Nanotechnology in Germany: From Forecasting to Technological Assessment to Sustainability Studies.

Axel Zweck, Gerd Bachmann, Wolfgang Luther and Christiane Ploetz

Future Technologies Division, VDI Technologiezentrum GmbH, P.O. Box 10 11 39, 40002 Duesseldorf, Germany.

Corresponding author: Christiane Ploetz, ploetz@vdi.de, Fax: ++49-211-6214 139

Abstract

The issues of innovations and sustainability are discussed more or less separately, so that risks and potentials of new technologies for a sustainable development often fail to be detected as early as possible.

The following article analyses this relation in the light of the development of the nanotechnology funding strategy in Germany which was guided by an integrated approach of technology management activities. This led from technological forecasting activities, the definition of application fields and market surveys to early technological assessment activities and sustainability studies combined with communication measures. The importance of sustainability aspects grew steadily throughout this process, and the integrated approach facilitated the early detection of relevant sustainability issues to be dealt with in the future. This underlines the importance of accompanying innovation measures in research funding for detecting sustainability potentials of new technologies.

Keywords: Technological forecasting, innovation and technology assessment, research funding, integrated approach, public perception
1. Introduction: Two Cultures: Innovation and Sustainability

Nanotechnology is seen as one of the most important fields of innovation and technology today. At the same time, the challenge of creating wealth and human well-being without exploiting natural resources on an unsustainable basis is seen as one of the most eminent global issues to be solved – a view which is not only held by environmentalist groups, but becoming more and more integrated into business activities. Sustainability is increasingly seen as a potential global market bringing opportunities to companies that manage to translate these issues into products and services (World Resources Institute [1]). Ideally, sustainability needs and criteria should be involved in the innovation process from the very beginning, so that the risks and potentials of new technologies can be detected as early as possible facilitating the precondition for these technologies to evolve their potentials for contributing to sustainability. Hitherto, the experience in this and many other research fields shows that the issues of innovation and sustainability usually are discussed and promoted separately, and that different research cultures with only a little overlap make it difficult to find synergies between these research areas – a situation reminding of the lack of communication between different research disciplines described as the two cultures of research by Snow [2].

This challenge is also typical of German research funding. Both nanotechnology and sustainability have been on the research agenda in Germany since the early nineties. A short overview on the organisational structure of the most important German research funding agencies (table 1) shows that nanotechnology and environmental/sustainability research are often based in different programmes, divisions or thematic sections, although some overlaps exist in certain programmes, institutes or funding activities. As a consequence, links between the research agendas of these two research fields and cultures do not form automatically but have to be implemented actively through systematic approaches that integrate both views. In the following, we describe the development of nanotechnology in the activities of Germany’s Ministry for Education and Research (BMBF) – the main public agency in Germany charged
with the promotion of pre-commercial research and development – between 1990 and 2005. The approach includes integrated measures covering forecasting activities through market analyses and technology assessment activities. We also trace whether and how these activities managed to establish links with sustainability issues as laid down in the national sustainability strategy (German Federal Government [3]).

<table>
<thead>
<tr>
<th>Organization</th>
<th>General type of research funding</th>
<th>Allocation of nanotechnology activities within organizational structure</th>
<th>Allocation of sustainability activities within organizational structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>German Ministry for Education and Research (BMBF)</td>
<td>Applied research</td>
<td>Division 5: Key Technologies – Research for Innovation</td>
<td>Division 7: Provision for the Future – Cultural, Basic and Sustainability Research</td>
</tr>
<tr>
<td>German Research Foundation</td>
<td>Basic Research</td>
<td>Engineering, Natural Sciences</td>
<td>Natural Sciences, Social Sciences</td>
</tr>
<tr>
<td>Helmholtz Association of German Research Centres</td>
<td>Applied Research</td>
<td>Key Technologies</td>
<td>Earth and Environment</td>
</tr>
<tr>
<td>Leibniz Association</td>
<td>Applied research</td>
<td>Section D - Mathematics, Natural Sciences, Engineering</td>
<td>Section E- Environmental Research</td>
</tr>
<tr>
<td>Fraunhofer Association</td>
<td>Applied, market-oriented research</td>
<td>Fraunhofer Nanotechnology Alliance, including 1/3 of all Fraunhofer Institutes</td>
<td>Fraunhofer-ISI, Fraunhofer-UMSICHT</td>
</tr>
<tr>
<td>Max-Planck-Society</td>
<td>Basic Research</td>
<td>Several research fields, e.g. Solid State Research/Material Sciences</td>
<td>Earth Sciences and Climate Research</td>
</tr>
</tbody>
</table>

*Table 1: Important German research funding organizations and their thematic structure with respect to nanotechnology and sustainability.*

2. The Evolution of Nanotechnology in Germany

Nanotechnology has been on the research agenda of the BMBF since the early nineties. Up to now, the funding of nanotechnology projects has increased more than tenfold to 134 Mio. Euro per year in 2006. Not only the volume of funding has increased significantly, but a sub-
A substantial shift in the strategic orientation of the nanotechnology funding policy has also evolved in the last decade, with sustainability aspects playing an increasing role.

