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Borup, M.

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Section D: Technologies for Sustainability Transformation

Green Technology Foresight as Instrument in Governance for Sustainability

Mads Borup
Technology Scenarios Research Programme, Risø National Laboratory, Denmark

There is increasing focus on foresight exercises as a tool in public governance of research and industrial innovation systems. Technology foresight has in recent years been carried out at the European level as well as in many individual countries e.g. Austria, France, UK, The Netherlands, Greece, and the Czech Republic. Technology foresight can be defined as systematic analysis and discussion about possible technology futures. The activities are in many cases set up as an input to research and technology policy and prioritisation, often with close connections to industrial policy and innovation policy. Apart from governmental institutions, innovation and engineering supporting institutions e.g. associations of engineers in Germany, Sweden, and Denmark have engaged in establishing technology foresight activities. Also people in the fields of technology studies and technology assessment are discussing technology foresight at present.

Green technology foresight (GTF), or environmentally oriented technology foresight, has occurred as part of this renewed and extended focus on technology foresight. The environmental and climate problems are widely acknowledged as serious problems facing the world today both locally and globally. Environment issues and thoughts about sustainability are if not high on, then at least visible, on the agenda in society in general. They have become part of the mainstream discussions. This has created a new area of relevance and legitimacy for technoscientific development and research and new opportunities and markets for environment technology are gaining importance. An integration of science and technology policy with environment policy seems more relevant and obvious than earlier. These things are reflected in the appearance of green technology foresight and also in the inclusion to some extent of environment aspects in more general technology foresight activities. Special methods of green technology foresight have been developed, as many normal technology foresight approaches are not suitable for dealing with environmental issues.

The foresight exercises usually happen in interaction with different actors e.g. from industries, science areas, and public governance and planning. The activities contribute to coordination and integration of expectations, knowledge and perspectives of the different areas. Thus foresight is a multi-actor activity that supports network developments across established institutional and sectorial borders. Green technology foresight can be seen as one of the important new instruments in the governance of the transformation of innovation and industry towards environmental sustainability. The chapter describes the character of green technology foresight and discusses critically the connections between technology foresight and environment. The description of green technology foresight is given primarily through presentation of examples of concrete projects. They are analysed with respect to: 1) the method employed, 2) the actors and organisations involved, including the embedment of the projects institutionally and in policy developments. The examples of green technology foresight are these:

1. 81 options – A Dutch Green Technology Foresight
2. The Danish Green Technology Foresight
3. Life cycle assessment and technology foresight
4. Precautionary principle and technology foresight

The main argument of the chapter is that green technology foresight can be a fruitful tool in environmentally oriented research and technology policy, but that technology deterministic understanding of innovation is still quite dominating in the normal foresight methods and hence alternative and specialised methods designs than these are needed. As an example of problem-oriented technology foresight, green technology foresight might be a useful element in a transformation of the innovation systems to sustainability as the experiences about integration of environment and technology development experiences from green technology foresight can be employed more generally in science and technology planning and discussion. When this is said, it shall also be emphasized that there still are only very few examples of actual green technology foresight exercises. There is not basis for saying that green technology foresight in general has so far had more than limited influence on environment policy, technology policy, science policy or the integration of these.

The perspective of the chapter builds on social studies of science, technology and society dynamics (STS), on governance studies, and on studies of the connections between environment problems and innovation. Before presentation of the specific approaches of green technology foresight, the chapter contains firstly an elaboration on the background for technology foresight, secondly a perspective on technology development and environment, and thirdly a brief description of environment issues in general technology foresight projects.

The chapter primarily describes green technology foresight as it appears in connection with public policy and planning processes at a central national or societal level. It does not deal with strategy processes internally in e.g. companies, research institutions etc. The chapter only considers activities, which are explicitly considered as technology foresight with focus on environmental/green issues. It does not claim to cover the huge amount of future-oriented discussions, scenario analyses, 'backcasting' etc. in one way or the other dealing with environment/sustainability and technology development. Neither does the chapter give a complete picture of strategic planning processes on environment and technology even though it discusses the role of green technology foresight in connection with planning and policy processes on environment, technology and science. Green technology foresight is but one of many ways to do strategy and policy processes on technology and environment.

Foresight and governance in a change-oriented society

The focus at technology foresight at present goes hand in hand with the tendency of an increasingly change-oriented culture (as pointed out by e.g. Giddens 1998). Contested technological futures are a central element in present time's policy discussions, agenda settings and power struggles (Brown et.al. 2001). Expectations and promises about the future play an increasingly significant role in science and technology development activities both at a macro, meso and micro level i.e. both at the levels of policy and planning, of industrial sectors and research programmes and of experiments and laboratory work (van Lente 1993, van Lente & Rip 1998). Generative visions are thus constructed and developed also by scientists and engineers (Borup 2001). At the same time the understanding of science and knowledge is under significant change. Science and knowledge are to an increasing extent considered strategic issues and objects of management and prioritisation. Knowledge production is by many considered the central driver of development and economy. This is captured in the term knowledge society. The relevance of science and scientific knowledge is not given by science internal assessment only. Science's new 'social contract' with society is under development and it is a challenge to develop knowledge that is socially robust (Gibbons 1999, Nowotny et.al. 2001). In this situation it is not surprising that technology foresight as a systematic tool for dealing with the future of not least research and science enjoys relatively high attention.

The significance of technology foresight is related also to the strong technology-orientation in general in society. Technological development and innovation are supported and encouraged in a multitude of ways. They are considered an important driving force for growth and societal development in general. When looking for solutions to the problems in the society of today, eyes are often turned in direction of technoscience and the promises of new technology. This technology deterministic understanding is reflected in technology foresight studies. The weight is predominately on technology push and science push issues and not on demand-pull or problem-oriented understandings. Technology foresight studies thus usually focus on the positive promises and potentials of new technologies.

