Technological Forecasting & Social Change 80 (2013) 444–452

Contents lists available at SciVerse ScienceDirect

Technological Forecasting & Social Change

The role of future-oriented technology analysis in the governance of emerging technologies: The example of nanotechnology

Petra Schaper-Rinkel

AIT Austrian Institute of Technology, Donau-City-Straße 1, A-1220 Vienna, Austria

ARTICLE INFO

Article history:
Received 24 July 2011
Received in revised form 7 July 2012
Accepted 3 August 2012
Available online 2 November 2012

Keywords:
Governance
Emerging technologies
Key enabling technologies
Nanotechnology
Public engagement
Foresight
Technology assessment
Responsible research and innovation

ABSTRACT

This paper analyzes the role that different types of future-oriented technology analysis (FTA) have played in the development of nanotechnology governance. In the US, FTA has been used to create visionary concepts and to promote cooperation between and among agencies, departments of the federal government, academia, and stakeholders. In Germany FTA has mainly been used to shape and define research and innovation agendas of established science–industry networks. The aim of the paper is to show what problems/challenges with regard to the innovation system have been addressed and what main actors have been involved, from the first monitoring and forecasting studies on nanotechnology to the establishment of national nanotechnology programs and continuing on until today. The paper offers a comparative analysis of the use and role of FTA where the focus is not on individual activities, but rather on the longer-term interplay between the organizational settings in both countries and the future-oriented nanotechnology analysis.

In countries such as the US and Germany, where FTA on nanotechnology were already underway in the late 1980s, the early stages of FTA relied on expert-based methods such as technology intelligence and technology forecasting to define the field and to explore what could happen in general. Participatory formats such as dialogues on ethical, legal and social aspects (ELSA) became more important only later on. Especially the inter-organizational setting can be considered a crucial condition for maximizing the impact that participatory FTA can have in the future governance of nanotechnology.

1. Introduction

As science and technology become more central to economic development, the question of future-oriented governance of emerging technologies gets raised repeatedly. A decade ago, the question addressed how to maximize the contribution of such technologies to economic innovation with the intention of enhancing competitiveness [1,2]. Today, the question also includes how to use these technologies to tackle societal challenges and to contribute to environmental sustainability [3, cf. 4]. In both rationales, different types of future-oriented technology analysis (FTA) are used to determine national science and technology priorities, to develop governance frameworks and to address national innovation systems. In the case of nanotechnology, a variety of FTA activities have been in use over the last quarter of a century to structure the field itself and to establish governance structures in the field of nanotechnology.

Compared with other countries, the US and Germany started assessing the status and future trends in the area of nanotechnology early on [5,6] and rank high with regard to R&D spending and output indicators such as publications and patent applications [7,8]. More than ten years have passed since the U.S. National Science and Technology Council published its first vision for nanotechnology research and development and Germany established its public funding program. Understanding what nanotechnology is and how it is governed requires first focusing on the governance processes associated with its development and then recognizing that the

E-mail address: Petra.Schaper-Rinkel@ait.ac.at.

0040-1625/$ – see front matter
http://dx.doi.org/10.1016/j.techfore.2012.10.007

emergence of nanotechnology is not just adjudicated in labs, but rather also in processes such as technology forecasting, technology assessment and participatory future-oriented studies, involving scientists, policymakers, media, and other public participants.

The aim of this paper is to show what topics have been addressed and what main actors were involved in the future-oriented activities conducted prior to and after the establishment of national nanotechnology programs. The paper analyzes the role that different types of future-oriented technology analysis played in the development of nanotechnology governance. The first set of national activities the paper analyzes is from the US, where FTA was used to create visionary concepts and to promote cooperation between and among agencies, departments of the federal government, academia, and other stakeholders. The second set of national activities the paper analyzes is from Germany, where FTA was mainly used to shape and define research and innovation agendas. In both countries, the public policy activities to foster nanotechnology were accompanied by efforts to establish governance structures to coordinate interactions between actors of the innovation system.

The paper considers the following questions: How is FTA embedded in the national innovation policy? How are specific governance measures related to FTA and to the establishment of focal organizations? What are the contributions of the distinct future-oriented approaches to the development of nanotechnology governance?

2. Analyzing the role of future-oriented technology analysis in the governance of nanotechnology

2.1. Nanotechnology: the field, its definition and its governance

The Technical Committee 229 on Nanotechnologies of the International Standardization Organization (ISO) issued a definition of nanotechnology in 2010 which contains the same elements as those used over the last decades: nanotechnologies include understanding and controlling matter and processes at the nanoscale, where the onset of size-dependent phenomena usually enables novel applications. Nanotechnologies utilize "the properties of nanoscale materials that differ from the properties of individual atoms, molecules, and bulk matter to create improved materials, devices, and systems that exploit these new properties".[1]

This broad definition covers clusters of technologies that may have different characteristics and applications. In the context of the US Nanotechnology Initiative, four generations of products were envisioned: the first generation includes *passive nanostructures* (nanoparticles, nanostructured materials), followed by a second generation of *active nanostructures* (e.g. targeted drugs and chemicals, actuators), a third generation of *3-D nanosystems and systems of nanosystems* (characterized by various syntheses and assembling techniques), and a fourth generation (starting in 2015) of *heterogeneous molecular nanosystems*, where molecules are envisioned as devices to build up engineered structures and architectures with fundamentally new functions [9].[2]

The emergence, funding and institutionalization of nanotechnology were closely linked to the ways that various branches of nanoscience and nanotechnology were contextualized and anticipated as the field called nanotechnology. Many studies in the field of science and technology studies (STS) have shown that nanotechnology is as much a political as a cultural phenomenon [11–14]. Visions, roadmaps, and visionary policy documents have been a main source for analyzing the social and political dimensions of nanotechnology in the broad range of STS, although the impact of FTA itself on the governance of nanotechnology has not been the subject of analysis.

