in power plants, which also substitute fossil fuels).

The examples illustrate how environmental aspects of science and technology are shaped through the contexts of application including users and the interaction with other technologies and not just shaped in the processes of research and innovation. New, generic technologies have to be combined with already existing and new, complementary technologies to reach the level of practical application (Andersen and Jørgensen 1997; Freeman and Perez 1988; Wengenroth 1993). Consequently the specific strategies and conditions of application were included in the foresight, which led to the development of advice not only for research and innovation policies but also for the governance of sector policies (Jørgensen et al. 2006).

With the words of Brown, Rappert, and Webster (2000) we see the role of SST based foresight as to 'look at the future' rather than 'look into the future' and trying to be predictive. When leaving behind the idea of just outlining future developments, foresight studies inspired by SST can open for not only different descriptions of possible futures, but also the engagement of societal actors in the controversies around the paths of development to be preferred and the risks and benefits, which society at large will be forced to handle. Such controversies are necessary and productive (Elam and Bertilsson 2002; Norges forskningsråd 2005):

- From a *democratic* point of view: the citizens have to live with the consequences of the research and the products and since the public funds for research and innovation are limited the priority of some research and innovation strategies will limit the funds available for alternative strategies for achieving the same types of values.

- From a *pragmatic* point of view: citizens and NGOs can contribute with other perspectives than the researchers and other experts, due to other experiences and other values.

Analyses in the green technology foresight

Five different analytical approaches were employed in the green foresight study in order to collect, develop and analyse information about ongoing research, innovation processes and applications including plans and visions for future research, innovation and applications (Jørgensen et al. 2006):

(1) Analysis of *emerging applications of technologies* within the three areas of technology. Impacts of corporate practice and other stakeholder practices, structural conditions in existing and emerging value chains, and patterns in the environmental potentials and risks. This included surveys of the prerequisites for further dissemination and application of such technologies.
(2) Analysis of *present research and innovation*, emphasising the mechanisms of prioritisation in research and innovation, the role of existing knowledge regimes in research and innovation, and visions shaping and framing research and innovation, including the eventual role of environmental concerns.
(3) Organisation of *dialogue processes* among proponents of the three areas of technology and actors from environmentally important areas of product applications in Denmark followed by an analysis of how these actors envisage possibilities of applying technologies for environmental improvements within the three areas.
(4) Development of *scenarios for probable, future paths* of innovation and application within the three areas of technology and possible alternative development paths.
(5) Identification of *environmental potentials and risks related to the three areas of technology* followed by a comparison of these potentials and risks with societal discourses on environmental problems and discussions of whether there are better ways of solving the addressed environmental problems. Based on these analyses, recommendations for integrated environmental and innovation policies were developed.

The methods applied combined desk research based on literature, qualitative interviews with resource persons within the areas of technology and stakeholder workshops with participants from a number of stakeholder groups, including researchers, companies, governmental authorities and NGOs.

Theories inspiring the green technology foresight

This paragraph explains how theories within the SST approach have been applied in the foresight study in order to identify spaces and situations, where socio-technical change can be analysed, addressed and opened for political controversy. Actors and institutions were seen as undergoing mobilisation, displacement and reconfiguration (including the establishment of new actors and institutions), as an integral part of technological change (Clausen and Yoshinaka 2004). The following four fields of theory have been applied in the five analyses in the green technology foresight (Jørgensen et al. 2006):

(1) Research and development processes with researchers, artefacts, theories and visions, were seen as laboratory programmes and techno-economic networks in an actor-network perspective.
(2) Innovation processes of stabilisation and transitions in systems of innovation systems, including technological regimes and path creation/dependency were seen in the economics and theories of innovation perspective.
(3) Environmental assessment was organised as social and scientific processes by using methods from life cycle thinking and methods of dialogue-based environmental assessment.
(4) Science and technology as policy network processes involving many different stakeholders, aspects of innovation and regulation was understood within a theory of governance perspective.

These four sources of inspiration are detailed in the following paragraphs.

Actor-networks in innovation

The actor network theory (ANT) developed by Callon (1986), Latour (1992) and Law (1991) is useful in technology foresight for several reasons. An actor-network approach 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, such as artefacts, humans, texts, symbols and concepts. The notion ‘actant’ is used to encompass the communality of both the human and non-human and the material and non-material elements in an actor-network. Actor-network as a notion refers to the definition of actors through the network relations they are part of. The approach can be extended to follow the network-building strategies of actors and stresses the mutual constitution and transformation of these elements in the generation of agency, knowledge, institutions and power as effects of the network-building (Russell and Williams 2005).