Not least the climate and environmental problems have to some extent challenged the technology optimism and an un-reflected belief in future technology. Recent discussions on technology foresight have to a higher degree considered the complexity of technology development and its' dependency on many diverse factors. The character of dynamic co-evolution between many actors and the mutual integration of social and technological aspects are considered (e.g. Rip 2002). Renn (2002) points out five central characteristics of foresight:

- Foresight is based on the philosophy that future developments are contingent on human actions and decisions; this is why foresight is not a process of forecasting the future but rather an attempt to explore the space for human actions and interventions to shape the future
- Foresight is aimed at producing orientations rather than predictions; it provides guidance to all actors and reduces uncertainty
- Foresight includes multiple perspectives, multiple actors and multiple disciplines on different levels of governance
- Foresight is focused on opportunities and risks alike
- Foresight emphasis the interrelations between the technological, economic, social, political and cultural sector of society

In practice, there is however still focus on approaches that primarily include scientific and technological experts for example through expert-oriented questionnaires ('delphi studies') and expert panels. The 'delphi study' approach has to some degree been paradigmatic for technology foresight activities. In Europe, it is not least the

German and the British technology foresights employing the delphi approach that have been a common reference point for design of foresight projects.

Technology foresight and other of the 'new' governance approaches are governance in and by networks of actors. They focus on interaction and coordination between actors instead of having a hierarchical view on governance and they emphasise the importance of decentralised activities and the interplay between centralised and decentralised steering. As it is the point in the recent years' governance literature, directions and strategies for innovation and technology development occur not as a governmental dictate or as autonomous processes detached from governmental influence, but are developed in interaction between governmental authorities and policies and actors in the covered activity areas. This is described as well in governance literature on innovation and research specifically (Hackmann 2001a+b, Fuller 2000, Glynn et.al. 2001, Fèron & Crowley 2002, Goncalves 2003) as in the more general governance literature that often emphasise the connection between forms of governance approaches and the issue of democracy (March & Olsen 1995, Pierre 2000, Hirst 2000, Christiansen 1999). The question is not if there is interaction between government actors and actors relevant for the research areas to be managed, but which actor groups and networks are included in the processes, and which are excluded. Secondly, it is a question how, in which interaction processes and with which weight the different actors are represented and involved in the processes.

Technology foresight must however be understood primarily as a practical, pragmatic activity. The methods and approaches are not developed and fully analysed within an academic research perspective. There is a lack of systematic and independent analyses of the impact of technology foresight. The impact is clearly smaller than and not as thorough as promoters of foresight will say, when talking about the single technology foresight project. A study of the influence of technology foresight as a science and research policy means concludes that there is no or only very little effect on values and practice in academic research. Primarily the effect consists of a shifting and more open attitude towards industry (Henkel 2000). Other studies find that there can be important impacts from foresight, however very dependent of institutional relations in connection with the foresight (van der Meulen 1999; van der Meulen & Löhnberg 2001). Especially it is concluded that foresight in the Netherlands has had important impact on research in sustainable technology as well as in environmentally oriented technology policy. In some circles of environmental policy makers it raised awareness that as part of the environmental policy a technology policy is needed. While the impact is seldom significant concerning the single foresight processes, technology foresight might gain importance if it becomes a widespread activity and a normal tool in policy, planning and strategy processes in connection with technology. On four contemporary and partly overlapping foresight processes van der Meulen concludes that:

> "The interesting point however is that at the system level a new balance has been constructed. The four foresight processes together create a new balance of future oriented strategy development which includes different perspectives and interests." (van der Meulen 1999, p. 20)

Technology development and environment

In discussion of green technology foresight, it is relevant to draw on the perspective of the well-known classification of technologies in relation to environment issues:

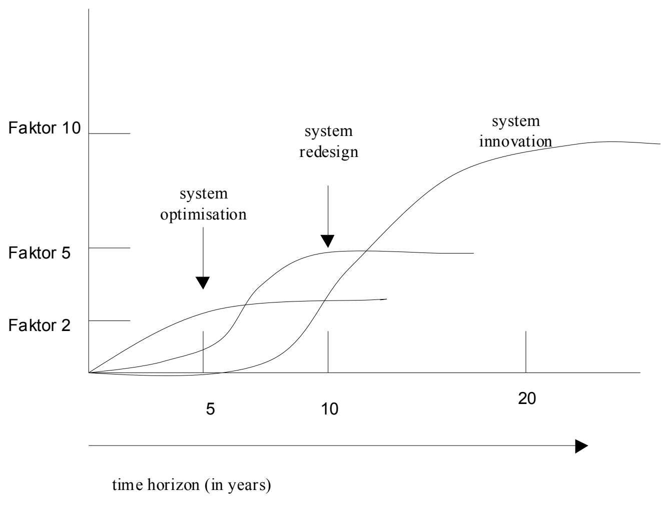
1. End-of-pipe and add-on solutions
2. Cleaner technology and integrated solutions
3. System changes for sustainability

The list can to some extent be seen as a historical development of environment technologies where end-of-pipe solutions were the first way of dealing with pollution and environment problems, then first cleaning technologies and later integrated solutions and cleaner production technologies appeared. And where sociotechnical system changes now are the 'environment technology' that shall be developed. However, there will still be a need for new cleaning technologies also in the future, and the third point on the list shall also be seen as a quality characteristics or a goal to employ as it points to a lack in many technology development activities. There are two dimensions in this: the system dimension and the value dimension. Firstly, the system changes indicate that changes at the level of the socio-technical systems, and not just in the single technological artefact or product, is needed if environmental sustainability shall be pursued. Approaches that include technology use and consumption patterns as well as institutional, organisational and market aspects are needed in order to obtain the radical reductions in resource and material consumption and in emissions that are required if sustainability shall be reached. This is often illustrated with figures like the one below that indicates that radical system innovations (and a factor 10 reduction rather than factor 5) are needed.

System changes for sustainability have to do with practices and norms within innovation and technology development:

> "...severe contradictions between innovation and sustainable development exist. ...we resume that the present practice of industrial innovation still stands in significant contradiction to sustainable development." (Meyer-Krahmer 1998)

> "...most if not all of the environmental problems facing the world ultimately derive from the long-run processes of technological change that began with the first industrial revolution." (Smith 2002)



Three types of changes for environment *(after Vollenbroek et al 1999).*

Thus system changes for sustainability also mean that changes in values and norms in direction of sustainability are a necessary element in connection with the technology development for sustainability. There will be no sustainable society if sustainability and environmentally awareness are not a part of the norm set in most areas and interaction arenas of society, including scientific and innovation oriented institutions.