The BMBF started its nanotechnology activities by funding single nanotechnology related projects in the context of its Materials Research and Physical Technologies programmes. In the late nineties, the BMBF recognised the importance of nanotechnology as a key cross-section leading to technological achievements in a lot of industrial fields of application, and therefore started to fund interdisciplinary and interdivisional joint projects with industry and academic consortia in order to facilitate the process from invention to innovation. In 2003, the BMBF realized that an overall national strategy for the future funding and support of nanotechnology was essential in order to remain competitive on the global market and to solve future challenges in the areas of health, the environment, and safety issues. Therefore, the BMBF has concentrated its nanotechnology project funding on so called “lead innovations” which are value chain oriented collaborative projects between partners from the scientific community and the commercial world with a strong focus on societal demands in the application fields of mobility, health, energy and ICT. Meanwhile, five lead innovations have been implemented:

- Nanofab (nanotechnology for high performance ICT components)
- NanoforLife (nanotechnology for new medical therapies and diagnostics)
- NanoMobil (nanotechnology for resource-saving automobiles)
- NanoLux (nanotechnology for energy efficient lighting)
- NanoChem (production and safety assessment of nanomaterials for industrial applications)

In addition to the funding of research projects, the BMBF has started some accompanying measures to support the industrial development of nanotechnology applications and to fully exploit the potential of nanotechnology for the societal progress. The objectives pursued by these accompanying measures are:
• Clustering of resources and networking
• Getting people informed and enhance public understanding of nanotechnology
• Investigation of societal implications and side effects/potential risks of nanotechnology
• Establishing of adequate education and training possibilities
• Enhancing the fascination of young people and pupils for nanotechnology.

In order to achieve these goals, the BMBF has initiated several accompanying measures:

• Establishment of nanotechnology competency centers in 1998 as nation-wide, subject-specific networks with regional clusters in the most important areas of nanotechnology
• Performance of several ITA (Innovation and Technology Analysis) studies to assess implications of nanotechnology on health, the environment and the economy
• Implementation of the touring exhibition “NanoTruck” to inform people and enhance public understanding of nanotechnology
• Initiation of the NanoCare project to explore and assess potential health risks of nanoparticles.

The evolvement of the BMBF nanotechnology funding strategy has been strongly influenced by an integrated approach of several technology management activities, which have been performed from the early nineties up to now. These technology management activities can be divided into four different phases and types of activities, with strong overlaps between those phases. Figure 1 gives an overview on the phases giving rise to increased consideration for sustainability aspects in the innovation process:

- Technological forecasting (both general and for special innovation fields such as nanobiotechnology)
- Market assessment and applications
- Innovation and technology analysis and
Communication.

Development of Nanotechnology Funding in Germany and Integration of Sustainability Aspects by Means of Integrated Technology Management

Figure 1 gives an overview over the most important steps and activities of the BMBF since the early nineties. As the application fields of nanotechnology become clearer in the forecasting process, ITA and sustainability issues become more important.

The four phases of technology management activities are also analyzed in the light of their relation to sustainability as being manifested in the following funding activities of the BMBF. The following section will describe these phases of the innovation process in detail. The phases, however, cannot be strictly separated or attributed to discrete periods, since different fields of nanotechnology are involved at different stages in the process (e.g. forecasting for nanobiotechnology as an issue started as late as 2001, while other fields like nanotubes have been in focus since 1993).
Phase 1: Technological Forecasting

The first phase is characterized by a strong focus on classic forecasting activities. "Technological forecasting" (TF), as understood in this paper is the continuous monitoring of technological developments leading to an early identification of promising future applications and to an assessment of their potentials (Holtmannspötter and Zweck [4]). TF is widely applied in and for both the public sector and business (Martino [5], Coates [6], Cleeman and Peiffer [7], Servatius [8]). A broad range of quantitative and qualitative methods is applied in forecasting studies, e.g. expert surveys (Porter et al., [9]), Delphi studies, interviews, questionnaires, patent and literature analyses. Reger [10] stresses the importance of a network and process orientation in technology foresight.