The scope of nanotechnology governance covers both anticipating and realizing future opportunities and identifying and reacting to potential risks. At the turn of the century, nanotechnology was mainly discussed with regard to content (future applications), not with regard to the future decision-making processes and the participation of stakeholders, which is central to governance. Governance is broader than government, covering non-state actors, and is characterized by continuing interactions among network members [15]. Today, future governance is seen as crucial for the development of nanotechnology [16].

2.2. Approaching the future of nanotechnology: the scope of future-oriented technology analysis

Several distinct approaches toward anticipating the longer-term implications of nanotechnology have been taken. Early and radical visions that shaped the field in the late 1980s were published by individual thinkers [17,18]. In the 1990s, studies mapping the field and technology assessment studies included actors and knowledge mainly from science and industry [1,19–22]. After the establishment of public funding programs in some countries and increasing risk debates, anticipatory activities included a wide range of stakeholders from politics, academia, industry and NGOs, as well as independent parties [cf. 23]. Examples of these participatory and future-oriented activities include consensus conferences in the US [24] and a consumer conference in Germany [25]. Governments that established nanotechnology funding programs later, such as Denmark, used national level technology foresight processes to prepare and implement their funding strategies [26]. The whole variety of these processes were used to "initiate collective learning and vision building which impact the complex interplay of factors governing innovation trajectories" [27].

[1] http://www.iso.org/iso/iso_technical_committee.html?commid=381983

[2] Nanotechnology and the governance of nanotechnology are furthermore intertwined with the discourse on converging technologies, referring to the "synergistic combination" of nanotechnology, biotechnology, information technology and cognitive sciences (NBIC), where a similar governance framework as in the case of nanotechnology is discussed [10] (M. Roco, Possibilities for global governance of converging technologies, J. Nanopart. Res., 10 (2008) 11–29). Indeed, it turns out there are strong analogies between nanotechnology and converging technologies, though they seem to be very different phenomena with regard to the funding and policy dynamics in the fields. The main difference is that in the field of nanotechnology the funding strategies were implemented before broader public discourses emerged, whereas in the field of converging technologies broad futuristic discourses took place that were not followed by funding strategies dedicated explicitly to converging technologies.

As FTA is commonly understood as "an umbrella term for a broad set of activities that facilitate decision-making and coordinated action, especially in science, technology and innovation policy-making," [28] the above mentioned activities can all be considered as FTA. In this paper, FTA is used as the umbrella term covering subfields such as technology foresight, technology forecasting, technology roadmapping and technology assessment [cf. the list in 29] and combining tools, ranging from quantitative methods such as bibliometrics and modeling to qualitative and participatory tools such as focus groups and scenario building [cf. 30]. In addition, the term also encompasses new participatory types of future-oriented nanotechnology-related studies and activities, such as dialogues on ethical, legal and social aspects [cf. 31].

The US and Germany differ with regard to their commitment to national-level foresight activities (as a highly comprehensive form of FTA). In contrast to many other developed economies where technology foresight is used to support strategic decision-making, national-level technology foresight studies are not seen as a prominent activity in the science and technology landscape of the United States. The "U.S. stands virtually alone in specifically avoiding centralized S&T planning" even though advanced forward-looking activities are used [32]. In contrast to the US, the German government has launched several technology foresight processes in the last decade [33,34]. Despite these different traditions, both countries used FTA to develop governance frameworks for nanotechnology.

3. Future-oriented technology analysis of nanotechnology in the US and Germany

The early history of nanotechnology as an emerging technology is heterogeneous. In the 1980s a first funding program was established in UK that has since fallen into oblivion. Usually, two US visions are seen as the starting point of nanotechnology as an emerging technology. The early individual vision of Eric Drexler, who envisioned a distant future vision of molecular manufacturing in the late 1980s, was the first. In his book *Engines of Creation*: *The Coming Era of Nanotechnology* [17], Drexler developed far reaching new ideas of the possibilities and risks of technologies on the nanoscale. He envisioned molecular machines programmed by integrated nanocomputers to perform specific tasks and to create molecular machines capable of manipulating individual atoms and building up precisely engineered artifacts from the bottom up. Drexler became a key figure for this new technological vision and his ideas became a disputed reference point in the debate around nanotechnology in the late 1980s and the 1990s. His work was highly influential in the early history of nanotechnology in that it imaged a new industrial revolution through nanotechnology [cf. 11, 35, 36].[3] The second vision was presented to the broad public in 2000 by the US National Nanotechnology Initiative called "Nanotechnology — Shaping the World Atom by Atom." [22]

3.1. Integrated vision-building and governance network-building in the US

At the end of the 1990s, the US science policy community established an organizational structure around nanotechnologies and developed a vision for nanotechnology R&D. This started in 1998 when the National Science and Technology Council (NSTC), the principal executive body responsible for coordinating science and technology policy, formally established a specific working group called the Interagency Working Group on Nanoscience, Engineering, and Technology (IWGN), which included members of different government departments and agencies.[4]

In 1999, the NSTC conducted a series of studies and published reports on the status of and trends in nanotechnologies. The studies brought together science and technology assessment of different fields of what would then be called "nanoscale science and technology". Visits to leading research laboratories in Japan and Europe and workshops held in the United States, Europe, and Russia were used to gather additional information for worldwide studies in the field of nanostructure science and technologies [37]. The resulting report most explicitly related to future orientation was the IWGN workshop report on nanotechnology research directions, which included a "Vision for Nanotechnology Research and Development in the Next Decade" [1]. Vision building at this stage was accompanied by early cooperation and coordination between and among agencies and departments of the federal government. In their work within the IWGN, the participating agencies and departments stated their major interests in nanotechnology, proposed themes for R&D support and stated their planned contributions of their programs to the nanotechnology initiative. Over 150 participants and contributors from government, science, and industry were involved in developing the vision. Nearly all of the experts from academia came from the natural sciences and engineering. Only one expert was from toxicology, and no experts represented the social sciences, humanities, innovation studies, environmental studies or science and technology studies. At this stage, the FTA activities did not involve a broad range of stakeholders. Rather, it was a process driven by technology experts.

