Nanoethics
DOI 10.1007/s11569-013-0168-4

ORIGINAL PAPER

Context Matters: Promises and Concerns Regarding Nanotechnologies for Water and Food Applications

Haico te Kulve · Kornelia Konrad · Carla Alvial Palavicino · Bart Walhout

Received: 17 January 2013 / Accepted: 7 February 2013

Abstract Expectations in the form of promises and concerns contribute to the sense-making and valuation of emerging nanotechnologies. They add up to what we call 'de facto assessments' of novel socio-technical options. We explore how de facto assessments of nanotechnologies differ in the application domains of water and food by examining promises and concerns, and their relations in scientific discourse. We suggest that domain characteristics such as prior experiences with emerging technologies, specific discursive repertoires and user-producer relationships, play a key role in framing expectations of nanotechnology-enabled options. The article concludes by suggesting that domain-specific discourses may lead to undesirable lock-ins into specific de facto assessments pre-structuring anticipatory strategies of actors.

Keywords Sociology of expectations · Nanotechnology · Water · Food · Domain characteristics · De facto assessment

Introduction

Expectations in the form of promises and concerns play a key role in shaping new and emerging technologies such as nanotechnologies. They contribute to the discursive construction of what nanotechnologies and their applications are supposed to be or to become; and they mobilize, legitimate and coordinate concrete activities supporting, shaping or impeding the 'real-world' construction of nano- and other technologies, as has been shown by the 'sociology of expectations' [1].

The close link between expectations and the very understanding of what nanotechnologies are supposed to be or become has been previously examined [2–4]. The so-called Drexler-Smalley debate [5], which featured prominently in early discussions on nanotechnologies, exemplifies how a struggle over the legitimacy of certain promises and concerns may be intricately linked to the question of what counts as nanotechnology, and what as mere 'fiction'. This debate not only shaped what was considered as more or less plausible or desirable developments, but also affected how nanotechnologies have been subsequently perceived, and which concerns are considered to be key societal issues. Nowadays, risks associated with 'grey goo' have been largely dismissed. Specific risks of nanoparticles are, instead, a major topic of debate and subject of research.

The construction of meaning of nanotechnologies by expectations includes more dynamics and often subtler questions of nanotechnologies' essential features than those apparent in the Drexler-Smalley debate, i.e. the delimitation of nanotechnologies by scientific experts. For instance, what are nanotechnologies good for, how do they work, what are the conditions in which claimed benefits might be realized, and which changes may be implied (cf. [6])? The meaning of nanotechnologies may change over time,

H. te Kulve (✉) · K. Konrad · C. Alvial Palavicino · B. Walhout
Department of Science, Technology and Policy Studies, University of Twente, PO Box 217, 7500 AE Enschede, The Netherlands
e-mail: h.tekulve@utwente.nl

Published online: 02 March 2013

and may also differ across types of nanotechnologies and application domains. As we will show in this article, expectations in the form of promises and concerns in different domains of application can be remarkably different. Expectations of specific nano-enabled products will not only need to be tuned to the specific needs and opportunities of an application domain, but will likely also have to link up with discursive patterns in these domains.

The article explores the role of domain characteristics in shaping promises and concerns and how this may affect the meaning ascribed to nanotechnologies. To do so, we first develop an analytical framework drawing upon the sociology of expectations literature, but also beyond. This framework is then used to examine promises and concerns regarding future nanotechnology-enabled applications in scientific discourses in the domains of water (e.g. purification, treatment) and food (e.g. processing, packaging). Both domains are considered as promising fields of application and feature prominently in a number of national nanotechnology research programmes [7, 8]. The envisioned applications in these domains draw for a significant extent upon similar nanotechnology platforms including membranes, nanosensors and antimicrobial particles [9–12]. The domains differ however in discursive repertoires, different prior experiences with emerging technologies, and business models. In the final section of this article we reflect on how the differences we found may affect future development and introduction of nanotechnology-enabled products in these domains.

Promises and Concerns as an Element of the De Facto Assessment of Emerging Technologies

It has been widely acknowledged – in the 'sociology of expectations' rooted in science and technology studies, but also beyond - that expectations play an important performative role in science and technology in general [1, 6, 13–15], and nanotechnologies in particular [3, 16–19]. Expectations regarding the future development and implications of emerging technologies are mostly not presented as neutral statements, merely referring to possible developments, but usually take the form of promises or concerns, implying a positive or negative valuation. By promises we mean optimistic expectations sketching the potential and assumed benefits which may be achieved by a technology, but nevertheless require work to be done. Concerns, in contrast, refer to expectations about possible problems and risks related to the development and application of a technology.[1]

The evaluative element of promises and concerns - implicit or explicit – may be regarded as de facto assessments of emerging technologies. Even if they may not be part of dedicated and explicit assessment procedures, they are an element of an ongoing 'informal technology assessment' [24]. So, expectations in the form of promises and concerns may contribute to the de facto assessment of emerging technologies in two ways. They are indicative of how certain technologies or applications are 'valued' within a certain community (cf. [25]) and at the same time they are part of the ongoing discursive - and eventually material - construction of what is being assessed.