A draw back of the three-step classification of environment technology is that it is a classification of technologies through the character of their positive environmental impacts, while negative environmental impacts are not in focus. Most technology developments in general are thus not covered and difficult to relate to the categories.

Environment aspects in general technology foresights

The amount of literature on environment and technology foresight is limited. An overview on the subject can be obtained through the proceedings of an OECD workshop on Technology Foresight and Sustainable Development (OECD 1999). This section also builds on a literature study on environment and technology foresights we have done for the Danish Ministry of Environment (Rasmussen et.al. 2003).

The typical picture in the general national technology foresights studies is that environmental issues appear clearly primarily in the two categories: 1) energy and 2) environment technology. To some extent environmental issues are also present in transport categories (energy efficiency and fuels). Energy is, whether defined in terms of a technology area, a sector, or in other terms, in many technology foresight studies among the overall main areas identified under which a number of sub-sectors and sub-technology areas are clustered. Typically there are between 4 and 15 of these main areas in a general national technology foresight. The sub areas within energy are for example energy savings technologies, energy production systems, renewable energy technology, fossil fuel clean technologies, and energy transport and storage. Environment aspects e.g. climate problems, resource consumption and efficiency, are a very central and explicit element in most parts of the energy main area.

Environmental technology categories have compared to energy not been among the typical overall main areas in the general technology foresight studies, but are found as smaller sub-areas subordinated other categories. Environment technology usually means cleaning technology and pollution and waste treatment technology in the technology foresight studies. Also environment monitoring and control technologies appear in this category.

There are exceptions of this general picture, for example in the Austrian technology foresight where 1) clean production and 2) biological (organic) food are among the seven overall areas in the technology and research oriented delphi study (ITA 1998). Environmental futures scenarios has been carried out in connection with recent rounds of the UK foresight programme (Eames & Skea 2002). Environment and Clean Production Technologies is one of the six key technology sectors selected in the European 'Futures Project', which builds on the various national technology foresight studies and has sustainable development as a priority concern (Cahill et.al. 1999). The 'high-ranked technologies for Europe' within this key sector and the energy key sector from this study are shown in the box. It is also found in this study, that examples of environment technologies and especially clean technologies can still be found within a number of sub-areas e.g. biodegradable plastic and carbondioxide fixation technologies within the area of material technology (the latter also within the biotech – agro food sector).

In a long range of other categories than energy and environment technology in the general technology foresight studies, environment aspects of future technologies are not or only to a very limited extent present. Environmental aspects are thus only dealt with in a minority of the areas and sub-areas covered, not because the potential future technologies are not connected with environment issues, changes in resource consumptions etc. but because technology foresights and their methods do not focus on this issue.

The Futures Project: Technology Map (Cahill et.al. 1999) High-ranked technologies for Europe in two main sectors Environmental and Clean Technologies and Energy	
Environmental and Clean Technologies	Recycling Separation New energy sources Solar cells Energy saving Global management of environment Clean production
Energy	Nuclear energy Fossil fuel clean technologies Renewable energy technologies Energy transport and storage Rational use of energy

Despite the fact that environment aspects are only dealt with in a minority of areas in the general technology foresight studies, the environmental dimension is usually explicitly present at the value level in the technology foresight studies and in the overall picture given of the relevance and legitimation of research and innovation. Sustainable development is generally viewed as a key future need to which science and technology should be directed (Fukasaku 1999). However, the connection from sustainability as overall value to practical method is not elaborated.

Some examples of environment-related issues identified in the different general technology foresight studies are listed below. The examples are from the Czech Republic foresight 2002 which as one of the cross cutting 'thematic panels' had an environment panel, from the classical delphi survey in UK 1995, and from the French 'critical technologies study' 1996 (the latter is shown in the appendix). Of course a list of issues is often a simplification and does not give the full picture of environmental aspects in the technology foresight studies. However in many cases, not least in the studies building primarily on the delphi method, the description of the individual technology or area is very brief. It is not unusual that a future technology is described through one sentence only, the 'delphi statement'. Some recent delphi surveys have adopted environmental criteria among the other criteria of importance like 'economic growth', 'competitiveness' that are briefly touched upon.

As the lists indicate the weight in the general technology foresight has mostly been on the single technology and on a number of individual changes in the future, treated more or less independently. The perspective is usually most often particularistic rather than systemic. It is also clear from the lists that it is the positive environmental effects of future technology developments that are described, while negative environmental impacts and risks seldom are represented. Important uncertainties are also often absent in the descriptions.

Technology Foresight in the Czech Republic: Thematic Panel Environment
(Ministry of Education, Youth and Sports of the CR 2002)

Expected trends in the Czech Republic in the next 10 years

- Expanding scientific discussion on key problems and methodology of their solution
- More attention will be paid to long-term effects of human activities on man and eco-systems
- Interconnection of environmental science and political agenda for sustainable development
- Concentration of research on the study of interactions between the environment and man and on possible ways of directing this interaction to a sustainable trajectory

Proposed key research directions in order of their importance

1. Technologies for the environment
2. Interaction between man and environment
3. Sustainable transport
4. Protection of natural resources and material flows
5. Sustainable power engineering
6. Environment and health
7. Economic and social context of sustainable development
8. Sustainable agriculture
9. Man and landscape
10. Long-term ecological research – LTER

United Kingdom Technology Foresight – Delphi Survey (Loveridge et.al. 1995)

Selection of environment related delphi statements from 'Top-10 Statements' within different sectors

- Widespread use of separation and membrane technologies and biotechnologies for waste management.
- Widespread use of genetically engineered plants and micro-organisms to control and/or reverse environmental contamination
- Development of an integrated approach to retrofitting existing buildings, using existing techniques and understanding, which improves the energy performance of refurbished buildings by 50%
- Widespread use of highly efficient (>20% improvement on current practice), low emission engines for transport.
- Development of cost-effective refinery processes that meet future requirements for clean transportation fuels
- New conversion/transmission techniques provide viable economic and environmentally acceptable alternative energy sources
- Widespread use of modelling techniques which predict and minimise waste products from an entire facility
- Development of novel and practical catalytic systems for SO_x/NO_x removal
- Widespread use of recycled building materials, composites incorporating synthetic materials such as plastics and alternative forest products, resulting from modified construction concepts and design standards

Part Two: Examples of Green Technology Foresight Projects

The number of specific green technology foresight projects is still very limited. Apart from examples that will be described below, there are however also other interesting activities. Some of the recent projects running currently which are worth keeping an eye on are e.g. The Science Forward Look 2004-2013 in the UK department for Environment, Food and Rural Areas (DEFRA 2003) and the project on Transitions towards sustainable production/consumption systems under the 'Factory of Tomorrow' programme in the Austrian Ministry of Transport, Innovation and Technology (Whitelegg & Weber 2003).

