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Sectoral demand articulation: The case of emerging sensor technologies in the drinking water sector

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ABSTRACT

Demand articulation plays a central role in innovation processes as it reduces uncertainties for innovating firms and offers guidance in innovation processes. Studies into demand articulation processes have mostly focused on users and user-producer interactions and paid less attention to the role of the broader environment in which users and producers are embedded. We conduct an exploratory case study into demand articulation regarding emerging micro & nanotechnology-based sensor technologies for drinking water applications. We trace the occurrence and dynamics of demand articulation processes at a sectoral level. We show that demand articulation processes at the level of a sector fulfill an important function in guiding demand articulation processes of individual and organizational actors. We develop a process model of sectoral demand articulation and discuss the relevance of sectoral contexts in explaining the direction of demand articulation processes.

1. Introduction

The articulation of demands, i.e. the identification, unfolding and specification of visions, requirements and preferences regarding the application of new and emerging technologies, plays an important role in innovation processes. Demand articulation may reduce uncertainty on the side of firms that introduce new products or radical innovations (Fontana and Guerzoni, 2008) and thus guide technological innovations and market introduction (Di Stefano et al., 2012). However, demands may not be clearly defined, particularly in early phases of innovation processes (Hoogma and Schot, 2001; Clark, 1985; Bohlmann et al., 2013; Bettman et al., 1998).

In fact, uncertainty about requirements and preferences of customers are often mentioned by firms as a major barrier to innovation (Edler, 2013: 10). Uncertainties about requirements may lead to 'waiting games' between users and producers (Te Kulve, 2010; Parandian et al., 2012) or cases where markets for specific technologies do not emerge (Jacobsson and Johnson, 2000). What is impeding or supporting the unfolding of requirements is however not always clear. A better understanding of demand articulation processes may lead to insights in underlying difficulties in such processes and to suggestions on how to stimulate demand articulation. The latter is especially relevant for demand-based innovation policies which are receiving increasing attention and of which supporting demand articulation is one of the areas of attention (Edler and Georghiou, 2007; Edler, 2013, 2010; OECD, 2011a).

There is a heterogeneous body of literature which contributed to understanding demand articulation processes (Boon et al., 2011; Tripsas, 2008; Teubal, 1979; Clark, 1985; Aversi et al., 1999; Bohlmann et al., 2013). The role of the environment in which users and producers are embedded for shaping processes and outcomes of demand articulation is typically neglected, even if studies acknowledge the importance of the broader environment around (envisioned) users of new technologies in such processes (Bharadwaj and Dong, 2014; Bohlmann et al., 2013; Boon et al., 2011; Klerkx and Leeuwis, 2008). Studies into demand articulation processes have a tendency to focus on micro-level rather than industry- and field-level dynamics (Peine and Herrmann, 2012; Schot and Albert de la Bruhèze, 2003).[1] This appears at odds with understandings of innovation processes as distributed (Garud and Karnøe, 2003) and systemic in nature (Edquist, 1997; Malerba, 2002). Moreover, demands formulated and recognized at the level of a field are likely to offer an important orientation point for actors in a domain, guiding search and innovation processes (see also 'guidance of the search' processes from a systems of innovation perspective; Hekkert et al., 2007; Bergek et al., 2008). We therefore assume that a broader, sectoral perspective contributes to the understanding of demand articulation processes and may lead to new routes for possible intervention strategies to stimulate demand articulation.

The aim of this paper is to contribute to understanding of demand articulation by developing a process model of field level dynamics in demand articulation. In particular, we explore how demand articulation at field level evolves and influences demand articulation by individuals

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[1] In this paper we understand a sector, such as the drinking water sector, as a particular field and use the terms field and sector interchangeably. See also Section 2.1.

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and organizations. For this we conducted an exploratory case study where field-dynamics can be expected to play a strong role: emerging sensor technologies in the drinking water sector. The drinking water sector is heavily regulated which implies that in addition to sensor suppliers and drinking water companies, regulatory authorities are likely to influence the formulation and legitimation of requirements regarding new (sensor) technologies. Moreover, dynamics and structures at the level of the sector, such as agenda building and regimes will prove to play an important role as emerging micro- and nano-enabled sensors challenge the existing rules and practices in this domain.