With the move of nanotechnologies into specific application domains such as water and food, the construction of meaning – or sense-making, as we will say further on – is likely to be shaped not only by a specific 'nano discourse', but also by the specific discursive patterns, and the needs, constraints and opportunities of these application fields. These application fields or sectors can be conceptualized as an 'organizational field' meaning "those organizations that, in the aggregate, constitute a recognized area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce similar services or products" [26: 148]. Following Swanson and Ramiller [6], sense-making of a new technology, or innovation in an organizational field, takes place in various 'spaces.' These may include, for example, industry journals, specialized publications, conferences, or more informal conversations. Sense-making is based on meanings and language from a store of cultural and linguistic resources provided by both the subculture linked to the technology and the specific organizational field. Sense-making has to respond to particular business concerns in the application context, and is

[1] In this article we use a rather broad notion of concerns, which does not only refer to risks, but includes concerns about the feasibility of promises as well. Limited attention has, at least to date, been paid to concerns within the sociology of expectations literature [20–23], although generally supposed to fulfil a similar role as promises [1, 22].

enabled and constrained by the core technology and its capabilities and it is eventually formed and reformed in the ongoing interpretation of the innovation's adoption and diffusion [6: 462].

Accordingly, if nanotechnologies are taken up within different fields with distinctive discursive patterns, as well as specific business concerns and opportunities, the meaning of the technology in these fields, as well as the valuation, may be different. Furthermore, meaning and valuation are likely to evolve as nanotechnologies are incorporated into concrete applications and eventually applied. So, what can currently be observed is the very initial stage of this process, which is not likely to be stabilized yet, but may nevertheless give indications about the directions it may take.

A further strand of literature relevant for our theme, which is largely concerned with the public understanding of science, has highlighted the importance of analogies and comparisons drawn from familiar technologies for the sense-making of new and emerging technologies [27–29]. The social and cultural context of a person or group will influence which analogies are mobilized; the analogies chosen are likely to shape the meaning and understanding of the new technology, as well as its appraisal due to the implied moral connotations [29]. While the aforementioned studies investigated the responses of so-called lay people, analogies as a resource for sense-making are likely to be used in expert discourse as well, with the application domain context guiding which analogies are more likely to be mobilized than others.

Finally, for the analysis of sense-making and assessment of emerging technologies by expectations, the *relation* between promises and concerns deserves attention as it contributes to the eventual de facto assessment. A common assumption is that promises and concerns will be directly related in assessments in the form of weighing assumed benefits and risks, so as to counterbalance each other. This assumption is underlying numerous studies from communication and media studies which have investigated the perception of nanotechnologies or particular applications by the public or experts [30–35]. However, linkages between promises and concerns can take various forms. Promises may be valued positively by some, but considered rather problematic by others [36]. Moreover, promises and concerns need not necessarily counterbalance each other, but may also form supplementary relations. On the one hand, perceived risks can build the ground for promises for technologies supposed to mitigate these risks [37]. On the other hand, promises can lay the ground for concerns. That said, a number of authors have criticized that debates about ethical concerns often uncritically build on technological promises [17, 38]. Furthermore, promises and concerns can be positioned as distinct, yet related discourses as part of a debate with a clear proponent-opponent structure (see for instance Kitzinger and Williams [20] for an analysis of the stem cell debate). So, if and how promises and concerns are related to each other, cannot be taken for granted, but needs to be investigated.

Empirical Approach: Promises and Concerns in Scientific Discourse

Our analysis of the promises and concerns surrounding applications of nanotechnologies in the food and water domains draws on a sample of articles chosen from three scientific journals: *Nature Nanotechnology*, *Trends in Food Science & Technology* and *Water Research*. *Nature Nanotechnology* is a leading journal for nanoscience and nanotechnologies and covers basic research as well as technology development for a variety of application domains. Therefore, it ensures a high comparability of the coverage on both food and water. Besides research articles, the journal publishes review and commentary articles which are often more explicit about promises and concerns.

Complementing this nanotechnology-focused journal, we chose two major journals covering research related to food and water science and technology, in order to ensure that we capture the domain-specific discourses. *Trends in Food Science & Technology* is the official journal of the European Federation of Food Science and Technology, and the International Union of Food Science and Technology. The journal, as formulated on the journal's website, aims to 'fill the gap between new scientific developments and their application in the food industry'. *Water Research* is the official journal of the International Water association, and according to their website a 'global network of 10,000 water professionals spanning the continuum between research and practice and covering all facets of the water cycle'. The journal contains publications on water treatment processes for various applications and analysis of water quality. Both journals are leading

in their respective fields. In addition to research articles, *Trends in Food Science & Technology* includes a number of review articles, which are scarcer in *Water Research*. These academic journals can be regarded as public and formalized arenas of discourse, so relevant spaces where sense-making takes place (cf. [6]).[2]

Articles have been selected in a first step by key word search.[3] As attention to nanotechnologies in these journals has increased since 2007, we selected texts from 2007 to May 2012. In a second step, we have manually selected those articles which have nano-based applications in the food and water domain as a major theme and referred to promises and concerns related to these applications.[4] For all articles we identified promise or concern-related statements in the sense explained above. We examined what was considered by the author of the analysed article as promising or an issue of concern, e.g. a particular nano-based application, and what exactly was considered to be promising or problematic. Specific attention was paid to references to more general discourses and to former experiences in the domain. Finally, we considered the overall tone of the text (promissory, neutral, cautious, pessimistic) and how promises and concern statements were related to each other.

Results: Nano Promises and Nano Concerns in the Water and Food Domain

In a first step, we compared if the number of articles which put either promises or concerns differed for the samples of the two domains. In *Nature Nanotechnology*, the majority of articles referring to applications in the water domain are focusing on promises. In contrast, articles referring to applications in the food domain present promises as well, though often more as a background assumption, but largely focus on concerns. In particular, concerns about possible consumer concerns are discussed in almost half of the articles. The domain-specific journals *Water Research* and *Trends in Food Science & Technology* give more emphasis to promises, as illustrated by Table 1.