In the case of nanotechnology, the BMBF has commissioned several forecasting studies between the early nineties and today. The aim of these forecasting exercises was to identify new and promising fields for research funding, to deliver a sound and broad information basis for funding decisions in these research fields and to prepare these issues for funding activities. The results of these processes were published in so-called “technology analyses”, which summarize the process and results of the forecasting exercise for nanotechnology in general (Bachmann [11], [12]) and various subfields of nanotechnology, e.g. fullerenes (Eickenbusch et al. [13]), SXM-technologies (Bachmann [14]), nanotubes (Hoffschulz et al. [15]), nanobiology (Wevers and Wechsler [16], Wagner [17]), and XMR technologies (Mengel [18]), providing information on the technology, reviewing its promising prospects for various sectors of industry and society, describing possible applications, analyzing research deficits and impediments, and submitting recommendations.

Like most TF processes, the approach in these studies comprised three steps: the identification of new technologies, the validation of these issues and the implementation of measures to harvest the expected benefits of the technology. In practice, these steps are often overlapping and iterative. The TF sequence is usually repeated, and it becomes more focused and specific with each round of forecasting. The forecasting process for nanotechnology in a
broad sense was intertwined with smaller processes centred on the various subfields mentioned above. Figure 2 portrays the TF process carried out in these studies at a glance. The approach applied in the abovementioned studies is described in full in Holtmannspötter and Zweck [4], which is based on earlier publications by Cleemann and Peiffer [7] and Servatius [8].

**Figure 2: Stages in technological forecasting**

The following section describes the three phases identification, validation and implementation for the above mentioned TF processes. A detailed description of the methods applied can be found in the respective technology analyses, since the focus, scope and criteria in the studies varied:

The *identification* of interesting topics was done by means of systematic screening and surveying of all available information sources. For the purpose of nanotechnology studies, litera-
ture databases (CA, INSPEC, in later studies Science Citation Index SCI) were screened with respect to specific keywords agreed upon with the client. Expert surveys were carried out through questionnaires, standardized telephone interviews or personal interviews during meetings and congresses, with emphasis placed on estimates of future applications for the respective technology. Expert workshops were specifically organized to define the upcoming technology field of nanotechnology (Bachmann [11]). Experts came from industry, academic research and institutional research.

**Technology Assessment Grid**

![Technology Assessment Grid Image](image)

**Figure 3**: The Assessment Grid employed in the "Technology Analysis" on the technology subfield nanotubes. (from: Hoffschulz et al. [18]).

Validation of the technologies was supplied by condensing, filtering and ameliorating the gathered information into an aggregated form. This process was based on a set of criteria developed in close coordination with the client of the assessment. Examples for criteria are the novelty of a research theme, the state-of-the-art of the technology envisioned (e.g. the BMBF focuses its funding activities on technologies at the interface between basic and applied research), the international competitiveness of the German research landscape, the economic potential and the possible contribution of the new technology to solve existing problems. Figure 3 offers an overview on the criteria applied in the TF studies. This assessment grid contains first aspects of the sustainability potential of the technology in question:
The potential contribution to the field “environment” is one of the application fields mentioned in part 1 and 2 of the grid. Under the column “Expected effects of technology on…” the classic three pillars of sustainability – ecology, economy and society – appear as assessment criteria. The validation was carried out with the help of experts from academic circles, industry and government agencies. For this purpose, written questionnaires, telephone interviews and personal interviews were carried out. The number of experts involved in these studies ranged from 12 (Mengel [18]) to 40 (Eickenbusch et al. [13]). In addition, patent and publication statistics were used as indicators for the development of a technology in certain time intervals and for international benchmarking with the USA, other EU countries and Japan.

The implementation step comprised a set of conclusions and recommendations for the client, which in case of the BMBF led to new funding activities (Fig. 1). For example, the result of the first technology analysis (Bachmann [11]) was a funding concept followed by the foundation of several competency centres in order to bridge the gap between science and industry from the very beginning of R&D activities.

At this stage, sustainability aspects and considerations did not play a central role in the process, yet. The main goal of (Bachmann [11]) was to define the research field in general. Possible fields of application could still not be clearly determined. Nanotechnology research and funding activities in the early nineties were mostly pushed by curiosity-driven research and just a few industrial applications (e.g. ultra precision manufacturing, nanomaterials, functional supramolecular systems, nano tools, biotechnology and ICT). Given the little information and few data available at the time when forecasting activities are usually carried out (the aim is to identify research gaps!) and due to the fact that potential fields of application are not necessarily clear at this stage, more ambitious aims like a quantitative assessment of sustainability effects cannot be regarded as realistic options at this stage.