In a foresight project an actor-network approach is useful in the analyses of both emerging and existing applications within an area of technology and of the priority mechanisms in research and innovation and the visions about future applications. The approach supports a focus on all the elements that seem to be necessary to make a technology either work or not work. In the foresight study this approach enabled, for example, a broader focus on a technology element such as nanoparticles, which included the supporting technologies needed to make this technology operational, as well as the need for, standards and measurement protocols for making the particles work in a technically and socially acceptable way, and the societal agendas they refer to (such as around competitiveness, health and environment). Thereby the approach supports a focus on those actants, which researchers and developers, sometimes explicitly but often unconsciously and implicitly, enroll into a network in order to make the technology become a working entity of a well defined kind and stabilised in such a way that it can be assigned certain properties (Jørgensen et al. 2006).

Laboratory programmes

The concept of laboratory programmes was used in the project to frame and identify how researchers organise the focus of their research and to demonstrate that research processes are not arbitrary and non-biased search processes. A laboratory programme is a sociological approach to research processes that applies the idea of actor-networks on the daily activities of scientists in the laboratory, understood as any kind of research environment. By applying this concept it is possible to identify what preconditions and assumptions that influence the choices and draw the attention of the researchers. The tools of the researcher are the assumptions, the instruments, the theories and not least the anticipated outcomes that constitute the laboratory setting. This implies that we have been tracing the implicit or explicit guiding visions of the researchers and seen these as very important for the framing of problems and interpretations and the practical repertoire of activities employed in the research process (Latour and Wolgar 1986).

Problems, which the researchers claim need to be solved, and the related solutions are seen as outcomes shaped in parallel during the research, when certain achievements are reached in the research process. What is taken into account as legitimate elements and included in the process as, for example, problems or parameters within the researchers' understanding and what is considered outside and difficult to approach are both shaped at the same time and in the same process. A laboratory programme will become more stable when instruments and theories are attached to the programme and alignment processes takes place, where physical objects and actors, for example, are given roles that mutually support the research activities and provide them with a legitimate perspective.

An example from the foresight project is the analysis of the discourses around genetically modified (GM) food and plants, which shows examples of such processes of co-shaping of problems and solutions, including the reframing of the activities within a different research perspective (Jørgensen et al. 2006). Originally GM researchers and companies pointed to pesticide resistant plants as an efficient agricultural strategy but after critique from environmental NGOs the use of GM plants was translated into an environmental strategy due to its claimed potential for reduced pesticide consumption. However, other researchers and environmental NGO's pointed to the risk of getting locked into a pesticide-dependent track and the risk of transferring genetic material coding for pesticide resistance to other related plants (Hansen 2000; Kuyek 2002). A similar example from the nanotechnology area seems to be the focus on applications of so-called nanosilver in product categories such as textiles, household equipment and paint as a solution to fight pathogenic bacteria and guaranteeing the consumer a clean household. Bacteria are regarded as an enemy to human beings, despite the fact that we could not exist as a species without the huge role played by bacteria in the human digestive system. The use of nanosilver has caused controversies about the risk of generating microorganisms that are immune to the well-known anti-microbial impact of silver, which is needed in the treatment of serious burns (see e.g. Nanotechnology Law Report 2007).

Techno-economic networks

The techno-economic networks (Callon 1991), which the interviewees (including researchers and companies) either are part of, or which they explicitly or implicitly anticipate will be developed in the future as part of possible future technology applications, were identified during the analysis of emerging applications and the priority mechanisms in research and innovation. In the analysis focus is on the dynamics between the past experience of the interviewee, the ongoing activities and the interviewee's thoughts about the future development. Furthermore, focus is on relations with existing technology paths and how these seem to influence the research and innovation or how the innovation paths and the companies and institutions shaping and reproducing them might be challenged or might be enrolled in certain visions for the future. An example in the foresight study was the analyses of the shaping of researchers' and developers' work with the future use of ICT for process optimisation, which showed the important role of a new interest from the

US FDA (Food and Drug Administration) for more flexible approaches to process regulation in the pharmaceutical industry, compared to the existing GMP approach (Good Manufacturing Practice), which demands the same process parameters from batch to batch. The new focus of the FDA seems to influence research and innovation within process modelling and process regulation directed towards the pharmaceutical industry (Jørgensen et al. 2006).

Changes in technological regimes and trajectories

When dealing with future technological development and its shaping, the SST approach stresses on the one hand the contingency and unpredictability of technological or rather socio-technical change and the plurality of actors involved, and on the other hand the structures and constraints shaping or restricting changes. Among the concepts used to describe regularity in technological changes in the foresight study were:

- Trajectories and paradigms (developed by Dosi 1982).
- Regimes as the combination of rules supporting a trajectory and guiding innovation (as defined by Russell and Williams 2005).