Looking more closely at the specific promises and concerns voiced for the two application domains, further differences come to the fore.

Nanotechnology-Enabled Water Applications

A major strand in the promissory discourse on nanotechnologies for water presents the technology as being an important element in addressing global challenges. Nano-based innovations are justified as a means to achieve universal access to clean water – in particular, as technologies suitable for developing countries with a need for cheaper and better water supply systems [39–43].

> "Clean and safe drinking water is the basic necessity for the healthy survival of every human being. The world is yet to address this challenge, with the rise in demand for the safe drinking water in developing countries. Bacteria are the common contaminants present in any water body. […] Removal or inactivation of pathogenic microorganism is a demanding task in any water treatment process. […] In this perspective polyurethane containing silver nanoparticles have been investigated recently for water treatment [Ref] which gave a new opening for polymer bound nanoparticles in water purification." [39: 5481-5482]

Occasionally, a link to the broader discussion of 'green' nanotechnologies, capable of improving the state of the environment, was drawn [41]. The technologies and/or applications are presented as having high potential; at the same time some of the articles mention that there are challenges of implementation to be overcome. For instance, difficulties of applying global solutions to different local contexts are expected, including issues of technology transfer and adoption:

> "Many organizations are considering the potential of nanoscience to solve technical challenges associated with the removal of water contaminants and provide 'potable' water to people in

[2] Initially we also explored potential sources for non-scientific discourse as for instance industry (association) journals and mass media. However, it turned out to be difficult to find sufficient coverage for a meaningful analysis, indicating that the discourse on nanotechnology for food and water is only emerging. This holds particularly in the case of water. Furthermore, by concentrating on the scientific discourse we avoided the need to account for national specifics in the discourse, which are likely to cross-cut non-scientific discourses.

[3] NANO + WATER + SUPPLY for retrieving water-related articles, and NANOTECHNOLOGY + FOOD for retrieving food-related articles.

[4] To enhance intercoder reliability, analyses of promise-concern statements were discussed and, if necessary, adjusted between the researchers.

Table 1 Overview reporting on promises and concerns about nanotechnology in water and food domains

	Water Research		Nature Nanotechnology				Trends in Food Science & Technology	
			Water		Food			
	Promise	Concern	Promise	Concern	Promise	Concern	Promise	Concern
2007	0	0	2	1	0	0	1	1
2008	1	0	2	1	0	0	1	3
2009	2	1	0	0	0	1	0	0
2010	3	2	2	0	2	1	3	0
2011	4	2	0	0	0	2	9	4
2012	2	2	0	0	0	1	3	1
Total	12	7	6	2	2	5	17	9

The number of articles in 2011 in *Trends in Food Science & Technology* is exceptionally high due to a special issue

> developed and developing countries. […] However it is not enough to develop technical solutions to these problems – the technology must also be transferred to the country that needs it." [40: 663-664]

A number of articles refer to promises of a general, revolutionary potential of nanotechnologies for the water sector. Yet the majority focus on promises of using nanotechnologies for specific applications as water filtration, removal of pollutants and disinfection for drinking and waste water [39–41, 43–49], biofouling control [43, 50], desalination [42, 51] and sensoring [52]. Partly, the specific promises refer to improvements of existing technologies or applications, due to reduced costs, higher efficiency and less unintended side effects from toxic byproducts of conventional treatment measures – rather than to revolutionary changes in water treatment. Still, a number of articles highlight that nanotechnologies may help to enable decentralized water systems, which differ more radically from conventional treatment measures [42, 43, 46]. For example, Li, Mahendra et al. [43: 4592–4593], suggest that,

> "Another potential application of antimicrobial nanomaterials is their use in decentralized or point-of-use water treatment and reuse system. [..] They are promising for low-cost and low-tech disinfection applications, particularly in developing countries."

Concerns are treated in some of the articles discussing the potential of nanotechnologies for water [40, 41, 43, 53], and in a more dedicated set of literature (more notably in *Water Research*) that deals specifically with aspects of human and environmental toxicity [42, 54–61]. Remarkably, the latter, concern-focused literature does *not* refer to risks related to applying nanotechnologies for water treatment, but to risks which may result from nanoparticles entering water bodies due to their application in various other domains and products. Thus, this literature can be considered as a somewhat separate discourse.

Articles dedicated to nano-based applications in the water domain rarely refer to environmental and health risks [40, 43]. Here, more attention is given to broader concerns related to issues of, for example, markets, costs, technical feasibility, local adaptation, and the appropriateness of technical solutions. If concerns regarding consumers and acceptability of the technology are mentioned, the question is generally framed in relation to the appropriateness of the type of solutions in a specific context of use. Hence, concerns are predominantly presented as requirements that can be studied, understood and solved, rather than major obstacles. Thus, in a way, this type of concerns rather supports the promise by specifying what is necessary for realizing it, rather than putting it into question. Occasionally, concerns about toxicity risks are even turned into promises. This is the case when research results on the toxicity of specific nanoparticles are turned into a promise for antimicrobial applications [43].

With the exception of one article that refers to the widespread analogy between nanotechnologies and

GMO (genetically modified organisms), which emphasizes the limitations of such a comparison, concerns about negative perceptions of consumer were not raised as an issue. The author stated that non-governmental organizations are not strictly dismissing nanotechnologies, and explains this by the "measure of the force of the argument that nanotechnology may lead to new opportunities for sustainable development" [41: 71] Assumedly, linking nanotechnologies strongly with sustainable development implies that drawing at the same time an analogy with GMOs would not be easily compatible, given that sustainable technologies and GMOs are hardly associated in common discourse.