This weak relation to sustainability in the basic studies is also reflected in the calls issued by the BMBF in the early years of nanotechnology funding. For example, the calls on functional supramolecular sytems (BMBF [19], [20]) mention the development of environmental-friendly
processes and systems, albeit very generally in the section describing the thematic focus of the calls. The 1997 call on innovative products (BMBF [21]) based on new technologies and processes mentions environmental aspects and resource management as specifically merit-ing research areas. However, there is neither a reference to the concept of sustainability nor a hint that these aspects are binding for the project proponents.

**Phase 2: Market Assessment and Applications**

The second phase was closely connected to the first phase of forecasting and included a thorough and systematic analysis of possible markets and applications for nanotechnology. Three market surveys (Bachmann [11], Bachmann [12], Luther et al. [22]) were carried out in 1994, 1998 and 2002. They applied a broad methodological setting, combining qualitative and quantitative methods such as desk research of existing market studies, patent analyses, and interviews with scientists, technology suppliers and prospective key users of nanotechnology with a scanning of databases.

To avoid overestimations, market figures were obtained adding up the market value of specific products containing nanotechnological components. For products that have not yet reached market maturity yet, there were indicators pointing to the substitution potential of existing products. If the value-added proportion of the nanotechnological component in the end product was not quantifiable, the value of the “smallest saleable unit” containing the nanotechnological function was assumed. However, overestimates may still occur, e.g. in the case of double counts of the nanotechnological product itself (e.g. nanocrystalline material) and the end product (e.g. suncream).

In the first market analysis (Bachmann [11]) the market potential was mostly characterized by ultrathin layers (market potential: 6.7 bn Euro), ultraprecision technology (3.8 bn Euro) and 0D-3D structures (Bachmann [11]). A specific relevance for the different economy sectors could not yet be given at that time. The numbers were gained by 67 standardized expert interviews conducted with both suppliers and (potential) users of nanotechnological products.
The second market analysis (Bachmann [12]) already distinguished a more differentiated picture for five sectors of the economy (medicine/biology, optics/optomechanics/analytics, chemistry/material science, electronics/information technology, automobile/engineering) and for five nanotechnology subfields (ultrathin structures, lateral structures, nanomaterials/molecular architecture, ultraprecision processing). Market figures were obtained for each subfield by scanning literature sources for single product groups and applications for 1996 (the year in which the study was carried out) and 2001. If market figures for 2001 were unavailable, they were extrapolated from the 1996 figures with an assumed annual growth rate of 15%. If no numbers were available for 1996 (e.g. for corrosion inhibitors), no market figures were given, so that the market figures obtained for the nanotechnology market in 1996 (27 bn Euro) and 2001 (52 bn Euro) can rather be seen as low estimates of the real potential. Indirect effects (e.g. energy savings or increased efficiencies in the manufacturing process) are not included in these figures.

For the third market analysis, Luther et al. [22] combined literature reviews, expert interviews, written questionnaires into German nanotechnology companies, patent analyzes and expert workshops.

The main focus was on the economic potential in some of the most important lead markets in Germany (chemistry, optics, automobile industry, medicine and life sciences, electronics) for the different subfields nanomaterials, nanoelectronics, nanooptics, nanobiotechnology and nanotools. The total market estimate was summed up to 120 bn Euro for 2004. For a comparison of this figure with other estimates of the current and future potential, see Luther et al. [22].

What information on the sustainability potential of nanotechnology can be inferred from these market surveys? First, the market analyses have helped in that they facilitated the identification of relevant application fields for nanotechnology: Once it becomes clear that e.g. nanolayers with certain properties (self-cleaning, anti-fouling …) can be applied for the production of coatings and paints, the sustainability potential of these materials and for these
applications can be estimated. This is also reflected in the BMBF calls on nanotechnology that were published after 1999: The calls on “nanotechnology” (BMBF [23]), nanostructured materials (BMBF [24]) in selected key technology fields and on magnetoelectronics (BMBF [25]) do not only mention ecological aspects. “Relevance for society (ecological aspects, workplace security)” or “ecological and employment impacts of the proposed project” are even introduced as one selection criterion for proposal evaluation.