A technological trajectory is the pattern of problem solving activity within a given technological paradigm. Economic priorities, together with social and institutional frames, will operate as selective devices as new trajectories emerge. Dosi (1982) defines a technological paradigm as a pattern of solution of selected technological problems. In (Russell and Williams 2005) a regime is defined broader than a paradigm and includes furthermore elements such as scientific knowledge, engineering practices, technologies and skills. The regime reduces uncertainty and influences the search space in innovation processes. The criticisms of the focus on regularities in innovation processes argue that the extent of patterns easily is overstated and often are identified afterwards. However the stress on fluidity and contingency has raised concerns too, because the analyses mainly are complex descriptions without recognition of the patterns and continuities that can be observed and the social structures, which these patterns reflect.

Technological regimes were found in the area of ICT and also in the emerging applications of biotechnology. Within the field of ICT computer systems has been defining working conditions in industrial production planning as well as household consumption of media and communication. The overall rationalisation impact of this technology is well documented in industrial production while the impact on administrative work and on household consumption has been critical in environmental terms and led to the need to regulate electronics waste (Jørgensen et al. 2006). Within genetic modified crops the technological regime includes non-reproducible, pesticide resistant seeds as well as the pesticides that the seeds are made resistant to from the biotechnological companies, which builds dependency among the farmers of the biotech companies (Hansen 2000; Jørgensen et al. 2006).

Identifying visions and constructing possible future paths of research, innovation and application

The approaches of techno-economic networks and of regimes and trajectories support the technology foresight process in two ways (Jørgensen et al. 2006). First, in the analysis of *the emerging applications* of a technology it is necessary to understand the background for the breakthroughs, the dead ends, and so on, in the research and development activities. It was for example not enough to know whether it becomes possible to manufacture a certain type of sensor, but also whether this manufacturing is based on, for example, a certain type of equipment, material, co-operation with others and demand from clients, is important knowledge. This tells about path dependency and path creation in research and innovation (and thereby also the potential influence of certain equipment or clients in the future). It was also important to try to make the developers explain the technological systems around the applications such as necessary supply of energy and materials, standards and competencies, which are emerging or need to emerge, so that relevant life cycles and environmental aspects could be identified and analysed (Jørgensen et al. 2006).

Second, in the analysis of *research and innovation* it was important to understand the background and the prerequisites for the expectations the actors have. What is the role they are anticipating, e.g. nanoparticles will have (a certain behaviour in terms of reactivity or stability etc.) and who are expected to be the future users, and in which technological systems does this imply the nanoparticles will be integrated? What are scientific and technological breakthroughs considered as necessary in order to obtain a 'working' version of whatever component it might be? The answers to these questions make it is possible to develop a picture of the future research needs as seen by the actors and sketch elements in future life cycles as basis for life cycle assessments of environmental potentials and risks (Jørgensen et al. 2006).

Identification and assessment of environmental potentials and risks

A methodology for the assessment of environmental aspects within areas of technology was developed as an iterative process during the project. The assessment of the future environmental aspects and impacts were based on (Jørgensen et al. 2006):

- *Life cycle thinking*, which means assessments 'from cradle to grave'. Some assessments were focusing on present emerging applications and others on the information from researchers about possible future applications, which enabled the sketching of product chains for assessment of environmental aspects.
- *Systems approach*, which implies that not only single techniques are taken into consideration, but also other system elements (like infrastructures), which the techniques are parts of or dependent of, are included in the assessment.
- A broad, *dialogue-based understanding of 'environment'*. The understanding of relevant environmental aspects was shaped through, for example, studies of literature and dialogue at project workshops. Part of the approach was inspired by the approach of 'participatory life cycle assessment' (Bras-Klapwijk 1998), where the focus of life cycle assessments is discussed among the concerned and involved actors in order to increase the legitimacy of the assessment among the actors afterwards.

An assessment of the environmental aspects of the future development within the areas of technology is complicated owing to the many unknown elements within the future development in research and innovation and the different societal areas of application and consumption. This challenge in the environmental assessment was dealt with by focusing on the societal problems and discourses, which have been addressed in the past and recent development, and on the understanding of societal problems and discourses and application areas, which researchers and companies addressed, when interviewed about the focus of research and development.

Besides the life cycle and system perspectives, it is also of importance for the assessment of environmental impacts of a technological change whether it implies substitution of previous technologies (with, for example, less positive environmental impacts) and/or implies an increased consumption of products and materials. A framework developed by Berkhout and Hertin (2001) for assessments of the environmental impacts related to the use of ICT was adapted and combined with the life cycle and system perspectives (Jørgensen et al. 2006).

Identified environmental potentials and risks

The following paragraphs presents the findings from the green technology foresight within the three areas of technology in a Danish perspective, which means potentials and risks involving Danish stakeholders as either researchers, innovators and/or applicants of technologies within the three areas of technology (Jørgensen et al. 2006).