The small section of the IWGN workshop report on the "social impact of nanotechnology" contains a "vision on the future" which names two factors that "will determine the competitiveness of individuals, organizations, and nations". These factors are, "how fast people adapt and how smart they become about the application of nanotechnology solutions". "Those societies that

[3] Today, most scientists do not give credit to Drexler's contribution to nanotechnology and instead focus on Feynman as the genius behind the origins of the field [11] (C. Selin, Expectations and the emergence of nanotechnology, science, technology & human values, (2007) 196–220). Historical analysis indicates that the process of drawing the boundary so as to exclude Drexler's ideas was closely connected with controversies around the question, what kinds of nanotechnology research should be funded [36] (S. Kaplan, J. Radin, Bounding an emerging technology: para-scientific media and the Drexler–Smalley debate about nanotechnology, Soc. Stud. Sci., 41 (2011) 457–485).

[4] Participating agencies included the Department of Commerce (DOC), Department of Defence (DOD), Defence Advanced Research Projects Agency (DARPA), Department of Energy (DOE), Department of Transportation (DOT), National Aeronautics and Space Administration (NASA), National Institutes of Health (NIH), and the National Science Foundation (NSF).

support nanotechnology education, research, and development the fastest will thrive in the new millennium" [1]. These statements illustrate that the report represented a future-oriented relation of technology, policy and society which can be characterized as a model of linear and science-driven innovation. In this model, technology results from research whereas society has to adapt to technology to make its applications successful. For its part, the government's role is to improve and accelerate the uptake of technology through funding, education and awareness-raising.

The report outlined the vision "that nanotechnology will lead to the next industrial revolution" [1]. It recommended a national nanotechnology initiative, stating that "The initiative, 'National Nanotechnology Initiative (NNI) — Leading to a New Industrial Revolution', should approximately double the Federal Government's annual investment in nanoscience, engineering and technology research and development from the approximately $255 million it spent in fiscal year 1999." [1]. The NNI was announced a few months later.[5] In hindsight, the technology assessment activities and the vision building process served to link disperse organizations and research fields and to create an organizational setting. At the same time a strong action orientation was established, as the activities of the working group on nanotechnology were directly linked with the preparation of the NNI.

In the years following the implementation of the NNI, the Nanoscale Science, Engineering and Technology (NSET) Subcommittee of the NSTC Committee on Technology (which succeeded the IWGN) called for the involvement of social scientists across the board [38] and the legislation called for an ethical and societal research program to ensure that societal concerns were considered [39]. Since 2004, risk has become the subject of political concern as well as the subject of analysis. Public opinion about nanotechnology and public perceptions about its risks and future benefits has been analyzed extensively [40,41] and the need for risk governance has been expressed [42]. NNI agencies incorporated components of research on Ethical, Legal and Social Implications (ELSI) into nanotechnology R&D programs and supported centers for nanotechnology in society.

In 2010, a follow-up report on the vision report of 1999, entitled "Nanotechnology Research Directions for Societal Needs in 2020" [3] combined retrospective and future-oriented analysis documenting developments in nanotechnology from 2000 to 2010 and presented "a vision for progress in nanotechnology from 2010 to 2020" [3]. Besides redefining the R&D goals for nanoscale science and engineering integration, and presenting concepts of how to establish nanotechnology as a general-purpose technology in the next decade, the presented vision for 2020 was conducted by involving a wider range of experts and stakeholders to generate broader knowledge than in 1999. These experts and stakeholders came from industry, from NGOs, from the physical and biological sciences, engineering, medicine, social sciences, economics, and philosophy. The report included insights from US experts in the field, examinations of lessons learned, and integrated international perspectives collected through multinational workshops held in the US, Europe and Asia.

In comparison with the first vision generated prior to the establishment of the NNI in 1999/2000, the new report written a decade later focuses more on governance and on concepts to involve and mobilize an increasing variety of stakeholders in the future. The report emphasized the concept of "anticipatory governance of nanotechnology", that was introduced by social scientists at the Center for Nanotechnology in Society at Arizona State University. The concept aims at having participatory FTA be taken up into ongoing sociotechnical processes to shape their eventual outcomes at all levels including to the point of the lab [43]. Another concept, highlighted in the report is real-time technology assessment, a research program to integrate natural science and engineering investigations with social science and policy research from the outset [44]. This concept also stems from the NNI[6] and became a part of the vision for 2020. Both concepts rely on experiences derived from participatory activities. The vision report states that during "the next decade, application-driven research will produce new scientific discoveries and economic optimization leading to new technologies and industries. Such translation will benefit society but will require new approaches in accountable, anticipatory, and participatory governance, and real-time technology assessment" [3]. The report refers to the previous involvement of a broad variety of stakeholders although it is not described in detail how they were involved in decision-making processes. The need "to increase multi-stakeholder and public participation in nanotechnology governance" is stated as one of the main lessons learned after ten years [3].

In 2011, the key architect of the National Nanotechnology Initiative, Mihail C. Roco, Senior Advisor for Nanotechnology at the National Science Foundation (NSF) recounted the history and envisioned the future of the US National Nanotechnology Initiative [16]. He distinguishes two foundational phases, called "Nano 1" and "Nano 2". The first foundational phase (2001–2010), which took place in the first decade after defining the long-term vision, focused on inter-disciplinary research at the nano-scale and was "dominated by a science-centric ecosystem". The second foundational phase (2011–2020) is planned to be focused on the integration of nano-scale science and engineering and the mass use of nanotechnology. The related future governance will be oriented on a "user-centric ecosystem", which is expected to become increasingly participatory and will be based on a techno-socio-economic approach [16].