Secondly, the relative importance of market potentials in each sector can also be taken as a first hint showing in which technology field large sustainability effects can be expected – large markets with a huge variety of products and applications will tend to be more relevant for sustainability issues than small markets with few products. The Identification of application fields for nano-innovations is therefore an important step for identifying areas of high sustainability relevance.

Taking these considerations and limitations into account, a broad range of potential applications for nanotechnology which can contribute to sustainability in key sustainability issues such as mobility, building, energy and pollution were identified. Figure 4 gives an overview on nanotechnology applications in important sustainability fields ranging from short-term, already available products to long-term applications that still need further R&D.

Some of these applications appear to be especially promising in their potential to contribute to sustainability, e.g.:

- Applications in energy conversion, storage and saving (European Nanoforum Gateway [26], Sutter and Loeffler [27])
- Indirect energy savings through surfaces reflecting thermal radiation or new insulation materials in buildings (e.g. Reim et al. [28], Schädler [29])
- Indirect material savings due to self-cleaning or anti-microbial effects (Morones et al. [30], Frazer [31])
More efficient and selective chemical reactions due to nano-catalysts (Schlögl and Abd Hamid [32])

New sensors and analytical devices that permit a closer monitoring of pollutants (Environmental Protection Agency [33], Takahashi et al. [34])

Replacement of toxic substances by less noxious nanomaterials, e.g. replacement of chromate coatings by sol-gel surface treatment (Steinfeldt et al. [35], ETAG [36])

Remediation of contaminated sites (Tratnyek and Johnson [37]), Yavuz et al. [38]).

Short, Mid and Long Term Applications of Nanotechnology Contributing to Sustainability

Figure 4: Nanotechnology applications with potential contributions to sustainability. Some of these applications are already available; others will only become relevant in the long term.
Some applications, e.g. nanotubes for hydrogen storage, have been questioned since storage capacities necessary for automobile applications could not be validated (Hirscher and Becher [39]). For other applications, e.g. dye solar cells, the long-term stability of the dyes and the electric efficiencies remain challenges (Hinsch [40]).

Phase 3: Innovation and Technology Analysis

From today’s state of knowledge, it is clear that, beside these beneficial effects nanotechnology also bears some hazards and uncertainties that have to be investigated and minimized. Examples for such hazards are:

- The distribution of nanomaterials in the environment (e.g. ecotoxicological effects on aquatic organisms)
- Potential hazards of nanoparticles to human health, especially through inhalable ultrafine particles
- Potential hazards of nanoproducts at the end of the life cycle (recycling and disposal)
- Environmental and health effects in connection with the production process of nanoproducts (e.g. increased energy need or noxious by-products).

The adequate instrument to deal with such questions connected with a new technology is technology assessment (TA) or innovation and technology analysis (ITA). TA has been widely applied for more than 30 years (Steinmüller et al. [41], Büllingen [42]) in order to assess the possible effects of technologies on society, economy and the environment. In recent years, TA has been criticized for being focused too much on the risks of new technologies while neglecting their potentials and chances and for being carried out without an adequate involvement of industry (Weber et al. [43]). Thus, the BMBF has changed its TA strategy towards a new concept “Innovation and Technology Analysis (ITA)” (BMBF [44]), which investigates and weighs the positive and negative effects of new technologies with the aim of using the opportunities they offer while minimizing the hazards. This concept uses a broad range of qualitative and quantitative methods to foresee potential risks and technologies in
the development process of a new technology as early as possible. The difficulty in ITA is finding the optimal moment of time for the analysis. The earlier an ITA is carried out, the better are the chances that the ITA results can still have an influence on technological and R&D development. A reactive ITA that only begins after completion of the R&D activities and at a time when the technology is already broadly applied has only limited effect and is carried out with a huge effort (Collingridge [45]). On the other hand, an early start of ITA bears the risk that insufficient data and information are available for a profound analysis. The best starting point for an ITA is probably the moment when the different application fields of a new technology have become clear. For example, carbon nanotubes have a broad spectrum of potential application fields that reaches from nanoelectronics to polymer-composites to products in medicine technology. Due to their small size which allows the nanotubes to penetrate deeply into the lung tissue and their asbestos-like geometry, toxicologists assume that they are potentially toxic for humans, and further research is needed to clarify this question. However, the toxicity of nanotubes depends largely on the way they are used: If they are incorporated as electron field emitters into displays etc., their potential for harmful effects is much reduced compared to applications where nanotubes are handled in large quantities and the risk of workplace exposure during the production process occurs (e.g. the use of nanotubes as fillers for polymers). It is quite clear that an ITA study on nanotubes in general would yield only limited insights while a study that takes these application fields into account can furnish valuable recommendations e.g. for measures to be taken at the workplace or having detailed studies concentrated on critical application fields.