Findings related to ICT

ICT is an area of technology, where present and previous applications make it possible to analyse how ICT development and applications have co-shaped the environmental impacts, whereby it was possible to analyse whether and how environmental concerns are addressed and managed as part of ICT-related technology paths. The ICT sector in Denmark has a strong position in communications technology and pervasive computing and is one of the leading countries regarding public and private use of ICT. Environmental potentials and risks were analysed within five application fields: (a) development of the environmental knowledge base, (b) improved product and process design, (c) improved process regulation and control, (d) intelligent products and applications and (e) reduction of transport through changes in logistics and mobility needs.

The use of ICT-based tools and devices for data collection and processing of more data in more complex calculations demonstrated potentials for environmental advantages from future ICT applications. Some tools enable more overall resource efficiency in for example industry so that it is the specific aim of the application by the single company that determines whether and how environmental achievements are in focus. The integration of electronic components into products, so-called intelligent products or pervasive computing and intelligent applications, could imply environmental potential from automatic optimisation of the function of products such as operational feedback to the user, and digital product information about maintenance and reuse. The overall picture, however, was that the improvements will be related mostly to optimisations in energy and resource usage, rather than dramatic reductions in the overall environmental impacts.

Telework, e-business and logistics are ICT applications with strongly appraised implications, especially in relation to future transport. Telework might imply that regular transport related to commuting and shopping in certain hours is replaced by more differentiated transport needs. However, although only a limited amount of employees will be able to telework this could challenge the existing infrastructure of public transport and strengthen individual transport solutions. Mobile telework will probably be more widespread and offer the same facilities at comparable costs as those offered from the office and thereby enable an increase in business travel in conjunction with the ongoing globalisation of manufacturing and trade. Within freight transport, e-business and the concept of just-in-time production in industry could imply more transport due to the request for more frequent supply of small batches of materials and products. Logistic tools might optimise the amount of transport, but the impacts are not simply related to the use of ICT but as much a consequence of transport costs and policies.

The identified environmental potentials within the five fields of application play no significant role in the development and use of software and ICT equipment today. Achievements within these fields demand environmental regulation of the respective application areas, which can influence the priorities made by the users and the dominant driving forces in research and innovation.

The increasing amounts of electronic products, miniaturisation of products, pervasive computing and a more dispersed use of sensors and other devices have, in contrast to the idea of ICT being environmentally friendly, led to increasing problems with electronic waste. An efficient implementation of the EU directive about reduction of hazardous substances in electronic products (RoHS) is seen as necessary in order to achieve the anticipated substitution of some toxic materials in the future (Jørgensen et al. 2006).

Findings related to biotechnology

Positive visions of the environmental contributions of biotechnology developments have been prevalent since the 1980s but the environmental visions have historically not been the dominating drivers of innovation. Strong efficiency drivers especially for pharmaceutical and agricultural applications of new biotechnology have dominated the development. The environmental agenda has only recently come more to the fore with a number of reports, policy documents and discussions papers, which refer to a number of more specific biotechnology developments with environmental perspectives. The motivations for these developments are referred to as an increasing emphasis on problems in the chemical-using industries, on resource scarcities and on the need to 'clean up'. Together with environmental regulation, government priority setting and biotechnology regulation, these have been drivers of an increasing, but still small part of biotechnology, with the potential to address environmental issues.

In Denmark, enzyme technology is promoted as a key technology for realisation of environmental potentials of biotechnology. Reference is made to applications, where enzymes address and reduce the application of toxic chemicals and resource consumption, including energy consumption. Representatives in industry as well as researchers expect enzymes will contribute further by increasing efficiency in production and use of enzymes, by being applied within more industries and by further use in industries already using enzymes.

With regard to developments within bioethanol and biopolymers, environmental concerns have been key motivators for innovation, together with concerns for fossil fuel scarcity. The environmental assessments demonstrate, however, a need for further evaluation and debate of the perceived environmental potentials. Future use of biological resources has to address the issue that biological resources are of limited availability, and environmental claims must compete with the use of the same land and crops for food and for fuels in the energy sector power plants (Jørgensen et al. 2006).

Findings related to nanotechnology

The environmental aspects related to the nanotechnology area are yet very uncertain. There are knowledge gaps both about environmental risks and potentials, because of the very early stage of development. There is rising international and national concern about environmental and health risks related to nanoparticles, which questions the overall environmental potential of nanotechnology and is seen as an argument for urgent inquiry by environmental and health researchers and by some nano researchers. The foresight project showed that Danish nano innovation trajectories are still at an early and fluid stage of formation. The current phase of path creation seems crucial to the direction that nanotechnology is going to take. The analyses of the researcher visions and corporate visions showed that, despite frequent references to environmental potentials in the general debate on nanotechnologies, the problem solving activities and the emerging technological paths among Danish nano researchers and companies are only to some extent addressing environmental potentials. Environmental risks are also overlooked, although there is a rising concern about these among stakeholders involved with nanotechnology.