We begin with developing a conceptual framework using a co-evolutionary perspective on demand articulation where we take into account the role of actor constellations, emerging technologies and institutional structures such as regimes and regulations. We use this framework to describe and examine demand articulation in our case study. In our empirical work we focus on developments in the Netherlands, a country where many developments around novel sensor technologies have taken place. We focus on contemporary developments and track and trace changes as they occur in demand articulation in order to limit retrospective bias in analysis of these fluid processes. Based on the findings of our case study we develop a process model of demand articulation where we differentiate between field-level (sectoral) and local demand articulation. We conclude by reflecting on the contributions and limitations of our study for understanding dynamics in demand articulation and highlight the relevance of our findings for innovation policies aiming to stimulate and support demand articulation.

2. Sectoral demand articulation processes

2.1. Demand articulation as a co-evolutionary process

Demand articulation is an integral part of innovation processes. It refers to the unfolding of preferences and requirements, and their linking with technological options (Lee et al., 2006: 291–292). Preferences and requirements are neither given or stable, but are constructed during the innovation process (Bettman et al., 1998).

Demands take different forms along the innovation journey and what shapes articulation of demands will change over time as well. During the signaling of and experimenting with new (promising) technological options, demand articulation will largely include anticipatory elements. Individuals and organizations will try to make sense of new technologies, which crystallize into collective expectations (and organizing visions) at the level of the organizational field (Swanson and Ramiller, 1997; Te Kulve et al., 2013). Expectations are commonly recognized to play a major role in science & technology development (Konrad et al., 2017). Here we focus on a specific set of expectations. Suppliers as well as users of novel options develop ‘scenarios of use’ (Konrad, 2008) on how these options might be used in practice and what will be preferred and required by users of these options. Later, during the demonstration of prototypes and market introduction of new options, the requirements and preferences will have become more stabilized and less anticipatory. However, the formulation of requirements may continue during the process of uptake and adoption of new options (Fleck, 1988).

Boon et al. (2008) proposed a broad definition of what can be understood as demands. In their definition they included various demand statements such as expectations, visions, ideas about problems and solutions, needs for current and future products, and concerns about ethical, legal and societal aspects (2008: 647–648). For the purpose of our paper, we will mainly focus on demand statements and articulation processes during early phases of the innovation journey. That is, situations of development of promising new options, sense-making and early experiences with new options.

A second key feature of demand articulation is that the formulation and evolution of requirements do not occur in isolation from the supply side (Leonard-Barton, 1988; Bohlmann et al., 2013; Rip, 1995; Saviotti and Pyka, 2013). Preferences and requirements regarding new technologies thus co-evolve with the development of new technologies (Leonard-Barton, 1988; Bohlmann et al., 2013) and their comparison with alternative options (Garud and Ahlstrom, 1997). Demand articulation can hence be conceptualized as a co-evolutionary process and an instance of the more general perspective of the co-evolution of science, technology and society (Sørensen and Williams, 2002).[2]

2.2. Sectoral demand articulation

Understanding demand articulation as a co-evolutionary process highlights the interactive character of such processes. It is not just a matter of ‘the market’ or ‘the users’. Instead demand articulation processes are “iterative, inherently creative process[es] in which stakeholders try to unravel preferences for and address what they perceive as important characteristics of an emerging innovation.” (Boon et al., 2008: 645).[3] Demand articulation involves both users and producers/suppliers of novel options (Lundvall, 1988; Rip, 1995), but is not limited to these actors. In addition, there can be particular actors such as intermediaries (Boon et al., 2011; Klerkx and Leeuwis, 2008) who shape demand articulation, up to ‘mediators’ (Schot and Albert de la Bruhèze, 2003) who articulate and align user requirement and product features.

In fact, demand articulation is distributed across a variety of actors, in line with perspectives on innovation as being distributed (Garud and Karnøe, 2003) and systemic in nature (Edquist, 1997; Malerba, 2002). Demand articulation is not limited to articulating requirements regarding novel products and their attributes, but also includes articulation of a) how technologies and their related use practices need to be integrated and accepted in specific industrial sectors and markets; b) relevant rules and standards in the sector; and c) advantages, disadvantages and desirability of novel products in a domain of applications (Deuten et al., 1997). These broader aspects related to the introduction and embedding of technologies in a particular domain will be voiced and taken into account by a variety of actors involved in the innovation process.

Understanding demand articulation as a co-evolutionary process and distributed across a variety of actors has implications for the dynamics that play a role here. Evolutionary scholars have already argued for broadening the notion of industry structure and taking more actors and relationships into account such as institutions (Malerba, 2002; Nelson, 1995; Murmann, 2003). Institutions regulate interactions between a variety of actors, which points to the relevance of non-market relationships and transactions. Actors are embedded in practices, organizational routines which exist in particular domains of application. Actors cannot simply do what they please, but are enabled and constrained by institutional structures (Garud and Karnøe, 2003).