A review paper opened by making a link to former, successfully implemented water technologies, thus framing nano-based treatment technologies in a rather positive way. Still, these conventional disinfection methods are presented as entailing certain risks, with nanotechnologies positioned as a remedy to these risks. So, according to this argumentation, nanotechnologies may not only be able to follow up on this rather successful history, but even do better by avoiding harmful byproducts of conventional methods.

> "Although disinfection methods currently used in drinking water treatment can effectively control microbial pathogens, research in the past few decades have revealed a dilemma between effective disinfection [by chemical disinfectants] and formation of harmful disinfection byproducts (DBPs). […] Unlike conventional chemical disinfectants, these antimicrobial nanomaterials are not strong oxidants and are relatively inert in water. Therefore, they are not expected to produce harmful DBPs. If properly incorporated into treatment processes, they have the potential to replace or enhance conventional disinfection methods." [43: 4592]

In summary, articles referring to a broader societal context mostly frame nanotechnologies for water as a 'sustainable technology' particularly appropriate for developing countries. This framing affects the type of promises put upfront, as well as the type of concerns taken into account: these are largely requirements for ensuring sustainable and – in some articles – also locally adapted technologies, aspects which are arguably related to a more general sustainability discourse. Environmental, health and safety risks (as a result of nanotechnologies), however, hardly enter this discourse, but remain confined to a toxicological discourse that focuses on nanoparticles entering from 'outside' the water systems.

Nanotechnology-Enabled Food Applications

In the promissory discourse on nanotechnology-applications for food we observe a recurring argument about the potential of the technology to affect the food industry in a comprehensive way. Nanotechnologies are expected to have significant impacts on key areas in the food domain: production of food, processing of food, protection and quality assurance of food and the quality of food [62–65].

Promises of nanotechnology-enabled food applications for developing countries are similarly discussed, yet in a broader perspective including agriculture and, as part of that, also water provision (see [66]). Whereas developing countries are one of the most prominent areas for future application in the discourse of nanotechnologies in the water domain, in the food domain developing countries do not feature as prominently.

Similar to our observation for water, the majority of the promises in the food domain focus on specific applications and their claimed beneficial properties rather than on the overall impact of nanotechnologies on the sector. Promises for novel packaging technologies have received most attention. Nanotechnologies are expected to contribute to materials with better, for instance antimicrobial properties; and to 'smart' packaging using sensors to indicate food spoilage [67–72].

In addition to packaging, a range of other application areas are discussed. Nanotechnologies are expected to enable encapsulation devices which protect sensitive food ingredients, improve their solubility and mask unpleasant tastes [73–75]. They enable processing technologies such as particle stabilized emulsions which can contribute to novel food structures which have novel 'mouth sensations' [62, 76]. Nanotechnologies may contribute to highly sensitive sensor technologies to detect food pathogens [77] and may be used to monitor crop growth [66].

With regard to concerns, we find two prominent strands. A major strand is about perceptions and attitudes of consumers towards novel nanotechnology-enabled food applications [63–65]. We found that the strand is largely about the perceptions by advocates of nanotechnologies (such as industry) about possible

negative perceptions of consumers, so concerns about concerns (cf. [78]), rather than examining actual data of consumer perceptions (e.g. see [64, 79]). Expectations about negative consumer responses are supposed to affect the way how the food industry approaches nano-based applications, namely by keeping silent about the respective activities.

> "…it is estimated that up to 400 companies around the world are researching possible applications of nanotechnology in food and food packaging — and many of them don't want their customers to know about this. The committee [UK House of Lords] says that it is "regrettable" that "far from being transparent about its activities, the food industry was refusing to talk about its work in this area." While acknowledging that the food industry is afraid that the public might react negatively to food and food packaging that contains engineered nanomaterials, the committee argues that "this is exactly the type of behaviour which may bring about the public reaction which it is trying to avert." [80: 89]

These – expected – concerns with consumers are presented as potentially endangering the future of nanotechnology-enabled applications for food, if not nanotechnologies as a whole. This perspective is supported by the common reference to past experiences with genetic manipulated foodstuffs. The anxiety about potential negative consumer reactions is often turned into requirements or calls for action for either (improved) communication and interaction with the public [65] or calls for risk assessment of novel nano-enabled products [64].

> "The future prospects of nanofoods are far from certain. In one sense, the mishandling of previous food technology debates (such as GMOs) has put nanofoods at a disadvantage by conditioning the public to distrust the food industry and the oversight system responsible for regulating it. […] it is an open question […] whether a gradual change to exaggerated headlines will lead to ripple effects that endanger not only the future of nanofoods, but also the future of nanotechnology as a whole. What ultimately happens will largely depend on how well we continue to research what drives consumer perceptions and adjust our approach to public engagement in the wake of past failures." [65: 688]

A further strand addresses possible health and safety issues including, for example, the possible migration of nanomaterials in food packaging [62, 67, 70] or possible toxic effects of nanoparticles used to improve taste or the nutritional value of food products [68]. Occasionally other issues are mentioned, such as possible environmental impacts of nanomaterials, i.e. impacts of disposed nanomaterials [67]. In addition, some voices do not refer directly or indirectly to health or environmental risks, but are skeptical about the performance of future products and their economic feasibility [70, 75].