The project identified nano-related environmental potentials within different parts of the nanotechnology area, which may contribute to abatement and prevention of environmental effects in four ways: (1) tailored, efficient products; (2) new materials with properties, which enable reduced consumption of energy and other resources in the manufacturing and/or the use of these products and materials; (3) technology for renewable or more efficient energy systems, including fuel cells, solar cells and wind turbines; and (4) environmental remediation with more targeted treatment of pollutants and more efficient catalytic cleaning. Many of these areas are in the early stages of research and innovation, but by the 2020s they may offer possibilities to abate and prevent environmental problems related to energy supply and transport, resource use, use of chemicals and treatment of waste and wastewater. Most of the identified environmental potentials are, however, not likely to be pursued in the current research and innovation trajectories in Denmark and need policy action to be realised. Furthermore, the existing environmental assessment procedures are not adequate for measuring and handling materials at the nanoscale (Jørgensen et al. 2006).

Recommendations for future governance of the three areas of technology

The project anticipated at the outset that technological change and environmental impacts would, only in a few special cases, be directly linked to the development of an area of technology and the materials or processes part of this development. The environmental impacts of, for example, the chemical industry is not only shaped by the development of ICT-based tools for process design and regulation, but also by innovation in process equipment and by the national and local governmental regulation of the wastes and emissions of industrial facilities. The studies of the three areas of technology confirmed this conceptual anticipation within all three areas despite their differences, including the different degrees of application. Based on the identified future environmental potentials and risks and inspired by earlier analyses of and experiences with governance of science and technology, three core policy perspectives were developed in the foresight project (Jørgensen et al. 2006):

(1) *Guiding research* to include environmental perspectives, including policy options for assessing research strategies and potential outcomes, creating visions and objectives for areas of research and prioritising the research to be supported.
(2) *Focusing innovative activities* on the combination of technologies within specific fields of application to establish specific strategic innovation policies supporting the creation of new paths of development and bridging the gap between research and market diffusion.
(3) *Regulating technology applications* through the regulation of driving forces and institutional frames determining the development of consumption areas and based on coordination of policies between different policy domains.

Within all three policy perspectives no single actor like for example a national government can set the course, as the results of the policies are dependent on the networks of actors cooperating and the controversies and resulting stabilising strategies. This is reflected in the *environmental governance* approach to policy developed as a fourth cross-cutting perspective. A deliberate focus on environmental aspects in research and innovation policies needs to establish a framework of social interactions focussing on the environmental concerns of different stakeholders and addressing the uncertainties in relation to both potentials and risks related to new technologies (Gibbons et al. 1994; Jørgensen et al. 2006).

Environmental policy usually addresses mature technologies looking for substitution possibilities to remedy urgent environmental problems. It is quite another issue to address generic technologies, or even, as in the case of nanotechnology, an area of technology that only is beginning to materialise. Obviously the interventions and questions raised are different in the idea generation phase compared to the later experimental, early production or full commercial phases of innovation processes. The following paragraphs discuss the proposals for future governance of research, innovation and application related to the three high tech areas in general and specifically for each of the three areas.

Governance of research

An important question to address in future research policy is when and how to introduce policy measures in relation to research in order to obtain an increased focus on environmental potentials and risks. The following types of guidance were identified in the foresight study (Jørgensen et al. 2006):

(1) Visions for the anticipated societal role of an area of technology and the environmental outcomes as a means of shaping the research policies and also the rules of attention in the research community.
(2) Environmental screening of research proposals as a way of qualifying the decisions and priorities made in research funding.
(3) Guidelines for the organisation of environmental assessment of technology research as integrated and/or independent research activity.

Measure (1) is inspired by the need to challenge the utopian ideas of researchers and the often tacit prerequisites such visions are building on (Grove-White et al. 2004). Dialogue processes with broad participation of interested stakeholders, including organisations seldom invited into planning and management of research (e.g. consumer organisations, environmental organisations and trade unions) might be a way of enabling assessments of the social and technical prerequisites of technology visions and of the environmental aspects of research and innovation.

Measure (2), screening of research proposals, is only a valuable measure if the researchers are able and willing to address these issues and, at the same time, those evaluating the proposals agree in the importance of environmental aspects *and* are able to assess these aspects. Some of the earlier Danish experiences within food technology research with a request for applicants to address aspects of the impacts on environment, health and safety have not shown too promising results. Many researchers chose not to address the issues and the evaluators did not find the aspects important enough to let these aspects influence the funding decisions. The experience with the present demand for addressing socio-economic aspects in EU research applications has neither been too promising, as many of the technical domains only have addressed these issues rather superficially (Jørgensen et al. 2006).