This draws attention to emergence and evolution of patterns at a collective level that are associated with, and influence, demand articulation. Literature on, among others, the social shaping of technology and social learning in technological innovation has already pointed to the role of communities, collectives and cultures in the formulation of visions of use, requirements and preferences (Swanson and Ramiller, 1997; Konrad, 2008; Rammert, 2002; Williams and Pollock, 2012). Konrad (2008) investigated how collective repertoires of scenarios of use influenced the articulation of demands in particular development projects.

The interactive nature of demand articulation and patterns at the collective level highlight the relevance of looking at field level dynamics and patterns instead of only individual articulations of preferences and requirements regarding product attributes in order to understand what is happening in demand articulation processes. In this paper we propose to differentiate between local demand articulation processes and

[2] See Geels (2006) for an overview of co-evolutionary processes in a variety of fields.
[3] Original italics removed.

sectoral articulation processes. Local demand articulation refers to individuals and individual organizations voicing demands in interaction with other actors. Sectoral demand articulation refers to the process in which preferences and requirements regarding the application and societal embedding of new technologies are identified, specified and aggregated at the collective level in a particular sector.

In contrast with local demand articulation, statements generated by sectoral demand articulation can no longer be attributed to a specific actor. Sectoral demand articulation generates a repertoire of statements which is widely recognized by actors in a specific sector and largely taken for granted. This is not specific for sectoral demand articulation, but a more general sociological phenomenon, see also Konrad (2006) on collective expectations. Sectoral demand articulation processes result in the formulation of functional requirements, i.e. the role new technologies should fulfill within the context of organizations and their sectoral environment. Exactly how these functions should be fulfilled, for instance according to which specifications, may differ between users and hence will be part of local processes. That being said, sectoral demand articulation can occasionally yield more specific requirements such as specific detection levels for sensors in line with requirements set forth by the current regime. Roadmapping exercises, such as the ITRS roadmap by the semiconductor industry, can be seen as part of sectoral demand articulation.

For the purposes of our paper we adopt the definition of an organizational field to characterize what we mean by a sector. In this definition a particular organizational field is comprised of "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. The virtue of this unit of analysis is that it directs our attention not simply to competing firms (…), or to networks of organizations that actually interact, (…), but to the totality of relevant actors" (DiMaggio and Powell, 1983: 148).[4]

2.3. Evolution of sectoral demand articulation and their effects on local demand articulation

Except for a few studies (Swanson and Ramiller, 1997; Konrad, 2008; Rammert, 2002; Williams and Pollock, 2012), the articulation of demands at a collective, sectoral level has been relatively understudied. Scholars argued that, in general, evolutionary literature on innovation has a tendency to focus on technological change and take demands as a given whereas evolution of the demand-side has received relatively less attention (McMeekin, 2001; Tripsas, 2008; Saviotti and Pyka, 2013).[5] To describe and examine developments in our exploratory case study we can build on a few evolutionary studies to outline an initial conceptual framework to describe how sectoral demand articulation evolves and influences local demand articulation.

Evolutionary studies on technological change and innovation have argued that the generation of variety follows certain patterns. These have been conceptualized as regimes (Nelson and Winter, 1977) or technological paradigms (Dosi, 1982). The more recent concept of socio-technical regimes encompasses rules, be they cognitive, normative or formal, on the user and policy side as well (Geels, 2004; Konrad et al., 2008). Accordingly, demand articulation will also be shaped by patterns at the collective level such as regimes. As explained by Hoogma (2000: 17), "the introduction of new technologies takes place against the backdrop of existing technological regimes. The existence of these regimes sets criteria for a new technology, which translate to preferences of producers, users, and regulators." Regimes give rise to technological trajectories and by way of analogy we will speak here of demand trajectories, referring to the formulation of requirements which is coupled with a specific technological trajectory, cf. Clark (1985) and Van de Poel (2003).[6]

Evolutionary approaches aimed at studying technological change, such as the multi-level perspective (Geels, 2002; Rip and Kemp, 1998; Geels and Schot, 2007), have further elaborated this approach by drawing attention to the background against which regimes themselves evolve and how novelties emerge in the context of a regime which may potentially change the regime. The multi-level perspective (MLP) recognizes patterns in technological change which influence ongoing action and interactions at different layers: niches, regimes and socio-technical landscapes.