As highlighted above, within the food domain, the wide-spread apprehension about (consumer) concerns are positioned as actually endangering the promise of nanotechnologies for food applications. Still, some concerns are also portrayed as requirements to be met, rather supporting than undermining the promise, if handled properly.

> "Iron and zinc deficiencies often affect the same populations, and these nanocomplexes have the advantage of being able to deliver iron and zinc simultaneously. However, to be successful as food forticants, they should be produced at low cost. Furthermore, before they can be introduced into the human food supply, studies of bioavailability and efficacy in humans should be conducted. Nevertheless, the nanocomplexes, which are bioavailable and non-reactive to food, represent a promising advance in iron forticants." [75: 319]

In summary, concerns about potential health risks – to a lesser extent environmental risks – as well as concerns about potential negative consumer responses clearly play a more prominent role in the food-related discourse than in the water-related discourse. Furthermore, the promise and concern discourses seem to be more related than in the water domain, with linkages appearing both as conflictive and supportive. Finally, the GMO analogy is regularly applied in the sense-making process, whereas sustainability and developmental benefits are mobilized predominantly in the special context of food *and* agriculture.

Discussion: The Role of Domain Characteristics in the Differentiation of Expectations

In our exploratory study we observed that expectations about nanotechnology-enabled applications differ strongly

between the food and water domains, as portrayed within three specific journals. The strong promise for sustainable and developmental applications in the water domain has no equivalent counterpart in the food domain, just as the debate on consumer concerns is, at best marginal, in water. These findings support our assumption that expectations differentiate when nanotechnologies link up with different domains, each having specific discursive repertoires, historical experiences with new technologies and specific business models and concerns.

A number of themes are apparently elements of the repertoire of a general discourse around nanotechnologies, such as potential environmental and health risks of nanoparticles, nanotechnologies for sustainable development, and/or nanotechnologies as the next GMO. However, it is clear that there is no simple diffusion from general to domain-specific discourses. The uptake of the general discursive repertoire is selective and adaptations are domain-specific.[5]

The different historical experiences of actors with emerging technologies in these domains shall play a role in the selective uptake of, or resonance with, particular frames within the general repertoire surrounding nanotechnologies. Actors in the food domain have had concrete experience with the refusal of GMO in food by consumers, whereas this has not been the case for the water domain.

The uptake of promises and concerns regarding nanotechnologies most likely also reflects the specific business models in a domain, that is, the specific ways business is organized and how actors relate to each other. In our two cases, the different position of users in the domains may contribute to explaining our findings. In the food industry, consumer preferences are a major reference point for firms following a paradigm of producing differentiated consumer products. The food industry, therefore, is more likely to be sensitive to potential consumer concerns and perceptions of emerging technologies, particularly in the light of the GMO experience. The water industry, in contrast, generally follows a paradigm of producing commodities in a monopolistic setting where end users are supposed to show little interest in specific characteristics of the product. Defining and assessing product quality is largely delegated to technical experts, with consumers supposed to accept these rather unquestionably, in contrast with the food domain.[6]

The diverging positioning of the potential users in the two domains is apparent in the way how users are presented in our sample. In the food-related, articles users appear as a group with agency, which needs to be taken into account; in the water-related articles they appear as comparatively passive or even a 'non-issue'. In the latter, users are mentioned almost exclusively in relation to applications for developing countries and as part of the legitimatory framing of nano for water as a contribution to address grand challenges, not as part of the core text. These users are not referred to as consumers with specific preferences (besides demanding clean water), but they are mostly presented as large, rather undifferentiated groups of people, referred to as "the poor of the world [40: 663], or "one-sixth of the world population […] lack access to safe water" [43: 4592]. This portrayal indicates that there is probably little consideration who these people exactly are and what they want. Only in the rare cases when experience with the potential users and use contexts are reflected, the aforementioned claim for a need to address specific local preferences are mentioned [40, 41]. Otherwise, users - for instance in industrial countries – are not a topic at all.

In the context of food applications, users are addressed clearly more frequently and they are regularly referred to as "consumers" or "the public" supposed to have specific preferences. Largely consumers from industrialized countries are addressed, mostly in the context of safety concerns and regulation, or expected consumer benefits and requirements. Even in the context of applications for developing countries, the 'domain-typical' framing of users as consumers with specific preferences is generally kept [62].

Conclusions

We showed that domain-specific patterns of promises and concerns in our sample from academic discourses

[5] In addition, within a domain, the arenas in which expectations are voiced and by whom, will affect the substance of expectations. For instance, the tone of articles in the journal Nature Nanotechnology tends to be more promissory compared to the domain journals. While beyond the scope of the present study, it would be worthwhile to study how assessments differ across spaces in a specific domain of application.

[6] There are additional considerations why 'nano-tinkering' with water technologies may be assessed as more desirable than food. Tinkering with food may be considered as unnatural and therefore undesirable, even if much food is nowadays engineered. Purified water may speak to more natural notions of water and therefore desirable.

added up to distinct de facto assessments of nanotechnologies for food and water applications. The assessments differed in terms of sense-making and interpretation of salient features of nanotechnology-enabled applications. At the risk of slightly overgeneralizing our findings, in the water domain nano-based innovations are often characterized as 'sustainable technologies', whereas in the food domain the characterization as 'risky' technologies is very powerful.[7] While partly related to the meaning, the de facto assessments differs furthermore in terms of valuation, exemplified in the specific emphasis given to more optimistic and more skeptical expectations, and as a result of the specific relations between both. In the water domain promises and concerns were either hardly linked, or related in a rather supportive way. Thus, while environmental and health risks and other concerns do play a role in the discourse about nanotechnologies in the water domain, they arguably do not counterbalance the positive de facto assessment of nano-based applications for water. In contrast, in the food domain concerns about negative consumer reactions to some extent counterbalance the promises of nano-based applications for food, to some extent shifting the overall de facto assessment to ostensibly 'risky technologies'. [8]