Measure (3) is inspired by strategies developed during the years 2000–2005 in the UK and the Netherlands with environmental assessments in relation to nanotechnology research. An important aspect of the assessment of environmental aspects of technology concerns the research funding schemes and the organisation of the environmental research as integrated into or independent of the technology research. Environmental researchers who are part of a nanotechnology research group could, on the one hand, develop trust in the relations with the nanotechnology researchers and have enough proximity to the research subject to allow detailed assessments. On the other hand, integrated environmental research without independent funding could become too dependent of the nanotechnology researchers. Two European examples show how environmental concerns may be related to nanotechnology research. At the University of Cambridge a researcher, who was trained as a chemist before switching to the social sciences, was employed within a nano research group. His activities included development of methods for reflection on the social implications of the research and considerations about how non-scientists might be involved in deciding what the nanotechnology research should focus on. The challenge is to avoid making the social sciences the handmaiden of technological innovation (Turney 2005). The Dutch constructive technology assessment (CTA) (Schot and Rip 1997) activity within the national Dutch nanotechnology programme, NanoNed, is organised as an independent, but integrated programme. The CTA programme has its own projects, but in connection to activities within the NanoNed programme. The aim of the technology assessment is to understand and improve the interaction between science, technology and society (Technology Assessment 2006). The challenge is how the CTA research avoids becoming social marketing of nanotechnology.

In relation to ICT the green technology foresight identified a need for more research about the actual and the potential roles of ICT-based technologies in the shaping of less polluting and resource consuming use patterns in order to develop more socio-technically advanced paradigms for ICT-based technologies. In relation to biotechnology more research about the environmental aspects of biotechnology seems to be one of the prerequisites for future application of these technologies. The key barrier to focus on environmental potentials related to nanotechnology is lacking awareness and knowledge of nano-related environmental potentials and business potentials (Jørgensen et al. 2006).

Governance of innovation

The integration of environmental aspects into strategic innovation policies aims at creating new paths of development and bringing new technologies to real life test. The identified limited focus on environmental potentials in innovation within all three areas of technology shows the need for measures, which can ensure environmental focus in innovation processes (Jørgensen et al. 2006). The results of this kind of measures should be the creation of new paths for technological development by supporting the critical and highly uncertain first steps of bringing ideas for potential environmental benefits from the research stage to real prototypes and tests. The approaches applied in the proposals are inspired by Danish experiences within cleaner technology (Andersen and Jørgensen 1997), cleaner products (Remmen 2002), wind power (Karnøe and Garud 1998) and organic food (Jørgensen 2004). The Danish experiences demonstrate that it is possible to develop new, more sustainable development paths within an application area in competition and cooperation with existing technological regimes. Such path creation demands a combination of reshaping of existing institutions, competencies and regulatory mechanisms, and development of new institutions, competencies and regulatory mechanisms. The overall proposals for measures include (Jørgensen et al. 2006):

- Support for innovation combining technologies into products for specific fields of application whereby the environmental impacts better can be identified and realistic user conditions confront the technologies.

- Integration of environmental concerns into the innovation processes at the earlier stages of laboratory and prototype developments are important to assure that these aspects are part of the creation of development paths.
- Support for market development through combinations of regulation of potential application fields, support for demonstration projects, and network activities involving potential suppliers, customers, knowledge institutions and intermediaries.

In relation to ICT the foresight study showed the need for more focus on the potentials of and limits to intelligent products and applications as elements in environmental strategies. Furthermore, need for strategies to ensure focus on hazardous substances and materials and radiation in the development of products and components. In relation to biotechnology there is need for development of enzymes with environmental potentials for a broader variety of industrial processes and a strategy for sustainable use of biomass as renewable resource. There is need for considerations about how the industrial up-take of nanoscience can be based on environmental potentials. A central barrier is lacking environmental competencies among Danish nano researchers, lacking nano competencies among environmental experts and in industry, and weak linkages among these groups (Jørgensen et al. 2006).

Governance of areas of application

If mature and market-introduced technology applications with environmental potentials are not realised under present market, production and user regimes more stringent regulatory policies could provide a difference. A sector or product domain approach may be needed instead of a technology approach (Jørgensen et al. 2006). Some findings from application areas identified in the analyses of the three areas of technology are presented in the following.