These different layers structuring interactions related to innovation can be identified in demand articulation as well. We have mentioned regimes as including criteria for new technologies as well as for preferences and requirements for users and producers. Such regimes exist against the backdrop of broader so-called socio-technical landscapes which are external to the regime and change relatively slowly. Large technical infrastructure, demographic changes, political systems and major societal debates and cultural changes are examples of elements of socio-technical landscapes which may create pressure on a regime or create windows of opportunity (Geels, 2002). As we will show below, changes in such landscapes may also give rise to new preferences and requirements.

Demand articulation may furthermore occur in niches when the development of new technologies and requirements do not 'fit' (Hoogma, 2000) with rule-sets in a regime, but rather challenge or 'stretch' the existing regime. In cases of stretch, actors may struggle to further specify requirements because they meet resistance as a result of regime pressures and/or because they venture into unknown territories and do not have strong reference points which may act as signposts. Such 'stretch' strategies in demand articulation may lead to the emergence of alternative demand trajectories, and typically unfold in protected spaces or niches, the third layer in the MLP perspective (Smith and Raven, 2012).[7] Developments in niches may eventually contribute to changes in regimes.

Thus, the key concepts in MLP can be used to identify forces such as regimes which shape demand articulation processes as well as forces such as landscape pressures or niche developments which may put regimes under pressure. That said, a framework capturing the co-evolutionary process of demand articulation also requires further conceptualization of the specific dynamics on the (demand) selection side.

McMeekin's (2001) study on chlorine offers a useful starting point for offering a general conceptualization of the emergence and unfolding of sectoral demand articulation by focusing on the selection or demand side. McMeekin showed how the selection environment changed as a result of a controversy around chlorine in which industrial as well as non-industrial actors such as Greenpeace participated. Discussions between various actors in the sector changed common assumptions about which issues are seen as important and how they should be addressed. The changed selection environment in turn influenced demand for chlorine and alternative products.

Thus, local discussions between actors can aggregate, adding up to a specific shared repertoire of application concepts, related requirements and preferences which are broadly acknowledged in a particular sector, though not necessarily shared in the sense of agreed upon (Konrad,

[4] See also Granovetter and McGuire (1998) and Malerba (2002) for similar understandings of what constitutes a sector.

[5] There are important exceptions where conceptualizations of technological supply and demand are linked such as in work on value networks (Peppard and Rylander, 2006; Christensen and Roosenbloom, 1995). See also Adner and Levinthal (2001), Tripsas (2008), Saviotti and Pyka (2013).

[6] Tripsas (2008) introduced the notion of preference trajectories, which include both incremental and discontinuous changes. In case of discontinuous change we prefer to speak about different trajectories, to highlight the branching of different technological options and underlying criteria or rule-sets.

[7] In this paper we take a broad view on niches. Whether technologies and demands developed in niches eventually may fit or stretch the regime is determined at a later point in time; see also Schot and Geels (2007) on different niches.

2008). Such aggregation processes are informal agenda-building processes (Van der Meulen and Rip, 1998). Put differently, aggregation of demand articulations at a local level can add up to sectoral demand articulation. One can see here analogies with how niches evolve (Geels and Raven, 2006: p. 379).

In addition to aggregation processes there may also be dedicated occasions where preferences and requirements regarding new technologies are discussed at a collective level and agendas are built. Characteristic spaces for demand articulation at a collective level are fora such as conferences, cf. Garud (2008), meetings organized by standardization organizations, associations such as branch organizations, and stakeholder working parties working on topics which address the whole sector. Sectoral demand articulation, then, is an emergent and aggregated outcome of ongoing interactions and articulations at the local level as well as the result of dedicated attempts to articulate demands at the collective level.

The content of demands in both sectoral and local processes is also influenced by the actors that are involved in demand articulation in a certain time period. The interactions contributing to demand articulation are shaped by characteristics of the technologies involved (Nahuis et al., 2012) and the distribution of roles between users and producers in innovation processes in a particular application domain (Van de Poel, 2003). We expect that especially in early phases of technology development interactions start between developers/designers and users, and gradually involve more actors, such as user organizations involved in implementing new technologies up to regulatory authorities and standardization organizations, cf. Deuten et al. (1997). The involvement of additional actors is likely to give new impetus to demand articulation processes.