81 Options – A Dutch Environment-oriented Technology Foresight

The first example of an environment-oriented technology foresight study that shall be described here was carried out in the Netherlands in 1996-1997. The objective of this foresight study was "to find handles for policy to stimulate technological systems that are able to raise the environmental efficiency of products, processes and activities" (Weterings et.al. 1997). The study was commissioned by the Dutch Ministry of Housing, Physical Planning and the Environment in connection with attempts to gain a further elaborated understanding of the possibilities technology presents to reduce or to resolve current environmental problems. According to Vollenbroeck et.al. (1999), it was explicitly meant to contribute to re-alignment of technological development with the long-term goal of achieving sustainable development. The study was carried out by TNO, which is a semi-public contract research organisation on applied science, innovation etc. The Central Planning Bureau (part of the Ministry of Economic Affairs) also contributed, primarily on the scenario parts.

The participants in the study process were primarily the project team and other staff members at TNO. A panel of 7 external experts from e.g. universities, DTO (a Sustainable Technological Development programme) and from innovation and technology assessment institutions was established and consulted in some parts of the process. A project-following committee consisted mostly of people from the Dutch ministries, primarily from the Ministry of Housing, Physical Planning and the Environment. In addition, interviews with a number of individual experts on the future technology development were made in the beginning of the process.

The basic design of the study is a technology push – demand pull model of development and innovation, with the environmental perspective integrated in the technology push side. This is reflected in the two main lines of work that were followed:

Technology Push
- Mapping out of the technology developments that could lead to a substantial environmental load over the next 15 to 25 years, or to a considerable reduction in the current environmental problems.

Societal demand pull
- Investigating the main societal driving forces which are decisive for the resulting development

This was spelled out in three main phases in the method:

1. Inventory of potential technological developments
2. Assessment of the environmental relevance of the technological developments on a system level
3. Scenario analysis and analysis of societal driving forces

The inventory primarily built on existing foresight studies and end up with long list of 2,500 technology developments. The title of the final report "81 options – Technology for a sustainable development" refers to that the study from the 2,500 technology developments identifies 81 environmentally relevant technological systems, which could lead to changes (positive or negative) in the environmental efficiency of products, processes, and activities. The 81 technological systems were clustered in five categories: Energy systems, new (raw) material supplies, production systems, information & communication systems, and transport systems. Examples of the identified technological systems are:

- Advanced separation
- Cultivation of biological raw materials
- Coal gasification
- New generation of photovoltaics cells
- Hydrogen for driving vehicles
- Intermodal goods transport
- Domestic communication systems
- Novel protein foods
- Optimization of horticulture behind glass
- Industrial waste as building material

The environment-oriented technology foresight study is significantly different from most traditional technology foresights on a number of issues. Firstly, the inclusion of demand pull aspects, though most emphasis is still on the technology push side. Secondly, it diverges from other studies by the integration of the environmental aspects and by approaching future technologies not only as potential solutions to existing environmental problems, but also as potential sources of new environmental problems.

> "…encouraging technological development is no guarantee of environment improvements. For example, new technology can lead to new forms of pollution. In other words technology implies threats as well as opportunities." (Vollenbroeck, p.83)

> "…we did not approach technology solely as a potential solution to existing environmental problems, but we also took into account any potentially new problems that could result from technological development." (Weterings, p.98)

A limited number of environmental aspects where considered: Utilisation of fossil fuels (including CO_2, SO_X, and NO_X emissions), utilisation of scarce raw materials, emissions to air, water and soil, generation of hazardous and non-hazardous waste. Also space use where considered. In this assessment process also a number of external specialists and generalists were consulted. The environmental aspects of each potential technological system were assessed according to the sphere of application and specific *social function* for which the system is developed. The assessment was made relative to the currently dominant system on this function. It is based on unit of output. Developments in production volume or amount of consumption and behavioural changes were not taken into account. Though this static system comparison might have some important limitations, the system perspective in the assessment of the technological opportunities is also at this point significantly different from the traditional object understanding in technology foresight studies.

The conclusion on this part of the process was that around 60 of the 81 technological systems lead predominantly to improvement in environmental efficiency and 20 had, in addition to positive effects, also adverse effects. The assessment of the environmental future technological systems was often uncertain, difficult and problematic and it was also a conclusion that:

"It is impossible to make an unequivocal assessment of the environmental relevance of all the systems." (ibid p. 3)

The demand pull side of the project consisted of scenario analysis based on three macro-political and economical, global scenarios made by the Central Planning Bureau: 1) Balanced growth: towards a sustainable, multi-polar growth; 2) European Renaissance: new opportunities for Europe; 3) Global Shift: shifting the centre of economic growth to the Pacific Rim. The potential integration and role of the different technological systems in the story lines of the three scenarios were analysed and it was assessed if and how the integration could lead to also more radical innovations in the social functions of society. Changes in social functions and not just less radical re-designs and optimisations of the existing systems were considered needed in the long term if significant environmental improvements shall be obtained. The policy handles identified by comparing the scenarios with the technological systems are these:

1. **Regulatory price measures on fossil fuels** should be established as the price of oil, gas and coal 'is evidently the main obstacle standing in the way of environmentally-efficient technological systems', not only with regard to energy supply innovations but also to innovations in industrial production systems and transport systems.
2. **Supply dynamism** of technology development should be encouraged, e.g. by combined public and private R&D, by facilitating knowledge transfer between companies, or by pursuing a prevention-oriented technology policy
3. **Selective demand articulation** e.g. by government acting as pro-active party on a market or by introducing price measures which selectively lowers the threshold for introducing new systems
4. **Direct governmental control and intervening** in the development of technological systems which could lead to adverse environmental effects

The Dutch environment-oriented technology foresight has been used in policy development in the Netherlands e.g. in connection with the National Environmental Policy Plan III and the research-programme on Economy, Ecology and Technology. While the green technology foresight activities seems to have had important impact on a technology and research-oriented element in the environment policy, there are no indications that it has significantly influenced the general technology policy and science policy or been integrated in these areas.