ICT-based process control is used in many industries and this kind of control could be a way of reducing environmental impacts if the process control is focused on reduction of resource consumption and emissions. However, stronger governmental regulation of industry in terms of demands to emissions combined with increased prices on resources and support for competence development is necessary to encourage industry to reduce the emissions through better process control and also wider use of enzymes (Jørgensen et al. 2006). The amount of transport of persons and freight is dependent on a number of socio-economic changes that have very little to do with the development of ICT equipment for transport and logistics. The amount of private transport depends more on the costs of housing in areas near the workplace of households and prices on public transport and fuel. Hybrid cars with engine and batteries with ICT-based control of the vehicle could give significant improvements in fuel efficiency. However, as a result of the present innovation strategies in the car industry and the tax system on vehicles and fuel, the market penetration of these types of cars is very modest (Jørgensen et al. 2006).

In relation to nanotechnology, regulation of applications is not yet a key instrument considering that most of the identified environmental potentials are pre-commercial. In specific cases, e.g. new types of energy efficient lighting, regulation of the application of nanotechnology could be feasible, but at a later stage (Jørgensen et al. 2006).

Conclusions

Visions of environmental potentials within all three areas of technology exist, but tend to be based on quite simplistic assigned properties to the technologies as idealised entities. At the same time there is only little recognition of the need to regulate research, innovation and application areas to reach a situation where the environmental potentials are critically assessed and where environmental aims become a core element in the priorities of research and innovation. In research and innovation policies the decoupled environmental characteristics assigned to the generic technologies seem to prevail. A number of more specific applications have been prioritised and argued based on their environmental potentials, though lacking the governance support to ensure the anticipated environmental potentials.

The foresight study has demonstrated that it is possible to identify future environmental aspects and impacts related to different paths of development within the studied areas of technology. The social shaping of technology approach, including the environmental assessments, applied in the foresight study enabled analyses of the shaping of present and previous societal applications of a mature area of technology such as ICT and of a somewhat mature area of technology such as biotechnology. Dynamics co-shaping research, innovation and applications were identified and enabled deconstruction of environmental hypes and hopes. The mapping and deconstruction of researcher visions about future application areas related to all three areas of technology, including the emerging nanotechnology area, have furthermore enabled identification and deconstruction of possible future environmental aspects and impacts. In relation to all three areas proposals for more advanced future governance of research, innovation and applications were developed.

Even though the developed approach to green technology foresight has been able to create a more complex understanding of the relation between technology, society and environmental aspects and impacts, the project has shown a need to focus more on sector transitions and the involved applications of technology instead of taking generic technologies as the outset. In such foresight studies the emphasis should be on the dynamics, which shape the application areas in order to avoid the translation of societal problems into simple technical solutions. Add-on technologies such as transport logistics and nanosilver may be faster to apply to societal problems, compared to changes in transport needs or intensive agriculture and its impact on bacteria in food. However, simplistic technical strategies will not abate and prevent the environmental problems and may even create new problems, such as the bacteria resistance in the case of nanosilver mentioned earlier, or divert the awareness of the complexity of the problems and the need for coherent and integrated solutions.

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References

Andersen, M.S., and U. Jørgensen. 1997. The support for cleaner technologies: results, diffusion and future activities – an evaluation of the support programmes 1987–1992. Environmental Review no. 14, Danish Environmental Protection Agency, Copenhagen.

Anon. 2003. Baggrundsnotat til sigtelinie 2 Innovation og spredning af miljøteknologier – 2. ansøgningsrunde 2003: 2.1 Grønt teknologisk fremsyn om design af miljøvenlige produkter og materialer (In Danish) [Background paper for line 2 innovation and diffusion of environmental technologies – 2nd application round 2003: 2.1 Green technology foresight on design of environmentally friendly products and materials].

Berkhout, F., and J. Hertin. 2001. Impacts of information and communication technologies on environmental sustainability: speculations and evidence. Report to the OECD, Science and Technology Policy Research Unit, University of Sussex, Brighton.

Bijker, W.E. 1995. *Of bicycles, bakelites and bulbs: towards a theory of sociotechnical change.* Cambridge, MA: MIT Press.

Bras-Klapwijk, B. 1998. Adjusting life cycle assessment methodology for use in public policy discourse. Delft University of Technology.

Brown, N., B. Rappert, and A. Webster, eds. 2000. *Contested futures: a sociology of prospective technoscience*. Aldershot: Ashgate.

Callon, M. 1986. Some elements in a sociology of translation: domestication of the scallops and fishermen of St Brieuc Bay. In *Power, action and belief: a new sociology of knowledge?* ed. J. Law, 196–233. London: Routledge & Paul Kegan.

Callon, M. 1991.Techno-economic networks and irreversibility. In *A sociology of monsters: essays on power, technology and domination*, ed. J. Law. London: Routledge.

Clausen, C., and Y. Yoshinaka. 2004. Social shaping of technology in TA and HTA. *Poiesis & Praxis* 2, no. 2: 221–246.

Dosi, G. 1982. Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technological change. *Research Policy* 11: 147–162.