The goals defined in the latest NNI strategic plan of 2011 address this "user-centric ecosystem" by covering the whole "ecosystem of innovation": they address R&D ("Advance a world-class nanotechnology research and development program"), innovation ("Foster the transfer of new technologies into products for commercial and public benefit"), infrastructure including education ("Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology") as well as risk governance ("Support responsible development of nanotechnology") [45]. Coordination among agencies and enhanced engagement by many stakeholders are seen as crucial measures to realize the NNI goals [45]. The core concept for the future development is "innovative and responsible governance of nanotechnology" [45], a concept rooted in

[5] The NNI itself is not a funding program. The funding is provided through the NNI member agencies.
[6] The Center for Nanotechnology in Society at Arizona State (CNS-ASU) is funded by the NSF.

approaches to address environmental, health, safety and societal impacts of nanotechnology as "environmentally responsible development of nanotechnology" [46] and to develop risk governance for nanotechnology [42].

In their United States case study on technology foresight in general, Porter and Ashton conclude: "The pluralistic nature of the US R&D system, the diverse, dynamic nature of US national political bodies and the limitations of US foresight history makes centralized goal-setting across many national issues in the US very unlikely" [32]. They see widespread skepticism among US leaders of most forms of centralized, formal government planning as a main reason for this. In the case of nanotechnology, there was no centralized and formal planning process, but rather a coordination of future-oriented activities that allowed the departments involved to develop their own individual agendas and to develop a shared vision. With regard to nanotechnology, it seems that for specific issues, as in the case of emerging technologies, the diverse and dynamic environment enables the actors within the pluralistic system to use FTA to build up governance networks and to integrate a growing number of stakeholders. The term technology foresight has not been used with regard to future-oriented activities in nanotechnology, but considering the nano-related FTA of the last fifteen years, the NNI uses advanced strategic planning methods and tools and acts as a kind of umbrella organization for pooling heterogeneous future-oriented activities. As is the case in "fully-fledged" technology foresight programs [cf. 47], the activities under the umbrella of the National Science and Technology Council Subcommittee were per se closely policy-related and, in the last decade, included prospective studies of long-term opportunities as well as participatory activities such as building networks to access disparate sources of knowledge and to legitimate the governance of nanotechnology. Over more than a decade, the US science policy community established a continuously working core organization, built up a network and opened the network gradually to new stakeholders and disciplines.

3.2. Germany — FTA for addressing the future of existing areas of strength

In Germany, nanotechnology has been on the policy agenda of the federal German Ministry for Education and Research (BMBF) since the late 1990s. The nanotechnology related activities of BMBF, the main public agency in Germany in charge of promoting pre-commercial research and development, started in the late 1980s and focused in the early stages on technology analysis, market analyses and technology assessment activities. The BMBF commissions the Association of German Engineers Technology Center (VDI-TZ), a subsidiary company of the Association of German Engineers (VDI), to monitor future technology trends that could be the subject of funding programs in the future. These reports are referred to as "technology analyses" and include both assessment and future-oriented parts, but focus predominantly on economic issues and impacts.

The BMBF commissioned several "forecasting studies" on nanotechnology-related fields starting in the early 1990s. Seen from the perspective of the VDI-TZ, which conducted the activities, 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" [48]. The results of the forecasting exercises were published in "technology analyses", summarizing the process and results of the forecasting exercises for nanotechnology in general and for various subfields of nanotechnology, including fullerenes, synthetic supramolecular systems, nanotubes, and nanobiology. These reports provided information on the technology field or sub-field, documenting its potential prospects from the perspective of various sectors of industry, describing future applications, analyzing research deficits, and making policy recommendations.

From 1988 to 1998, the technology field was monitored by analyzing the literature, visiting conferences and other relevant actors internationally, organizing expert panels on different aspects of nanotechnology, conducting studies on specific nano-subfields and by bringing together relevant actors from science and industry through workshops and expert discussion [6]. Technology intelligence, technology assessment, and future market assessment were used to identify the promising areas of the field and to assess the market potentials of future nano-applications. In 1998, these early monitoring and forecasting activities were followed by an initiative of the BMBF to establish the first six national nanotechnology competence centers with annual funding. They were established to bridge the gap between science and industry from the very beginning of R&D activities [48]. At the onset of the German national nanotechnology initiative, officially started in the late 1990s by widely publicized funding programs for nanotechnology, a network of important actors was already in place revolving around one federal ministry. Priorities were set focusing on the positions, needs, and interests of industry and on the transfer of knowledge between industry and natural sciences. By conducting these FTA on behalf of the BMBF, the VDI-TZ built and stabilized actor networks representing industry and science.[7] These early network activities did not involve other ministries or government agencies, as opposed to the US case.

In 2003, the BMBF developed a national strategy for future funding and support of nanotechnology. The strategy focused on so-called "lead innovations", value chain-oriented collaborative projects with partners from science and industry. They focus on the following areas:

- Nanofab (electronics, nanotechnology for high performance ICT components).
- NanoforLife (pharmaceuticals, medical technology nanotechnology for new medical therapies and diagnostics).
- NanoMobil (automotive sector, nanotechnology for resource-saving automobiles).

[7] These networks represent organizations that have been funded by the Ministry before. Especially industrial players such as Bayer, Degussa, Siemens, Zeiss, industry-oriented organizations of applied science such as Fraunhofer-Institutes, and a few universities (e.g., University of Münster, Technische Hochschule Aachen) participated first in defining the field and then received public funding later. Before special nanotechnology funding programs were installed, they received funding from other programs of the German Federal Ministry of Education and Research (BMBF) (e.g., optical technologies, new materials).

• NanoLux (optics industry, nanotechnology for energy efficient lighting).
• NanoChem (production and safety assessment of nanomaterials for industrial applications).