What do these findings imply for the further introduction and societal embedding of nanotechnologies? Actors' actions and strategies in these domains are likely to build upon these de facto (and other) assessments of nanotechnology-enabled options, as briefly indicated in the discussion of food industry's responses in our articles. Diverging meanings will also impact actors' anticipation of potential issues for the introduction of these technologies, including what currently policy relevant notions of 'responsible innovation' may actually mean in the respective cases. This is likely to pre-structure actual anticipatory strategies. An application which is framed as a 'sustainable technology' such as nanotechnology-enabled water applications may predominantly be perceived as desirable and in need of (adequate) support. When applications are largely framed as ostensibly 'risky technologies' such as nanotechnology-enabled food applications, debates about desirability of such innovations, regulation and risk management will appear as more pertinent issues.

In principle, responsible innovation for emerging technologies such as nanotechnologies is supposed to entail both elements in a balanced way (cf. [81]). However, how it turns out in practice, and where the emphasis will be laid on, will be co-shaped by domain-specific discourses.

In a more critical perspective, this may be seen as a possibly problematic bias, which may lead to neglecting possible risks of supposedly (desirable) sustainable technologies on the one side, or a presupposition of negative consumer reactions, which may turn out differently. So, the domain-specific framing of expectations may lead to lock-ins which are difficult to avoid altogether. This is not, however, a message of despair. Possible undesirable lock-ins into specific framing of future technological options may be avoided or mitigated by critically questioning analogical reasoning and by explicitly opening up the analogical repertoire. Analyst and practitioners may draw on frames from other domains or even other technology fields to broaden their assessments.[9] For instance, in the case of nanotechnology-enabled food technologies, actors may take into account sustainability considerations. Drawing upon other domain discourses may not always make sense, but it is a way to open up and possibly broaden assessments of future technological options.

Acknowledgments We gratefully acknowledge financial support by the Dutch NanoNextNL research programme.

References

1. Borup M, Brown N, Konrad K, Van Lente H (2006) The sociology of expectations in science and technology. Tech Anal Strateg Manag 18(3/4):285–298
2. Rip A, Van Amerom M (2010) Emerging de facto agendas surrounding nanotechnology: two cases full of contingencies, lock-outs, and lock-ins. In: Kaiser M, Kurath M, Maasen S, Rehmann-Sutter C (eds) Governing future technologies: nanotechnology and the rise of an assessment regime. Springer, pp 131–155
3. Selin C (2007) Expectations and the emergence of nanotechnology. Sci Technol Hum Values 32(2):196–220

[7] There are multiple meanings within one domain, but some are particularly salient.

[8] Given the size and scope of our sample the findings should be treated with some caution. Still, core differences have also been corroborated in interviews and talks the authors conducted with experts in the two domains.

[9] For a similar argument in the context of public engagement see [82].