The BMBF has managed to launch a study on ITA of nanotechnology (Malanowski [46]) very early in the development of R&D activities. This was possible because the close interplay of technological forecasting and ITA had provided the Ministry with the relevant information derived from the TF activities at a very early stage (Zweck [47]). The ITA study could be started once the potential application fields of nanotechnology had been identified. The study was focused on the dimensions technology, economy, ecology, health, politics as well as the indi-
vidual and social sphere. Experts from these domains were interviewed in order to sound out the consequences of nanotechnology applications in these fields. The ITA study resulted in recommendations for open questions to be dealt with, which were implemented by the BMBF in more detailed studies. These ITA studies focused on the aspects health (applications of nanotechnology in medicine, Farkas et al. [48]), environment (elements of LCA analysis, first attempt towards quantification of environmental effects, Steinfeldt et al. [49]) and economy (market assessment, Luther et al. [22]), thus reflecting important aspects of sustainability. Simultaneously with the publication of Malanowski [46], the BMBF entered into a third phase (since 2002) of introducing sustainability aspects into its calls by extending the concept of sustainability aspects beyond ecology towards technology assessment and sustainable development, e.g. in the initiatives NanoLux, NanoMobil and NanoChance. Proponents were now requested to provide an assessment of risks and potentials for all three pillars of sustainability (ecology, economy and society) along with their project proposal. The compliance with this criterion was part of the evaluation process. In a paper stating its new strategic orientation, the BMBF sees the assessment of risks and potentials as an important pillar for future activities (BMBF [50]).

Phase 4: Communication

In Germany, but also in other countries, the public discussion (indicated by media coverage) of nanotechnology stepped up around the year 2000. Our own analyses of newspaper articles (Figure 5) show that sustainability aspects do play a role in the media coverage of the technology, albeit their importance (with 5% of all articles) is small compared to other themes on the subject like funding policy, business or research. Articles discussing environmental chances and sustainability aspects of nanotechnology are nearly as frequent as articles on potential risks.

Despite increasing media coverage of nanotechnology in the popular press, the public is not very well informed about nanotechnology, although the situation has improved in recent years. A 2005 study on the public perception of nanotechnology (Grobe et al. [51]) showed
that in the early years of the 21st century the public still felt that they do not have sufficient information on nanotechnology. Although there is little knowledge about nanotechnology, more people expect higher benefits than risks of nanotechnology. But this perception might change if negative headlines about health risks of “nano” labelled products continue to occur, as we recently noticed in Germany in the case of the “magic nano” spray which had to be withdrawn from the market due to health damages caused to customers. Although it could be demonstrated that these negative health impacts were not caused by the use of nanoparticles, this kind of media coverage could impair the public acceptance of nanotechnological developments.

![Nanotechnology related articles in German newspapers in 2005](chart.png)

*Figure 5: Share of nanotechnology related articles dedicated to special topics in larger newspapers in Germany in 2005 as a percentage of all articles on nanotechnology (n=273)*

Thus, the BMBF decided to initiate a series of information and communication measures in order to provide the public with a balanced information base on both the risks and potentials of the new technology. One prominent example is the “nanotruck”, a mobile exhibition area of 60 m² which was launched in 2004 and provides information on nanotechnology for the general public. The campaign was designed to provide information on the current state of research and development potential in nanotechnology. It also aims at promoting the dialogue...
between the world of science and the general public. Target groups for the campaign are research institutes, companies, schools and the whole sector of education and training.

At the same time, the BMBF has entered a new phase of activities. In addition to funding of research projects and competency centres, it has broadened its activities towards dissemination and innovation accompanying measures. These include (BMBF [52]): SME funding (NanoChance), dialogues with industry sectors and the general public, especially on risks and potentials, calls directed at young scientists (NanoFutur), supporting networks of women scientists (nano-4-women) and entrepreneurs. Actor-orientation has been claimed as an important aspect of research and technology policies for sustainable development (Katz et al. [53]).

3. Discussion

The contribution of nanotechnology research to sustainability

For a closer examination of the relation between the nanotechnology funding activities of the BMBF and sustainability, it is necessary to define what exactly is meant by „sustainability“ and what the criteria for this assessment could be. Since these activities are based in a Federal ministry, they can be regarded as a contribution to the national policy and should as such be congruent with national strategies aimed at sustainable development. Such a strategy exists in Germany: In 2001, the German government launched a national sustainability strategy which defines four guiding principles (generational equity, quality of life, social cohesion, and international responsibility), six areas of activity and 21 indicators for monitoring progress in these areas. An overview on the criteria of the national sustainability strategy and how the BMBF funding activities relate to them is given in table 2.