In 2003 the Office of Technology Assessment at the German Parliament conducted a broad technology assessment on nanotechnology [49]. In 2006, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) established the "NanoKommission" – a stakeholder commission on nanotechnologies – as part of the federal government's high-tech strategy. The commission, which worked in two phases until 2011, identified more than 25 examples of German dialogue processes concerned with the potential benefits and risks of nanotechnologies. These unrelated processes cover dialogues at the federal and state levels as well as stakeholder dialogues and processes of public understanding of science and technology [50]. The NanoKommission itself organized a dialogue where representatives of environmental and consumer organizations, a women's association and a medical practitioners' organization, trade unions, churches, academia, industry and government bodies (such as federal ministries and agencies as well as ministries on the regional and state level) discussed their positions [51]. Its mandate was solely to foster exchange among the various stakeholder groups in society on the potential benefits and risks of nanotechnologies and to discuss the responsible use of nanomaterials.

In 2007, the "Nano-Initiative — Action Plan 2010" emerged as an important part of the high-tech strategy of the German government. Through the action plan, other federal ministries[8] finally joined the German nanotechnology initiative — more than fifteen years after the first monitoring and forecasting activities were conducted. The action plan was planned as a "cross-departmental initiative". However, the next strategic document, the "Action Plan Nanotechnology 2015" refers to only some initiatives of other ministries and agencies (mainly with regard to regulation, rather than future strategies) without mentioning past or future cooperation and collaboration among ministries and agencies of the federal government [52]. A broader concept of responsible development of nanotechnology in general was not developed (only the identification of risks "for safe and responsible handling") [52]. A concept for future governance of nanotechnology is also not part of the action plan. The work of the NanoKommission is mentioned but the action plan was finished before their final results were available.

One of the recommendations published in the NanoKommission's final report in 2011 is that the German federal government should establish a national, cross-departmental internet platform providing information on developments and activities in the field of nanotechnologies [51]. A national, cross-departmental coordination board was not suggested.

In summary, for over a decade, the German variety of FTA activities was governed mainly by one ministry (BMBF) and focused largely on science–industry relations. The activities were strategically directed to building on existing areas of strength such as in the automotive industry and micro-electronics. Unlike in the US, there was no initiative in the beginning that brought together different actors under an independent umbrella organization. Other actors, such as other ministries and their agencies (for instance the BMU and the Federal Environment Agency) stepped in only after the funding strategy was already established. In contrast to the US, Germany lacks an organizational structure that brings together the expertise of the broad variety of ministries, agencies, stakeholders, and research to pool the distributed "strategic knowledge" gained from different activities such as technology intelligence, parliamentary technology assessment, technology monitoring and dialogue processes. The German research system is characterized by its high level of institutional fragmentation [53] and this institutional fragmentation can also be observed with regard to the governance of science, technology and innovation in the field of nanotechnology.

4. Comparing the US and Germany

4.1. Timing and intervention

Between the late 1980s and the late 1990s, FTA aimed mainly at assessing the potential of the field known today as nanotechnology. Several industrial countries established their first programs in that field in the late 1980s and early 1990s. But only in the end of the 1990s were the formerly disconnected fields of nanoscale science and engineering brought together under the broader umbrella definition of nanotechnology. FTA activities were used in this early stage to facilitate a common understanding, develop visions, build up policy networks, as well as shape and prepare funding programs.

FTA in the governance of nanotechnology started with forecasting activities and expert-driven identification processes in which expertise was limited by involving actors exclusively from government, science, and industry. Later processes included expertise from a broader range of disciplines and – in the case of the US – a growing recognition to include a wider range of stakeholders and sometimes also the knowledge of lay people. Not only the range of stakeholders involved was increasing in the last decade, but also the kinds of processes expanded from studies based on expert surveys to processes involving more stakeholders (such as NGOs and citizens). On the one hand, the emergence and increase of participatory FTA activities is a positive reflection of increasing public attention to nanotechnology after the funding programs were established. On the other hand, the increase was triggered by critics coming from voices outside the networks established in both countries. Participatory FTA activities increased in both countries after 2004, when nanotechnology risks was first perceived as problems and became the subject of global discussion among NGOs [54] and reinsurance companies [55]. These interventions can be characterized as "uninvited participation" [56] or uninvited forms of civil participatory action.

[8] The ministries involved were the Federal Ministry of Labour and Social Affairs (BMAS), Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), Federal Ministry of Defence (BMVg), Federal Ministry of Health (BMG), and Federal Ministry of Economics and Technology (BMWi).

In this later stage, heterogeneous stakeholders beyond the actors of the early established nano-policy networks, such as NGOs and representatives of the lay public, were often involved in FTA processes, although the role of these processes differs significantly with regard to decision making. The function of these participatory processes can be seen as part of "acceptance politics" [57] that attempts to increase acceptance of emerging technologies. Participatory processes as well as different concepts of responsible research and innovation in nanotechnology were triggered by global debates on the risks of nanotechnology.

4.2. International screening and cooperation

Globalization and the shift in the role of nation states [58] are important factors driving future-oriented technology analysis. Efforts to identify promising areas of science and technology as early as possible have given rise to efforts to monitor emerging technologies on a global scale. This approach started early, as evidenced by first reports in the US and Germany, which documented mutual visits and mutual screening activities in the 1990s. The US Interagency Working Group on NanoScience, Engineering and Technology (IWGN) published a worldwide study on "Nanostructure Science and Technology" in 1999. The report includes site reports for visits conducted by the IWGN expert panel to leading research laboratories in Japan and Europe. The report also documented workshops held by the panel not only in the US, but also in Germany, Sweden, and Russia to gather additional information on activities in those countries [5]. In Germany, the report on the first forecast activities also documented international activities, analyzing nanotechnology related activities in the US [6]. While the US NNI continued this international screening and networking by conducting multinational workshops in and outside the US [3], the BMBF did not report similar activities.