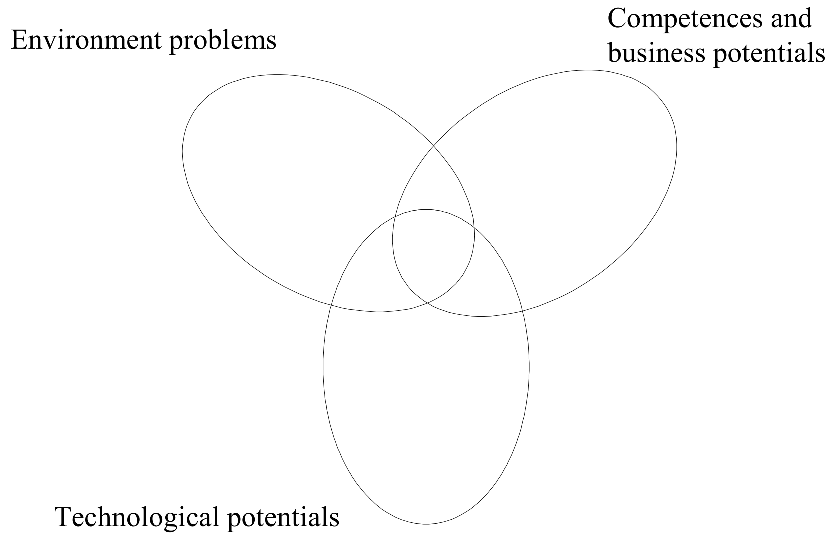
The Danish Green Technology Foresight

The Danish Green Technology Foresight is part of the national technology foresight programme that has been running since the beginning of 2001. The programme was first managed by the Ministry of Trade and Industry and then, after the change of Government in late 2001, by the Ministry of Science, Technology and Innovation. The Green Technology Foresight is one of the first three areas selected for a foresight exercise after the establishment of the programme and the initial definition of the foresight perspective employed. (The other areas are pervasive computing and bio & health technology). The work in the Danish Green Technology Foresight is carried out from early spring 2002 to spring 2003 (www.teknologiskfremsyn.dk, Erhvervsfremmestyrelsen 2001, Cowi 2002 (all in Danish)).

Under the general objective of identifying and debating technologies and scientific breakthroughs and assessing the opportunities and challenges in a Danish perspective, the specific objectives of the green technology foresight are:

1. to map the global environment problems in a 10-20 years perspective, including the aspects of behaviour and consumption that intensify the environmental problems
2. to identify and debate technological and institutional solutions

3. to map competences and potentials in Danish industry and the innovation system with departure in the identified environmental problems, driving forces, and solutions
4. to make recommendations on radical and outstanding environment innovations with business potentials and recommendations on which market and policy initiatives that are needed to support them



The process consists of four steps to a large extent corresponding to the four objectives: 1) The environmental challenge, 2) Technological advances with environmental potentials, 3) Danish competences and business potentials, 4) Integration of the three steps: Challenges for the technological development and definition of 'focus areas'. Most time is used on the last step. Schematically the method can be illustrated by this figure, where point four is represented in the middle.

The foresight is organised as an expert panel process, with five discussion meetings as the central element. There are 18 members of the panel, most of which both have technological, research and managerial background. 6 are industry managers, 6 public researchers, 2 from other innovation system institutions and 2 from environment NGOs. The last 2 members are respectively from a large investment institution and from the Ministry of Environment. The members of the panel are selected by the science ministry's project group, building on recommendation of persons made by e.g. members of the advisory group and scientific background group connected to the Danish technology foresight programme in general, who were also involved in the definition of the green technology foresight and its objectives. The expert panel discussion is supported by a consult group which acts as process consultant and secretariat that prepares presentations, background papers, reports etc. drawing also on the experience from other external experts and existing analyses.

With the many-sided and complex objectives, it is clear that the weighting and the specific integration of them will be decisive for the character of the results of the exercise. The mapping of the environmental problems (step 1) builds on analyses from a number of international organisations: OECD, World Watch Institute, European Environment Agency, World Resources Institute, UNEP, and the European Commission. The identification of technological solutions in step 2 builds among other things on other technology foresights and on interviews with external experts on environment-related technology. This step results in a first list of around 65 potential technological solutions of varying size and form within different areas. From the panel's discussions and prioritisations around one fourth of these were selected for deeper description and analysis.

The competences and potentials of Danish business and industry and of the knowledge and research institutions relevant for the selected technology solutions were mapped and discussed. Market potentials and use forms as well as institutional and regulatory opportunities and constraints were discussed. This also included so-called SWOT analyses (assessments of Strengths, Weaknesses, Opportunities and Threats).

The green technology foresight ends up with the identification and definition of four or five 'focus areas' as recommendations of technology innovations and connected business, production and consumption opportunities that could mean important environmental differences, if pursued. The focus areas can be said to represent important elements in the intersection of the environment problems, the technologies and the competences and business potentials, as indicated on the figure. The focus areas have character of socio-technical systems. They are comprehensive, integrated pictures of production and use patterns with emphasis on the role of technological changes. For example a potential focus area related to transport could be 'integration of public and private transport through traffic information technology and road pricing'. It would not be defined as 'public transport infrastructure' or new vehicles or engine types. A focus area on energy would similarly rather be defined as hybrid renewable energy supply systems rather than biomass waste systems or wind energy technology.

The selected focus areas are:

1. Flexible energy systems with increased wind energy
2. Systematic energy optimisation of buildings
3. More environmentally-friendly agriculture
    a. Precision agriculture
    b. Organic farming
4. Design of green products and material

The descriptions of the focus areas are typically a text of around 6-12 pages each and include sections on the related knowledge and innovation institutions and clusters and on market aspects, incentives, and regulatory elements. The level is not industrial sectors, rather sub-sectors. The same is the case concerning knowledge aspects where the focus is not on scientific areas or disciplines, but on different, more specific sub areas of development and research and the interaction between these.

Scenarios development processes supported the final discussion and selection of the focus areas. For each of the selected areas, four different scenarios (2x2, going along two axes) are presented. The dimensions of the axes are for example 1) technology object - integrated systems; 2) central – de-central solutions; and 3) market/product - regulation.