The overview shows that nanotechnology funding activities address 11 out of the 21 criteria of the national sustainability strategy in three of the four guiding principles. Besides contributions in ecological indicators such as resource productivity and energy efficiency, social and economic indicators like employment and gender issues are also addressed by the programmes.
An analysis of the nanotechnology-related calls of the BMBF between 1995 and 2006 shows that sustainability issues have mainly been introduced as an ex-ante selection criterion for project proposal evaluation (see chapter 2 for details).

The national sustainability strategy and BMBF funding policy

<table>
<thead>
<tr>
<th>Goals of the national sustainability strategy</th>
<th>Contribution of BMBF-funded nanotechnology activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Generational equity</td>
<td></td>
</tr>
<tr>
<td>1 Increase of resource and energy efficiency</td>
<td>According to BMBF [53c], the typical property of nanotechnology is providing functionality with a minimum use of material. Thus it can be considered as principally resource- and energy saving. NanoLux and NanoMobil contribute to this goal.</td>
</tr>
<tr>
<td>2 Protection of the climate; reduction of greenhouse gas emissions</td>
<td>NanoLux and NanoMobil address applications that enable a reduced use of energy for lightning or mobility</td>
</tr>
<tr>
<td>3 Increase of renewable energy sources in energy production</td>
<td>Surface technologies with nanocomponents enable the development of new types of solar cells. However, in Germany, research for renewable energies currently does not lie within the competency of the BMBF.</td>
</tr>
<tr>
<td>4 Reduction of land use</td>
<td>-</td>
</tr>
<tr>
<td>5 Halt of biodiversity loss</td>
<td>-</td>
</tr>
<tr>
<td>6 Consolidation of the national budget</td>
<td>Not applicable</td>
</tr>
<tr>
<td>7 Increase of innovation dynamics</td>
<td>Yes, since nanotechnology is generally accepted as one of the most important strategic innovation fields for the international competitivity of the national economy</td>
</tr>
<tr>
<td>8 Increase of F&amp;E expenditures</td>
<td>Expenditures for nanotechnology funding by the BMBF have increased from 27.6 to 112.1 Mio Euros between 1998 and 2003 (BMBF [53c]).</td>
</tr>
<tr>
<td>9 Increase of number of highly-qualified degrees in education</td>
<td>-</td>
</tr>
<tr>
<td>II. Quality of life</td>
<td></td>
</tr>
<tr>
<td>10 Wealth: increase of gross domestic product per inhabitant</td>
<td>Not applicable</td>
</tr>
<tr>
<td>11 Mobility: decrease of transport intensity</td>
<td>-</td>
</tr>
<tr>
<td>12 Nutrition: increase of the share of organic farming</td>
<td>-</td>
</tr>
<tr>
<td>13 Air quality: decrease of pollutants sr</td>
<td>New sensors and membranes can improve supervision of pollutants. The development of</td>
</tr>
<tr>
<td>14 Satisfaction with health</td>
<td>The initiative NanoforLife addresses health issues, e.g. tissue engineering, medicine technology</td>
</tr>
<tr>
<td>15 Decrease of criminality</td>
<td>-</td>
</tr>
<tr>
<td>III Social cohesion</td>
<td></td>
</tr>
<tr>
<td>16 Increase of employment rate</td>
<td>Nanotechnology has and will have beneficial effects on employment. Luther et al. [14] estimate that currently between 20.000 and 114.000 jobs in Germany are in the field of nanotechnology</td>
</tr>
<tr>
<td>17 Improvement of childcare opportunities</td>
<td>-</td>
</tr>
<tr>
<td>18 Equality (gender)</td>
<td>The nanotechnology initiative nano-4-women aims at increasing the number of women in this emerging technology field.</td>
</tr>
<tr>
<td>19 Integration of foreign citizens</td>
<td>-</td>
</tr>
<tr>
<td>IV International responsibility</td>
<td></td>
</tr>
<tr>
<td>20 Increase of official development aid</td>
<td>Not applicable</td>
</tr>
<tr>
<td>21 Open markets towards developing countries</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

Table 2: Goals of the German sustainability strategy [2a] and nanotechnology funding activities of the BMBF that address them.
Effects of the integrated approach