4.3. Governance structures

Beside many parallel developments in the US and Germany, such as the late consideration of societal challenges, there are also differences in governance structures. In Germany, disparate sources of knowledge were not pooled, a nano-specific organizational context was not established that could serve as an umbrella organization to promote cooperation among agencies and ministries of the federal government and to pool the knowledge gained in stakeholders processes conducted beyond the BMBF. As a result, the knowledge from the various nano-related FTA and participatory processes remains unconnected, making it unclear to what degree these activities are policy-related. Unlike in the US, the BMBF does not include the input from the social sciences in setting a future agenda. In Germany other ministries and government agencies have their own agendas with regard to the future governance of nanotechnology without being part of a common board where strategies are compared and aligned.

The forward-looking activities of the US nanotechnology initiative have had a major impact on the future orientation within the US political realm with regard to nanotechnology governance and have also greatly influenced stakeholders and researchers outside the government. The vision-building process of 2010 served as an instrument to pool and coordinate FTA activities among government departments, agencies, and research communities. It remains to be seen whether the US initiative will be as effective in implementing its far-reaching goals as it was in pooling disparate sources of knowledge to design its vision for 2020.

4.4. Participation

The NNI fulfilled the functions usually associated with foresight initiatives [59]. The NNI's early nanotechnology assessment studies indicated to the public that policy was based on scientific knowledge information *and* oriented to "revolutionary" future technologies. The early study exercises provided justification for a policy that was under consideration (symbolic function) and the results lead to policy conceptualization, design and implementation (informing policy and supporting policy definition). The capacity for change (facilitating policy implementation, embedding participation in policy-making and reconfiguring the policy system) was enhanced by building networks among government departments, agencies, industry and a broad variety of academic disciplines. The new vision embraces participation at the conceptual level but it remains unclear how the highly ambitious concept will be implemented and what will happen if stakeholders hold opposing positions and claims, for example with regard to risk governance.

In Germany, early FTA activities also provided justification for a policy under consideration (symbolic function) and were also used for policy conceptualization, design and implementation (informing policy and supporting policy definition). Unlike in the US, the governance network in Germany is centralized around one ministry (the BMBF) lacking a continuously working governance structure to bring together the variety of actors involved in nano-related innovation processes. Other ministries, such as the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) focus on regulation issues relevant for their domain without being fully involved in the ecosystem of nano-related innovation. Policy definition and implementation is not organized by involving a broad variety of stakeholders and the policy system remains unchanged. These differences may reflect how specific processes and their "engagement designs" are constructed, as well as how "the public" is constructed in such settings [cf. 60, 61].

5. Discussion and conclusion

FTA activities were used to shape the emerging field of nanotechnology in the early stages (priority-setting and preparation of funding programs) and to influence the national innovation systems by implementing nanotechnology programs and nanotechnology regulatory structures in later stages. In the late 1980s and early 1990s, several industrial countries established their first programs in the field later called nanotechnology. Expert-driven FTA activities were used in the first stages to build a common understanding and develop these visions. These early activities brought together the formerly unconnected fields of nanoscale science and engineering under a broad definition of nanotechnology and served as the foundation in developing long-term R&D visions and strategies. Both in the US and Germany, actors conducting early FTA did not claim to have a broad impact on public policy, as they intended to *identify* emerging technologies and not to shape the field. Nonetheless, these activities contributed to forming the field and shaping the expectations. In both countries, early FTA envisioned innovative future nanotechnologies but did not provide guidance either for future innovative governance or for using nanotechnology for disruptive innovation to address grand societal challenges. The implication for future emerging technologies is that the methodology and practice of FTA should consider the governance dimension from the beginning by acknowledging that monitoring and identifying a broad field implicitly includes the shaping of the field and its governance structure by including or excluding a certain type of knowledge and expertise. This claim, which is not new, implies the need for an organizational structure that includes a variety of actors and perspectives from the outset.

In the last two decades, FTA activities were important means for integrating the field and in spreading the idea that nanotechnology would become one of the key enabling technologies of the 21st century. Coherent and powerful statements of what the future governance of nanotechnology should aim to accomplish can be seen as a precondition that could potentially lead to binding prioritization of the goals to be reached by using nanotechnologies. In the US the new vision for 2020 represents such a concept, while in Germany many different agendas were developed in parallel without a common strategy. Comparing these two countries, the main difference lies in the existence of an umbrella organization in the US that pools heterogeneous stakeholders and that ensures the organizational continuity to use the experience and knowledge gained in distributed FTA activities.

While early FTA involved experts almost exclusively from science and industry and governmental bodies, current future-oriented activities involve at least in the US experts from social science and humanities. Future oriented activities that are not directly linked with decision making in policy, such as public engagement activities organized by researchers in the US or dialogues organized by the German NanoKomission were involving increasingly other stakeholders such as non-governmental organizations and citizens. The updated nanotechnology vision in the US [3] is envisioning the involvement of a broader range of experts and stakeholders and addresses societal challenges through a sophisticated concept of future nanotechnology governance. The US nanotechnology governance is conceptually oriented toward responsible research and innovation and broad participation. It has established broad networks with a focal organization as the basis for implementing its strategic vision. The German nanotechnology policy, in contrast, has no continuously operating nano-related inter-organizational setting; it is therefore less coordinated and does not include the requirements of heterogeneous stakeholders nor make use of the knowledge gained in various FTA. The inter-organizational setting can be considered a crucial condition for maximizing the impact that participatory FTA can have in the future governance of nanotechnology. Looking ahead to the next decades, an inter-organizational governance framework is crucial to uptake the knowledge as well as the requirements derived from various stakeholders.

Acknowledgements

This paper builds on earlier research on the governance of nanotechnology in Germany funded by the German Research Foundation *DFG* and also on studies for an AIT funded project on the impact of Foresight (SuFo—Sustainable Foresight). I would like to thank the anonymous reviewers who provided insightful comments and suggestions.