The results of the green technology foresight process are published in a report in May 2003. The target group is stated to be politicians, other decision-makers and the broad public. Until the publishing of the foresight report, the project is a closed process in the sense that it is not open for broad participation. The communication of the contents to a broader audience is a planned part of the activity. In connection with the public presentation of the report, an open debate conference is held in the parliament building. It is the intention that the green technology foresight shall create a broad political debate in Spring 2003. At first this goal is not reached as only few politicians participate in the conference and the mass media coverage is limited. However, a considerable number of relevant industry representatives attend the conference and the results of the exercise are employed in quite a number of discussions in the rest of 2003 both in industries, in NGOs and in public governance of innovation and research e.g. in the energy area.

It has been an idea in the planning of the Danish Green Technology Foresight, that the exercise shall function as a phase one in a two-phase process, where the first phase is a general study that points out a number of areas that can be analysed in more details in a phase two. Phase two will however not be carried out in the national technology foresight programme in the Ministry of Science, Technology and Innovation but by the Ministry of Environment and other ministries. How integrated the results of the Danish green technology study will be in the innovation policy and prioritisation is too early to say. Through the Phase two carried out by other ministries, the experiences and recommendations can be utilised within the specific areas. There is at the same time a risk that the identified potentials for research and innovation in the green technology foresight by the Phase Two will be left out of the general technology and innovation policy. If that happens, the potentials of integration of environment policy, science policy and technology policy will only partly be exploited.

For the time being two green technology foresight exercises are about to start under the Ministry of Environment: one relatively broad and general on design of environmentally friendly products and materials and the environment challenges and potentials of biotechnology, nanotechnology, and information and communication technology, and one specifically on environmentally-friendly agriculture. Both are to be carried out in 2004 – 2005. Whether the focus areas on energy will continue in a second phase is still an open question.

Summing up on the method structures in the Dutch and the Danish green technology foresight, it can be concluded that there are similarities in goals and methods but there are also important differences:

a) The Dutch foresight has a symmetrical method structure on the analysis of environmental aspects in the sense that both positive and negative impacts are included, while the Danish method only works systematically with the positive potential impacts and looks for solutions to the general environmental problems mapped in the initial phase.

b) The system perspective in the Danish foresight is integrated and multifaceted on the selected focus areas including specially developed scenarios, while the Dutch system perspective appear through a breakdown of the present overall society in a number of societal functions within which each future technological system is compared with the currently dominating system. The scenarios are external to this and are general macro-political scenarios. The main method structure of the Danish foresight does not include other social driving forces than the existing competences and potentials in industry areas and in research and innovation institutions.

c) The time dimension to some extent seems more spelled out in the Dutch project with its distinction between long-term radical changes of systems and shorter-term redesign and optimisation and with its inclusion of possible new environment problems through the changes. The Danish is more focused on the present business potentials and present environmental problems.

d) The Dutch foresight is carried out as a consultancy research project while the Danish is an expert panel discussion process. In both cases there is little emphasis on broader or public participation.

Life cycle assessment and technology foresight

In the last three years we have in our research group carried out projects that combine traditional technology foresight methods with life cycle assessment methods (LCA). The third example on green technology foresight is a project with this hybrid LCA and foresight approach in the wind energy area.

The key element in the methodological approach of life cycle assessment is an identification and analysis of all the different processes included in the entire lifecycle of a product or a technological system, including a careful accounting of the materials and energy flows associated with the processes. The method is primarily used for assessing the environmental impacts of industrial products. There is, however, increasingly focus on life cycle assessment as a tool in strategy, and planning processes, also on long-term issues, in scenario processes etc. (Frankl & Rubik 2000, Pesonen et.al 2000, Christiansen 2001).

LCA and technology foresight methods (like e.g. delphi surveys, brainstorming etc.) are very different and, in some respects, quite opposite. For example technology foresight usually addresses partial elements of the (future) technological systems in the sense of the main technical functionality, while LCA addresses all processes in the different life cycle phases and gives a more comprehensive picture of the actual technological system. LCA is in its traditional form a very detailed method, focusing on certainties and the most precise data available while foresight is more sketchy, process-oriented and at least to some extent trying to deal with the large uncertainties concerning future developments. Some of the typical characteristics are listed in the box. In practice, the differences can be used productively to structure the interaction process of green technology foresight especially designed according to the specific purpose and area.

The two frameworks, typical characteristics

Lifecycle Assessment	**Technology Foresight**
- Present	- Future, changes
- Products	- Technology
- Lifecycle perspective, processes of different phases	- Functionality, the single technical characteristics
- Comprehensive	- Partial
- Environmental impacts	- Not focus on environment
- Detailed	- Sketches, scenarios, strategies
- Objectified, results	- Interaction processes, actors
- Certainties	- Uncertainties

The green technology foresight project I will mention is entitled 'Environmentally sound design and recycling of windmills'. It is funded by the Energy Research Programme managed by the Danish Energy Agency. It is carried out in collaboration with the Wind Energy Department at Risø National Laboratory. The objectives of the project are, apart from the method development:

- in a long term perspective to analyse the environmental impact of the manufacturing and removal phases of windmills' life cycles
- to make societal recommendations on dismantling, recycling and waste handling of existing and future windmills

The focus on the production/manufacturing and removal phases of the life cycles of the windmills (and not on the important operation phase) is due to the fact that the environmental aspects of the operation phase are already relatively well-described (the main positive impact through green electricity production, the land use aspects, noise etc.)

There are several target groups of the project. The recommendations on the societal level go to among others the public planning authorities. The project contributes to the discussion on LCA guidelines and standards in the wind energy area at international and national level. And it is an input to actors in the energy sector, wind turbine manufacturers and windmills owners/operators on future design and handling of wind farms and windmills. The project has both been reported to the international and Danish wind energy community (Dannemand et.al. 2001, Borup et.al. 2002).