Elam, M., and M. Bertilsson. 2002. Consuming, engaging and confronting science: the emerging dimensions of scientific citizenship, STAGE (Science, Technology and Governance in Europe) Discussion Paper 1, Gothenburg University and Copenhagen University.

Freeman, C., and C. Perez. 1988. Japan: a new national system of innovation? In *Technical change and economic theory*, ed. G. Dosi, C. Freeman, R.R. Nelson, G. Silverberg and L. Soete. London: Pinter.

Gibbons, M., C. Limoges, H. Nowotny, S. Schwartzman, P. Scott, Peter, and M. Trow. 1994. *The new production of knowledge*. Thousand Oaks, CA: Sage.

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

Hansen, A.G. 2000. Danish development of genetically engineered herbicide resistant beets and the role of environmental controversies. Danish country account of the growing of genetically modified plants and their use. Report for the EU project 'Consumer, environmental and sectoral networks in the societal management of food technology'. Unpublished report. Department of Technology and Social Sciences, Technical University of Denmark, Lyngby.

Hughes, T.P. 1987. The evolution of large technological systems. In *The social construction of technological systems*, ed. W.E. Bijker, T.P. Hughes and T. Pinch, 51–82 Cambridge, MA: The MIT Press.

Jørgensen, M.S. 2004. Policy integration in the shaping of organic food as strategy in the Danish food sector – what happened to the environmental concern as driving force. Paper presented at a Conference on 'The Human Dimension of Global Environmental Change: Greening of Policies – Policy Integration and Interlinkages', 3–4 December 2004, at Free University of Berlin, Germany.

Jørgensen, M.S., M.M. Andersen, A.G. Hansen, H. Wenzel, T.T. Pedersen, U. Jørgensen, M. Falch, B. Rasmussen, S.I. Olsen, and O. Willum. 2006. *Green technology foresight about environmentally friendly products and material – the challenges from nanotechnology, biotechnology and ICT*. Working Report no. 34, Danish Environmental Protection Agency, Copenhagen. http://www.mst.dk

Karnøe, P., and P.R. Garud. 1998. Path creation and dependence in the Danish wind turbine field. Papers in Organization no. 26, Institute of Organization and Industrial Sociology, Copenhagen Business School, Copenhagen.

Kuyek, D. 2002. Genetically modified crops in Africa: implications for small farmers. Brief written for GRAIN (Genetic Resource Genetic Resources Action International), Spain.

Latour, B. 1999. *Pandora's hope – essays on the reality of science studies*. Cambridge, MA: Harvard University Press.

Latour, B. 1992. Where are the missing masses? The sociology of a few mundane artefacts. In *Shaping technology, building society*, ed. W.E. Bijker and J. Law, 225–258. Cambridge, MA: MIT Press.

Latour, B., and S. Woolgar. 1986. *Laboratory life: the construction of scientific facts*. Princeton, NJ: Princeton University Press.

Law, J., ed. 1991. *A sociology of monsters: essays on power, technology and domination*. London: Routledge.

Nanotechnology Law Report. 2007. http://www.nanolawreport.com/tags/nanosilver/ (accessed 6 January 2008).

Norges forskningsråd. 2005. Nanoteknologier og nye materialer: Helse, miljø, etikk og samfunn. Nasjonale forsknings- og kompetansebehov [Nanotechnologies and new materials: health, environment, ethics and society. National research and competence needs]. Norges forskningsråd, Oslo.

Remmen, A. 2002. Greening of Danish industry – changes in concepts and policies. In *Technology studies and sustainable development*, ed. A. Jamison and H. Rohracher, 171–198. München: Profil.

Russell, S., and R. Williams. 2005. Social shaping of technology: frameworks, findings and implications for policy with glossary shaping concepts. In *Shaping technology, guiding policy: concepts, spaces and tools*, ed. K.H. Sørensen and R. Williams, 37–133. Cheltenham: Edward Elgar.

Schot, J., and A. Rip. 1997. The past and future of constructive technology assessment. *Technological Forecasting and Social Change* 54, no. 2: 251–268.

Technology Assessment. 2006. About technology assessment in the Dutch NanoNed programme. http://www.nanoned.nl/TA/Technology+Assessment.htm (accessed 4 December 2006).

Turney, J. 2005. Before you build that nanobot. *The Times Higher Education Supplement*, 28 January 2005. http://www.nanoandsociety.com/news/documents/THES%20-%2005.pdf (accessed 4 December 2006).

Wengenroth, U. 1993. How they won the market: electric motors in competition with steam engines, 1890–1925. In *Technological competitiveness. Contemporary and historical perspectives on the electrical, electronics, and computer industries*, ed. W. Aspray, 270–286. Piscataway, NY: IEEE Press.