The integrated approach followed by the BMBF resulted in a very quick switch from a mere technology push to a market pull strategy, since a high level of involvement of companies (mainly SMEs but also larger companies) in the research programmes was achieved. The focus switched from curiosity-driven research to applied research, and this development was supported by the market assessments and patent analyses carried out in the accompanying measures of the development of research programmes and funding activities. The early orientation towards industry interests had two (maybe adverse) effects on the role of sustainability in the development of nanotechnology:

On the one hand, the strong focus on industry interests and marketable solutions fostered a concentration on potential future lead markets like the automobile sector, the chemical industry or ICT technologies. This did not preclude sustainable solutions, but the main focus and the main criterion for project and funding decisions was the perspective of opening up new emerging markets as opposed to pointing to sustainability effects produced by these technology fields. The concentration on lead innovations and lead markets has certainly neglected other fields where nanotechnology could contribute to sustainability, e.g. soil remediation, water purification or pollution control.

On the other hand, the market assessments and patent analyses served to define the application fields for the new technology at a very early stage during the process. This in turn paved the road for an early launch of the innovation and technology analysis. The insights gained from the technology forecasting process and the market analyses could be used directly and without time delays for a substantiated first ITA study. Thus, the relevant fields for further ITA questions (like toxicity of nanoparticles, behaviour in the environment) could be identified and decisions on rewarding issues for first quantitative life-cycle assessments of nanotechnology products could be made.

The identification of relevant issues for ITA also helped to design the communication and education process at a time when the debate was still open and fixed pro- and contra-groups
had not yet formed within society. From the very beginning, critical issues such as health, toxicity and environmental effects were integrated into the communication measures such as the NanoTruck and built a knowledge base for the discussion on the acceptance of the new technology.

The integrated approach pursued in the accompanying measures related to nanotechnology has been referred to as Integrated Innovation and Technology Management (ITIM, Zweck [54]). ITIM is characterized by a moderated and coordinated connection of technology-accompanying measures and activities. Its aim is to increase the effects of the single measures such as TF and ITA, and to optimize synergies between the measures and phases. For the decision-maker, this approach offers the advantage that information about the status quo of technology development is available as highly up-to-date knowledge any time in the process.

The basis for this is a permanent monitoring of the technology field of nanotechnology. It is especially relevant in this context that the potential for shaping the field of technology development is considerably influenced by one’s own competitive position. Only those who work in the forefront of technology development have the potential to develop manufacturing methods, product quality standards, diffusion channels and ecological requirements through market trends, safety standards, norms etc.

4. Lessons Learned – Recommendations

The description of the integrated approach in the development of nanotechnology research in Germany has shown how a link between sustainability questions and technology development evolved over time and how it was supported by various technology accompanying measures. Certainly, the potential of nanotechnology to contribute to sustainability has not been fully exploited by these activities. It remains interesting to ask how this potential could be fully exploited and used as early as possible. The activities described above – integrating sustainability issues in technology development as early as possible – can be seen as complementary and supportive to approaches that focus more on the sustainability challenges
(e.g. climate change, water purification) and then derive the activities and technology developments necessary to achieve progress in these fields.

One important step in this direction can be joint research initiatives and networking activities that require the interdisciplinary cooperation of sustainability-oriented and technology-oriented scientists in common research projects. Similarly to the timing of ITA, these programmes must be timed in a way that the technology in focus is already at a stage of maturity when application fields emerge, but when product and process developments are still underway. As a basis for such programmes, the authors recommend to step into a new round of forecasting by analyzing nanotechnology from a sustainability perspective.

Another approach could be technology research programmes that are explicitly launched with the aim to contribute to sustainability. One example is a recent initiative by the German Ministry of Education and Research. Under the Framework Programme "Research for Sustainability", the BMBF has launched the call “Innovation as a Key for Sustainability in the Economy” (BMBF [55]). This initiative is looking for broadly applicable innovations across all sectors of the economy, and many of the projects that are being funded include nanotechnology (e.g. surface technology, nanofiltration). In these projects, sustainability aspects are either integrated through accompanying LCAs or other innovative sustainability assessment tools, or become part of the central research question of the research cluster (e.g. “increased energy efficiency through…”).

The main challenge in this context remains how to merge the different research cultures of innovation/technology and sustainability research that have been described in the introduction to this article.
References


[23] BMBF. Richtlinien über die Förderung von Forschungs- und Entwicklungsvorhaben im Rahmen des Förder schwerpunkts „Nanotechnologie“. [Regulations governing the funding of research and development projects within the framework of the funding priority “Nanotechnology.”] Bundesanzeiger 1999; 45: 3370.