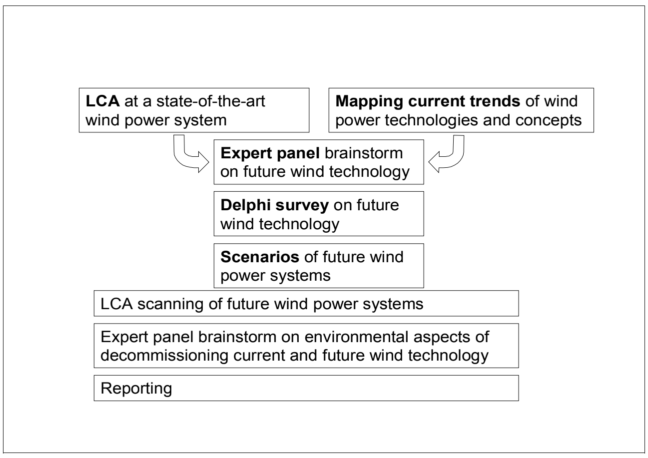
Though there are connections from the project to the national policy level and public authorities, the project is not in the same way as the above described green technology foresights part of the general research and technology policy. It is more a sector-oriented project. However, the life cycle assessment perspectives and the principles of the hybrid method might, with suitable adjustments and changes, be employed in national green technology foresight studies as well.

The different steps in the project's method design are shown in the figure below. All in all the method is quite complex and I will not go into all details here but elaborate briefly on a few points. The initial LCA is a traditional, complete and detailed LCA of present time wind power systems and their environmental impacts. (This is a whole project in itself and in fact this step is building on a separate, parallel LCA project and on existing LCAs on wind power systems).

The first expert panel step is a workshop identifying central elements and driving factors for the development of future windmill technology. The 10 participants in this panel were representatives of public research, wind turbine industry, power grid operators, wind farm operators, LCA consultants and a representative of an environmental NGO.

The delphi-like survey was a questionnaire with 24 statements building on future windmill technology. It was handed out to participants at a large international wind energy conference in Copenhagen 2001. Emphasis in the questionnaire as well as in the expert panel workshop was on technological factors (two third) while one third was on socio-economical and policy/regulatory issues. For each potential future development, the respondents were, in addition to the traditional delphi questions on when (if ever) the change is going to come true, asked about the environmental effects of the change on a scale from highly beneficial to highly harmful.

Phases of the project



The expert panel involved in the workshop on environmental aspects of decommissioning and removal is another one than the first panel. It is in its composition reflecting the end-of-life phase of the windmills. The 11 participants were representatives of consultants and knowledge institutions on dismantling, recycling and waste handling, removal/recovery companies, LCA consultants, and wind turbine manufacturers.

The discussions on the workshop were influenced on the life cycle and environmental considerations earlier in the project. The life cycle scanning elements and the scenarios were relatively simple sketches of different elements of future windmills and windfarms and their environmental aspects. They are both qualitative (e.g. on the future materials of the blades of the windmills) and quantitative (e.g. on the future sizes of windmills, blades and of the wind energy area.) A LCA comparing offshore and onshore windfarms was carried out in this period.

It is likely that the most important results of this green technology foresight occur through the interaction processes with and between the many different actors involved and through the outwards communications of the process during the project. The concrete results in terms of conclusions concerning the environmental aspects of future of wind energy systems and their handling are very diverse in character. Some of the results are e.g.:

- Environmental impacts
    - Windmill blades will constitute an important waste problem if the present development with large fibreglass blades continues (around 2020 it will be very visible in the fibre glass disposal statistics for a country like Denmark)
    - Future blades of carbon fibre constitute a similar problem
    - In future offshore windfarms far from the coast, the cables will constitute an important environmental impact
- Societal role of wind energy technology
    - Wind power can contribute with 10% of the electricity production in Europe at some point between 2011 and 2020
- Windmill concepts
    - Two-bladed flexible windmills will probably never have a radical breakthrough on the market
- Organisational and knowledge development
    - The institutional organisation of future removal phases is uncertain. Three models for the organisation and actor set-up were identified
    - There is a need for knowledge development on some of the recovery and waste handling processes
    - A short cut between the knowledge of dismounting/recycling actors and windmill designers is needed

The conclusion on the integration of the life cycle perspective in technology foresight method is first of all that environmental aspects of future technology and future socio-technical systems can be included with this approach. Not only the positive environmental potentials but also negative environmental aspects are included. Once the life cycle perspective is introduced through the detailed LCA early in the project, it helps maintaining the focus on environmental aspects throughout the project. The life cycle perspective in addition maps out the socio-technical system. Through this it also points to a number of actors and knowledge areas that are relevant to include in the technology foresight processes.

With the integration of life cycle assessment methods there is a risk that the foresight project will become too restricted to the socio-technical landscape of today, including the present institutional set-up, production and consumption patterns etc.

In addition there can be a tendency to focusing on the certainties, not giving enough attention to the uncertain aspects. The specific project design is most fruitful if the LCA elements are seen as parts of a learning process, rather than a 100% objective analysis.

There are similarities between the hybrid LCA-TF approach and the approach of the Dutch green technology foresight not least on the more or less symmetrical inclusion of both positive and negative environmental aspects and on working with demand pull factors. As life cycle assessments are becoming more and more normal in many industrial areas, it is likely that green technology foresight through integration of LCA with TF methods can be done more easily, as it can to a higher degree build on existing reports and data material.

Precautionary principle and technology foresight

A last example of method principle of environment-oriented technology foresight shall be mentioned. It is widely acknowledged that technology development is a central element in many of the most important risk issues facing society. Many efforts are made to deal with, minimize and avoid environmental risks in connection with new technological developments and to handle the high degree of uncertainty that is connected with these. The precautionary principle has been adopted in some policy areas at European level and in a number of national states as a way of dealing with the risks. The definition of the precautionary principle is still discussed both at the political level and at an operational level. Within technology assessment and foresight efforts are done to take the environmental risks, and not only the more certain environment impacts, into consideration (Hellström 2003). In connection with the work in the European STRATA project PRECAUPRI, combination of the precautionary principle with traditional technology foresights approaches is suggested as a way of doing technology foresight and assessment that include the environmental risk aspects (PRECAUPRI work, especially Stirling 2002).

The basic principle of the combination is that the precautionary principle and the technology foresight methods are complementary and opposite and that a combination of them will result in a more balanced perspective. Through this balanced perspective the environmental risks of potential future technologies will be treated adequately. (Another way around: that technology foresight methods can be employed in order to find solutions for risks problems, is an alternative, which is not offered so much attention in this connection.)