References

[1] NSTC, National Science and Technology Council, Nanotechnology research directions: IWGN workshop report, Vision for Nanotechnology Research and Development in the Next Decade, 1999.
[2] BMBF, Bundesministerium für Bildung und Forschung, in: Strategische Neuausrichtung. Nanotechnologie in Deutschland, BMBF Publik, Bonn, 2002, p. 16 S.
[3] M. Roco, C.A. Mirkin, M. Hersam, Nanotechnology Research Directions for Societal Needs in 2020, Berlin/ Boston, Retrospective and Outlook, Springer, 2010.
[4] European Commission, Green Paper, in: E. Commission (Ed.), From Challenges to Opportunities: Towards a Common Strategic Framework for EU. COM(2011) 48, Green Paper, European Commission, Brussels, 2011.
[5] NSTC, National Science and Technology Council, IWGN, E.a.T., The Interagency Working Group on NanoScience, Nanostructure Science and Technology, in: A Worldwide Study, 1999.
[6] G. Bachmann, in: Zukünftige Technologien (Ed.), Analyse und Bewertung zukünftiger Technologien. Innovationsschub aus dem Nanokosmos, VDI Technologiezentrum, Düsseldorf, 1998, p. 220.
[7] J. Youtie, P. Shapira, A. Porter, Nanotechnology publications and citations by leading countries and blocs, J. Nanopart. Res. 10 (2008) 981–986.
[8] K. Blind, S. Gauch, Research and standardisation in nanotechnology: evidence from Germany, J. Technol. Transf. 34 (2009) 320–342.
[9] M.C. Roco, Nanoscale science and engineering: unifying and transforming tools, AICHE J. 50 (2004) 890–897.
[10] M. Roco, Possibilities for global governance of converging technologies, J. Nanopart. Res. 10 (2008) 11–29.
[11] C. Selin, Expectations and the emergence of nanotechnology, Sci. Technol. Hum. Values (2007) 196–220.
[12] A. Nordmann, No future for nanotechnology? Historical development vs. global expansion, in: F. Jotterand (Ed.), Emerging Conceptual, Ethical and Policy Issues in Bionanotechnology, Springer, Netherlands, 2008, pp. 43–63.
[13] P. Schaper-Rinkel, Governance von Zukunftsversprechen: Zur politischen Ökonomie der Nanotechnologie, Prokla 36 (2006) 473–496.
[14] M. Kaiser, S. Maasen, M. Kurath, C. Rehmann-Sutter, Governing future technologies. Nanotechnology and the rise of an assessment regime, in: Sociology of the Sciences Yearbook, Springer, 2010.
[15] R.A.W. Rhodes, Understanding governance: ten years on, Organ. Stud. 28 (2007) 1243–1264.
[16] M. Roco, The long view of nanotechnology development: the National Nanotechnology Initiative at 10 years, J. Nanopart. Res. 13 (2011) 427–445.
[17] K.E. Drexler, Engines of creation, The Coming Era of Nanotechnology, Anchor Press, New York, 1987.
[18] K.E. Drexler, C. Peterson, G. Pergamit, Unbounding the Future: The Nanotechnology Revolution, William Morrow, New York, 1991.
[19] G. Bachmann, Technologieanalyse Nanotechnologie, VDI Technologieanalyse, in: VDI, Düsseldorf, 1994.
[20] POST, Parliamentary Office of Science and Technology Policy, in: Making it in Miniature – Nanotechnology – Report Summery, POST, Parliamentary Office of Science and Technology Policy, London, 1996, p. 4.