4. Wood S, Geldart A, Jones R (2008) Crystallizing the nanotechnology debate. Tech Anal Strateg Manag 20(1):13–27
5. Drexler KE, Smalley RE (2003) Point-counterpoint. Chem Eng News 81(48):37–42
6. Swanson EB, Ramiller NC (1997) The organizing vision in information systems innovation. Organ Sci 8(5):458–474
7. Federal Ministry of Education and Research (2011) Action plan nanotechnology 2015. BMBF, Bonn/Berlin
8. NanoNextNL (2012) Overview. http://www.nanonextnl.nl/themes.html. Accessed October 10 2012
9. Balannec B, Gésan-Guiziou G, Chaufer B, Rabiller-Baudry M, Daufin G (2002) Treatment of dairy process waters by membrane operations for water reuse and milk constituents concentration. Desalination 147:89–94
10. Bonifacio LD, Ozin GA, Arsenault AC (2011) Photonic nose–sensor platform for water and food quality control. Small 7(22):3153–3157
11. Sekhon BS (2010) Food nanotechnology - an overview. Nanotechnol Sci Appl 3:1–15
12. Van der Bruggen B, Mänttäri M, Nyström M (2008) Drawbacks of applying nanofiltration and how to avoid them: a review. Sep Purif Technol 63:251–263
13. Brown N, Rappert B, Webster A (2000) Introducing Contested Futures: From Looking into the Future to Looking at the Future. In: Brown N, Rappert B, Webster A (eds) Contested futures: a sociology of prospective techno-science. Ashgate, Aldershot, pp 3–20
14. Konrad K, Markard J, Ruef A, Truffer B (2012) Strategic responses to fuel cell hype and disappointment. Technol Forecast Soc Chang 79(6):1084–1098
15. Van Lente H, Rip A (1998) The rise of membrane technology: from rhetorics to social reality. Soc Stud Sci 28(2):221–254
16. Lucivero F, Swierstra T, Boenink M (2011) Assessing expectations: towards a toolbox for an ethics of emerging technologies. Nanoethics 5(2):129–141
17. Nordmann A (2007) If and then: a critique of speculative nanoethics. Nanoethics 1(1):31–46
18. Parandian A, Rip A, Te Kulve H (2012) Dual dynamics of promises, and waiting games around nanotechnologies. Tech Anal Strateg Manag 24(6):565–582
19. Van Merkerk RO, Robinson DKR (2006) Characterizing the emergence of a technological field: expectations, agendas and networks in Lab-on-a-chip technologies. Tech Anal Strateg Manag 18(3–4):411–428
20. Kitzinger J, Williams C (2005) Forecasting science futures: legitimising hope and calming fears in the embryo stem cell debate. Soc Sci Med 61(3):731–740
21. McGrail S (2010) Nano dreams and nightmares: emerging technoscience and the framing and (re)interpreting of the future, present and past. J Futur Stud 14(4):23–48
22. Nehrlich B, Halliday C (2007) Avian flu: the creation of expectations in the interplay between science and the media. Sociol Health Illn 29(1):46–65
23. Tutton R (2011) Promising pessimism: reading the futures to be avoided in biotech. Soc Stud Sci 41(3):411–429
24. Rip A (1986) Controversies as informal technology assessment. Knowl Creation Diffus Util 8(2):349–371
25. Schaeffer GJ, Uyterlinde MA (1998) Fuel cell adventures. Dynamics of a technological community in a quasi-market of technological options. J Power Sources 71:256–263
26. DiMaggio PJ, Powell WW (1983) The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. Am Sociol Rev 48(2):147–160
27. Burri R (2009) Coping with uncertainty: assessing nanotechnologies in a citizen panel in Switzerland. Public Underst Sci 18(5):498–511
28. Davies S (2011) How we talk when we talk about nano: the future in laypeople's talk. Futures 43(3):317–326
29. Michael M, Brown N (2004) The meat of the matter: grasping and judging xenotransplantation. Public Underst Sci 13(4):379–397
30. Petersen A, Anderson A (2007) A question of balance or blind faith? Scientists' and science policymakers' representations of the benefits and risks of nanotechnologies. Nanoethics 1(3):243–256
31. Priest S, Greenhalgh T, Kramer V (2010) Risk perceptions starting to shift? U.S. citizens are forming opinions about nanotechnology. J Nanopart Res 12(1):11–20
32. Donk A, Metag J, Kohring M, Marcinkowski F (2011) Framing emerging technologies: risk perceptions of nanotechnology in the German press. Sci Commun 34(1):5–29
33. Aldrich HE, Pfeffer J (1976) Environments of organizations. Annu Rev Sociol 2:79–105
34. Cacciatore MA, Scheufele DA, Corley EA (2011) From enabling technology to applications: the evolution of risk perceptions about nanotechnology. Public Underst Sci 20(3):385–404
35. Gupta N, Fischer ARH, Van der Lans IA, Frewer LJ (2012) Factors influencing societal response of nanotechnology: an expert stakeholder analysis. J Nanopart Res 14. doi:10.1007/s11051-012-0857-x
36. Swierstra T, Rip A (2007) Nano-ethics as NEST-ethics: patterns of moral argumentation about new and emerging science and technology. Nanoethics 1(1):3–20
37. Brown N, Kraft A (2006) Blood ties: banking the stem cell promise. Tech Anal Strateg Manag 18(3/4):313–327
38. Hedgecoe A (2010) Bioethics and the reinforcement of socio-technical expectations. Soc Stud Sci 40(2):163–186
39. Gangadharan D, Harshvardan K, Gnanasekar G, Dixit D, Popat KM, Anand PS (2010) Polymeric microspheres containing silver nanoparticles as a bactericidal agent for water disinfection. Water Res 44(18):5481–5487
40. Hillie T, Hlophe M (2007) Nanotechnology and the challenge of clean water. Nat Nanotechnol 2(11):663–664
41. Jones R (2007) Can nanotechnology ever prove that it is green? Nat Nanotechnol 2(2):71–72
42. Kim SJ, Ko SH, Kang KH, Han J (2010) Direct seawater desalination by ion concentration polarization. Nat Nanotechnol 5(4):297–301
43. Li Q, Mahendra S, Lyon DY, Brunet L, Liga MV, Li D, Alvarez PJJ (2008) Antimicrobial nanomaterials for water disinfection and microbial control: potential applications and implications. Water Res 42(18):4591–4602
44. Chen G-C, Shan X-Q, Wang Y-S, Wen B, Pei Z-G, Xie Y-N, Liu T, Pignatello JJ (2009) Adsorption of 2,4,6-trichlorophenol by multi-walled carbon nanotubes as affected by Cu(II). Water Res 43(9):2409–2418