Put very briefly, the understanding is that technology foresight approaches usually are optimistic and positive to technology development. They focus on the positive opportunities in new technology and identify, develop and promote the promising expectations. Opposite to this, the precautionary principle is said to be sceptical and critical to new technology. It focuses attention to negative consequences of the technology. The precautionary principle identifies environmental risks etc., which are normally hidden in the technology foresights, and points to policy actions for how to deal with the risks.

"Of course, there are obvious constraints between precaution and foresight discourses. Whereas precaution reflects pessimistic and critical perspectives on technological innovation, foresight embodies more up-beat sentiments. Precaution addresses the restrictive aspects of social ambiguity and the dangers of ignorance. Foresight highlights the creative propensities of social diversity and the positive potentials of incertitude. For all these differences however, both precaution and foresight are concerned with intrinsic indeterminacy, social contingency and path dependency in processes of technological innovation. ... Together, they offer the prospects of more socially responsive technologies." (Stirling 2002, p.25)

A general model for instrumental implementation of precaution in connection with science and innovation is suggested. The model understands the treatment of the risks issues as a social process that takes place at a number of organisational and discursive levels and involves questions of institutional structure and process design. The combination of foresight and precaution is understood as a process between social actors and it is argued that it can lead to more social responsive technologies.

The work on the precautionary principle and technology foresight is at an experimental level. To my knowledge there is not yet carried out full-blown practical experiments with the approach. The approach is criticised for a too simple understanding of technology foresight and especially of the precautionary principle. It has been noted that while it is true that technology foresight is usually technology optimistic, the principle of precaution does not embed a general pessimistic and negative attitude to technology development. It is usually only on a single few specific aspects of the technology, that the precautionary principle is critical. Not on all aspects, and not on all technologies. The quality of the precautionary principle instead consists in its deliberate aspects. It can contribute to a more qualified and reflected view on future technologies. Despite the critique that can be raised against the precaution & foresight approach, it is important that work is done to find ways of including the aspects of environmental risk and the related uncertainties in technology foresight and similar strategy processes.

Concluding remarks

Contrary to the existing tradition of technology foresight in general which is not suitable for integrating environment and sustainability issues in technology policy and development, green technology foresight seems to have a large potential for making a valuable contribution to governance for sustainability. Usually, the method designs of the green technology foresight projects are system-oriented and capable of addressing future technology as integrated developments and solutions, instead of as isolated and partial technical function developments. Instead of technology push/science push aspects only, green technology foresight studies include 'pull' aspects of environment problems and social matters and address the complicated, mutual integration of push and pull aspects. The precautionary & foresight approach might, at the level it is developed so far, be an exception to this picture, however the approach emphasises the important aspects of including environmental risks and uncertainties in foresight activities. In all four examples, there is still large emphasis on technology push. The assumptions and details of this side might be more explicitly reflected. A symmetrical method in the sense that both environmentally negative and positive aspects are systematically considered seems also to be a reasonable requirement to green technology foresight.

While the Dutch green technology foresight activities have contributed to a technology-oriented dimension in the environment policy, the Danish green technology foresight exercise is an element of integration of environment issues in the general technology and innovation policy. However, with the Phase Two still to come in Denmark, the integration in environment policy issues might become at least as significant.

One of the aspects of technology foresight in general that still needs to be described, is the communication of the foresight to other actors. Who are the results and processes communicated to, what do they use it for, and how do the foresight activities relate to other strategy and policy activities. Though not always explicitly accounted for in the material I have used, it seems plausible that the green technology foresight projects, with their integrated and system-oriented perspectives, also can have an important function of contributing to development of new niches and networks of innovation.

The green technology foresights are interesting also for the area of technology foresight in general both at a national and European level. In connection with a more general integration of sustainability perspectives in technology development and innovation systems, the method principles of green technology foresight can play an important role. Moreover, the green technology foresight projects are examples on how technology foresight processes can be designed explicitly according to the specific purpose and target groups in case. Usually in technology foresight the influence on the specific perspective is, apart from the clear perspective of science and technology push, only implicitly reflected in the descriptions of the project designs.

It is a very common method element of technology foresight studies to build on the technology expectations of other technology foresight studies. The technology foresight community is across the single studies growing and maintaining a body of knowledge and technological futures which to some extent has its' own life and is independent of other policy and strategy processes. This might in many cases be an advantage and not a problem (and it is moreover a very normal feature of knowledge production). There is however a risk that this professionalized body of technological futures can gain too much weight and momentum, so that important new, maybe local opportunities are overlooked and the potentials of the diversity of research and technology areas are not used adequately. A similar thing might be the case concerning the environment problems where a limited number of global accounts, outlooks etc. from a limited number of institutions is employed across a large number of studies. Green technology foresights should be careful not only to rely on the global environment problems but also to deal with more local environment problems and with local forms of appearances of the global problems.

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Appendix

Critical environmental technologies in France

Source: Fukasaku 1999, referring to Ministere de l'Industrie (DGSI) 1996: Les 105 Technologies clés pour l'Industrie Francaise a l'Horizon, Paris

Health and environment area
- High yield crops for use as bio-fuels
- Genetic modification of plants
- Decontamination and remediation of polluted soil
- Biological purification of water
- Radioactive waste treatment and disposal
- Final treatment and disposal of harzardous wastes
- Measurement and monitoring of environmental pollution (air, water, solid wastes)
- Modelling the impact of industrial pollution
- Cleaning without using hazardous substances
- Recycling of polymers
- Treatment of urban wastes
- Treatment and quality control of drinking water
- Collection, stocking and compression of urban wastes
- Using 'filières transversales' for waste disposal

Transport area
- Improving the recyclability of cars
- Batteries for electric cars
- Traffic flow control and management system
- Reducing the fuel consumption of motors
- Clean combustion engine
- Reduction of the weight of cars by using lightweight materials
- Reducing noise of airplanes and rapid trains
- Reducing noise of automobiles

Materials
- Intelligent materials
- High temperature resistant materials

Energy
- Biomass conversion
- Clean and safe nuclear energy
- Photovoltaics
-

Housing and infrastructure
- Management of water resources

Production, instruments and measuring
- Intelligent sensors
- Catalysts
- Continous processing in steel
- Membrane separation processes