[21] I. Malsch, Nanotechnology in Europe: Experts' Perceptions and Scientific Relations Between Sub-areas, Brussels–Luxembourg, Institute for Prospective Technological Studies, 1997.
[22] National Science and Technology Council, Nanotechnology, in: Shaping the World Atom by Atom, 1999, p. 12 S, Washington.
[23] L.M. PytlikZillig, A.J. Tomkins, Public engagement for informing science and technology policy: what do we know, what do we need to know, and how will we get there? Rev. Policy Res. 28 (2011) 197–217.
[24] M. Powell, D.L. Kleinman, Building citizen capacities for participation in nanotechnology decision-making: the democratic virtues of the consensus conference model, Public Underst. Sci. 17 (2008) 329–348.
[25] R. Zimmer, R. Hertel, G.-F. Böl, BfR Consumer Conference Nanotechnology, Federal Institute for Risk Assessment, Berlin, 2009.
[26] P. Dannemand Andersen, B. Rasmussen, M. Strange, J. Haisler, Technology foresight on Danish nano-science and nano-technology, Foresight, J. Futur. Stud. Strateg. Think. Policy 7 (2005) 64.
[27] M. Keenan, R. Barré, C. Cagnin, Future-oriented technology analysis: future directions, in: C. Cagnin, M. Keenan, R. Johnston, F. Scapolo, R. Barré (Eds.), Future-oriented Technology Analysis, Springer, Berlin Heidelberg, 2008, pp. 163–169.
[28] A. Eerola, I. Miles, Methods and tools contributing to FTA: a knowledge-based perspective, Futures 43 (2011) 265–278.
[29] M. Rader, A.L. Porter, Fitting future-oriented technology analysis methods to study types, in: C. Cagnin, M. Keenan, R. Johnston, F. Scapolo, R. Barré (Eds.), Fitting Future-oriented Technology Analysis Methods to Study Types, Springer, Berlin Heidelberg, 2008, pp. 25–40.
[30] A.L. Porter, W.B. Ashton, G. Clar, J.F. Coates, K. Cuhls, S.W. Cunningham, K. Ducatel, P. van der Duin, L. Georghiou, T. Gordon, H. Linstone, V. Marchau, G. Massari, I. Miles, M. Mogee, A. Salo, F. Scapolo, R. Smits, W. Thissen, Technology futures analysis: toward integration of the field and new methods, Technol. Forecast. Soc. Chang. 71 (2004) 287–303.
[31] A. Rip, Futures of ELSA, Sci. Soc. Ser. Converg. Res. 10 (2009) 666–670.
[32] A.L. Porter, W.B. Ashton, United States case study, in: L. Georghiou, J.C. Harper, M. Keenan, I. Miles, R. Popper (Eds.), International Handbook on Foresight and Science Policy: Concepts and Practice, 2008, pp. 154–169.
[33] K. Cuhls, From forecasting to foresight processes — new participative foresight activities in Germany, J. Forecast. 22 (2003) 93–111.
[34] K. Cuhls, A. Beyer-Kutzner, W. Ganz, P. Warnke, The methodology combination of a national foresight process in Germany, Technol. Forecast. Soc. Chang. 76 (2009) 1187–1197.
[35] C. Milburn, Nanotechnology in the age of posthuman engineering: science fiction as science, Configurations 10 (2002) 261–296.
[36] S. Kaplan, J. Radin, Bounding an emerging technology: para-scientific media and the Drexler–Smalley debate about nanotechnology, Soc. Stud. Sci. 41 (2011) 457–485.
[37] NSTC, National Science and Technology Council, Nanostructure Science and Technology, R&D Status and Trends in Nanoparticles, Nanostructured Materials, and Nanodevices , 1999.
[38] M.C. Roco, W.S. Bainbridge, Societal Implications of Nanoscience and Nanotechnology: NSET Workshop Report, National Science Foundation (NSF), 2001.
[39] E. Fisher, Lessons learned from the Ethical, Legal and Social Implications program (ELSI): planning societal implications research for the National Nanotechnology Program, Technol. Soc. 27 (2005) 321–328.
[40] M.D. Cobb, Framing effects on public opinion about nanotechnology, Sci. Commun. 27 (2005) 221–239.
[41] M.D. Cobb, J. Macoubrie, Public perceptions about nanotechnology: risks, benefits and trusts, J. Nanopart. Res. 6 (2004) 395–405.
[42] O. Renn, M.C. Roco, Nanotechnology and the need for risk governance, J. Nanopart. Res. 8 (2006) 153.
[43] D. Barben, E. Fisher, C. Selin, D.H. Guston, Anticipatory governance of nanotechnology: foresight, engagement, and integration, in: O.A. Edward, J. Hackett, Michael E. Lynch, Judy Wajcman (Eds.), Handbook of Science and Technology Studies, MIT Press, Cambridge, Mass, 2008, pp. 979–1000.
[44] D.H. Guston, D. Sarewitz, Real-time technology assessment, Technol. Soc. 24 (2002) 93–109.
[45] NSTC, National Science and Technology Council, Committee on Technology, Subcommittee on Nanoscale Science Engineering and Technology, The National Nanotechnology Initiative: Strategic Plan , 2011. Washington.
[46] M.C. Roco, Environmentally responsible development of nanotechnology, How the U.S. Government is Dealing with the Immediate and Long-Term Issues of this New Technology, Environmental Science & Technology, 2005. (107–112).
[47] I. Miles, The development of technology foresight: a review, Technol. Forecast. Soc. Chang. 77 (2010) 1448–1456.
[48] A. Zweck, G. Bachmann, W. Luther, C. Ploetz, Nanotechnology in Germany: from forecasting to technological assessment to sustainability studies, J. Clean. Prod. 16 (2008) 977–987.
[49] TAB, in: D. Bundestag (Ed.), Bericht des Ausschusses für Bildung, Forschung und Technikfolgenabschätzung (17. Ausschuss) gemäß § 56a der Geschäftsordnung Technikfolgenabschätzung hier: TA-Projekt – Nanotechnologie. Drucksache 15/2713, 2004, p. 232 S, Berlin.
[50] NanoKommission of the German Federal Government, in: W.-M. Catenhusen, A. Grobe (Eds.), Responsible Use of Nanotechnologies: Report and Recommendations of the German Federal Government's NanoKommission for 2008, 2008.
[51] NanoKommission of the German Federal Government, Responsible use of nanotechnologies: report and recommendations of the German NanoKommission 2011, in: W.-M. Catenhusen, A. Grobe (Eds.), Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), 2011, Berlin.
[52] BMBF, Action Plan Nanotechnology 2015, BMBF, Bonn, 2011.
[53] T. Heinze, S. Kuhlmann, Across institutional boundaries?: Research collaboration in German public sector nanoscience, Res. Policy 37 (2008) 888.
[54] ETC Group (Action Group on Erosion, Technology and Concentration), Size matters! The case for a global moratorium. No small matter II, in: Occasional Paper Series, vol. 7, nr. 1, 2003, p. 20S, (Winnipeg).
[55] R.C. Swiss Re, in: Nanotechnology. Small Matter, Many Unknowns, 2004, p. 57S, Zürich.
[56] B. Wynne, Public participation in science and technology: performing and obscuring a political–conceptual category mistake, East Asian Sci. Technol Soc: Int. J. 1 (2007) 99–110.
[57] D. Barben, Analyzing acceptance politics: towards an epistemological shift in the public understanding of science and technology, Public Underst. Sci. 19 (2010) 274–292.
[58] E. Altvater, B. Mahnkopf, The world market unbound, Rev. Int. Polit. Econ. 4 (1997) 448–471.
[59] O. Da Costa, P. Warnke, C. Cagnin, F. Scapolo, The impact of foresight on policy-making: insights from the FORLEARN mutual learning process, Tech. Anal. Strateg. Manag. 20 (2008) 369–387.
[60] U. Felt, M. Fochler, Machineries for making publics: inscribing and de-scribing publics in public engagement, Minerva 48 (2010) 219–238.
[61] K. Braun, S. Schultz, " … a certain amount of engineering involved": constructing the public in participatory governance arrangements, Public Underst. Sci. 19 (2010) 403–419.

Dr. Petra Schaper-Rinkel, political scientist, is a senior scientist and scientific project manager at the AIT — Austrian Institute of Technology in Vienna. Her current research focuses on foresight, governance of emerging technologies, and methods and practices of futuring.