45. Dror-Ehre A, Adin A, Markovich G, Mamane H (2010) Control of biofilm formation in water using molecularly capped silver nanoparticles. Water Res 44(8):2601–2609
46. Liga MV, Bryant EL, Colvin VL, Li Q (2011) Virus inactivation by silver doped titanium dioxide nanoparticles for drinking water treatment. Water Res 45(2):535–544
47. Liu L, Liu Z, Bai H, Sun DD (2012) Concurrent filtration and solar photocatalytic disinfection/degradation using high-performance Ag/TiO2 nanofiber membrane. Water Res 46(4):1101–1112
48. Xu B, Li D-P, Li W, Xia S-J, Lin Y-L, Hu C-Y, Zhang C-J, Gao N-Y (2010) Measurements of dissolved organic nitrogen (DON) in water samples with nanofiltration pretreatment. Water Res 44(18):5376–5384
49. Crane RA, Dickinson M, Popescu IC, Scott TB (2011) Magnetite and zero-valent iron nanoparticles for the remediation of uranium contaminated environmental water. Water Res 45(9):2931–2942
50. Celik E, Park H, Choi H, Choi H (2011) Carbon nanotube blended polyethersulfone membranes for fouling control in water treatment. Water Res 45(1):274–282
51. Shannon MA (2010) Water desalination: fresh for less. Nat Nanotechnol 5(4):248–250
52. Li XX, Cao C, Han SJ, Sim SJ (2009) Detection of pathogen based on the catalytic growth of gold nanocrystals. Water Res 43(5):1425–1431
53. Simate GS, Iyuke SE, Ndlovu S, Heydenrych M (2012) The heterogeneous coagulation and flocculation of brewery wastewater using carbon nanotubes. Water Res 46(4):1185–1197
54. Alpatova AL, Shan W, Babica P, Upham BL, Rogensues AR, Masten SJ, Drown E, Mohanty AK, Alocilja EC, Tarabara VV (2010) Single-walled carbon nanotubes dispersed in aqueous media via non-covalent functionalization: effect of dispersant on the stability, cytotoxicity, and epigenetic toxicity of nanotube suspensions. Water Res 44(2):505–520
55. Chun AL (2007) Nanoparticle toxicity: part of the solution. Nat Nanotechnol. doi:10.1038/nnano.2007.421
56. Heinlaan M, Kahru A, Kasemets K, Arbeille B, Prensier G, Dubourguier H-C (2011) Changes in the Daphnia magna midgut upon ingestion of copper oxide nanoparticles: a transmission electron microscopy study. Water Res 45(1):179–190
57. Petosa AR, Brennan SJ, Rajput F, Tufenkji N (2012) Transport of two metal oxide nanoparticles in saturated granular porous media: role of water chemistry and particle coating. Water Res 46(4):1273–1285
58. Sheng Z, Liu Y (2011) Effects of silver nanoparticles on wastewater biofilms. Water Res 45(18):6039–6050
59. Tiede K, Tear SP, David H, Boxall ABA (2009) Imaging of engineered nanoparticles and their aggregates under fully liquid conditions in environmental matrices. Water Res 43(13):3335–3343
60. Zhang H, Smith JA, Oyanedel-Craver V (2012) The effect of natural water conditions on the anti-bacterial performance and stability of silver nanoparticles capped with different polymers. Water Res 46(3):691–699
61. Kiser MA, Ryu H, Jang H, Hristovski K, Westerhoff P (2010) Biosorption of nanoparticles to heterotrophic wastewater biomass. Water Res 44(14):4105–4114
62. Chaudhry Q, Castle L (2011) Food applications of nanotechnologies: an overview of opportunities and challenges for developing countries. Trends Food Sci Technol 22(11):595–603
63. Chun AL (2009) Will the public swallow nanofood? Nat Nanotechnol 4:790–791
64. Cushen M, Kerry J, Morris M, Cruz-Romero M, Cummins E (2012) Nanotechnologies in the food industry – recent developments, risks and regulation. Trends Food Sci Technol 24(1):30–46
65. Duncan TV (2011) The communication challenges presented by nanofoods. Nat Nanotechnol 6(11):683–688
66. Chen H, Yada R (2011) Nanotechnologies in agriculture: new tools for sustainable development. Trends Food Sci Technol 22(11):585–594
67. Bradley EL, Castle L, Chaudhry Q (2011) Applications of nanomaterials in food packaging with a consideration of opportunities for developing ountries. Trends Food Sci Technol 22:604–610
68. Chaudry Q, Castle L (2011) Food applications of nanotechnologies: an overview of opportunities and challenges for developing countries. Trends Food Sci Technol 22:595–603
69. Fernández A, Cava D, Ocio MJ, Lagarón JM (2008) Perspectives for biocatalysts in food packaging. Trends Food Sci Technol 19:198–206
70. Lagaron JM, Lopez-Rubio A (2011) Nanotechnology for bioplastics: opportunities, challenges and strategies. Trends Food Sci Technol 22:611–617
71. Mahalik NP, Nambiar AN (2010) Trends in food packaging and manufacturing systems and technology. Trends Food Sci Technol 21(3):117–128
72. Sorrentino A, Gorrasi G, Vittoria V (2007) Potential perspectives of bio-nanocomposites for food packaging applications. Trends Food Sci Technol 18:84–95
73. Fang Z, Bhandari B (2010) Encapsulation of polyphenols - a review. Trends Food Sci Technol 21:510–523
74. Fathi M, Mozafari MR, Mohebbi M (2012) Nanoencapsulation of food ingredients using lipid based delivery systems. Trends Food Sci Technol 23:13–27
75. Miller DD (2010) New leverage against iron deficiency. Nat Nanotechnol 5:318–319
76. Dickinson E (2012) Use of nanoparticles and microparticles in the formation and stabilization of food emulsions. Trends Food Sci Technol 24(1):4–12
77. Pérez-López B, Merkoçi A (2011) Nanomaterials based biosensors for food analysis applications. Trends Food Sci Technol 22(11):625–639
78. Rip A (2006) Folk theories of nanotechnologists. Sci Cult 15(4):349–365
79. Rollin F, Kennedy J, Wills J (2011) Consumers and new food technologies. Trends Food Sci Technol 22:99–111
80. Nature Nanotechnology (2010) Nanofood for thought. Nat Nanotechnol 5:89
81. National Research Council (2006) A matter of size: triennial review of the national nanotechnology initiative. National Research Council, Washington, D.C
82. Schwarz C (2012) Firing and restricting imagination: tackling the double-edged character of analogies in debates about emerging technosciences. Paper presented at the Fourth Annual Conference of the Society for the Study of Nanoscience and Emerging Technologies, Enschede, The Netherlands, 22–25 October