When sectoral demand articulation occurs at a collective level, it is likely to fulfill a guiding function by offering orientation for further articulation at sectoral and local levels, similar to the roles expectations are known to play in science & technology development. The existence of a repertoire does not necessarily mean that demand articulation follows only one direction and that application concepts and requirements converge. Demand articulation may also lead to divergence and opening up of new trajectories (Konrad, 2008). As the agenda and repertoire plays on the field level they have some authoritative force. Actors cannot easily neglect it, but local demand articulations will not be fully determined by it either.

Given the existence of niches, regimes and socio-technical landscapes as patterns shaping demand articulation, which forces may then generate changes in the evolution of demand articulation?[8] Tripsas (2008) in her study on the evolution of preferences identified a range of forces driving changes in preferences and requirements, in line with the claims of the multi-level perspective. First, she identified changes in the socio-political environment, such as new laws or political unrest. Secondly, she identified changes in the socio-technical system, such as changing interdependencies between elements of a socio-technical system or issues that require new functionalities or performance improvements. Thirdly, she identified changes on the consumer side such as changes in consumer organizations or the discovery of new uses of technologies which may shift preferences. We add here that in cases of business users, changes downstream the value chain, such as changes in customers' customers and their competitive environment may also generate changes in requirements for novel technologies, see also Bohlmann et al. (2013). Fourthly, Tripsas identified dedicated actions by producers to change preferences as another set of forces. Firms may undertake dedicated action to change preferences of customers, for example by advertising or the creation of standards. All identified forces can be considered to reshuffle the selection environment of new technological options.

[8] Process dynamics such as negotiation and co-ordination also influence the unfolding of demands. For a detailed discussion of (micro-level) mechanisms and demand dynamics see Boon et al. (2008, 2011) and Aversi et al. (1999).

Evolutionary studies on innovation thus offer a number of concepts and patterns to describe and examine the evolution of sectoral demand articulation and its effects on local demand articulation. In our empirical study on demand articulation of sensors for drinking water applications we will use these conceptual building blocks to describe and examine demand articulation in our case study and develop a more detailed process model of demand articulation.

3. Research site and methods

We used the conceptual framework developed in the previous section to examine demand articulation in the case of emerging sensors for drinking water applications. This case can be expected to be a rich site for exploring the occurrence and effects of sectoral demand articulation. In addition to (professional) users and producers of new technologies, also policy makers and inspection authorities, and to some extent end-users are involved in formulating preferences for sensor applications. The variety of actors indicates the need for taking a broad perspective on demand articulation processes. Secondly, the drinking water sector is heavily regulated and new technologies such as sensors need to comply with existing rules and practices, or these need to be adjusted in order to facilitate introduction of novel sensors. Such developments go beyond local discussions on requirements for sensor applications, which imply that collective dynamics are important as well. We start with introducing the role of sensor technologies in the drinking water system and identify some particularities for the Dutch case which put limitations on the generalizability of our findings.[9] We then present the research methods applied to trace and analyze sectoral demand articulation.

3.1. Introducing sensors & the drinking water sector in the Netherlands

The development and introduction of sensors for real-time measurement of water quality or water quantity is not a goal in itself. Sensors are part of a larger socio-technical system, the production and distribution of safe and high quality drinking water. Currently, water quality is predominantly monitored by sampling and lab-analysis following procedures prescribed by detailed regulations and company policies. This means that in practice water quality can only be determined in retrospect. One of the main advantages associated with sensor technologies is on-line or real-time data acquisition which is expected to enable quicker interventions to steer water quality and safety. There are four main application areas in the drinking water production and distribution chain: (1) sensors as early warning systems near drinking water sources, in particular at places with rapid fluctuations of water quality such as surface waters; (2) sensors in process and control systems in production plants in order to optimize the use of resources; (3) sensors to monitor and intervene in the distribution network. Sensors may also be used for asset management purposes such as monitoring the conditions of pipes; and (4) sensors at the site of consumption of drinking water.

Since the 1960s many research initiatives and activities on the development and implementation of novel sensor technologies have been carried out. Currently more than 250 companies around the globe supply instruments and around 100 parameters can be measured (Van den Broeke et al., 2014). Existing technological platforms include solid state technologies, gas or liquid chromatography, UV light and, relatively recent, biomonitors such as algal and fish monitors (Storey et al., 2011). Sensor technologies to measure parameters such as pH, conductivity, temperature, turbidity are by now widely used (Storey et al., 2011).

[9] We focused on sensors in relation to the quality of water. Sensors measuring water quantities, or sensors used for asset management purposes were not considered.

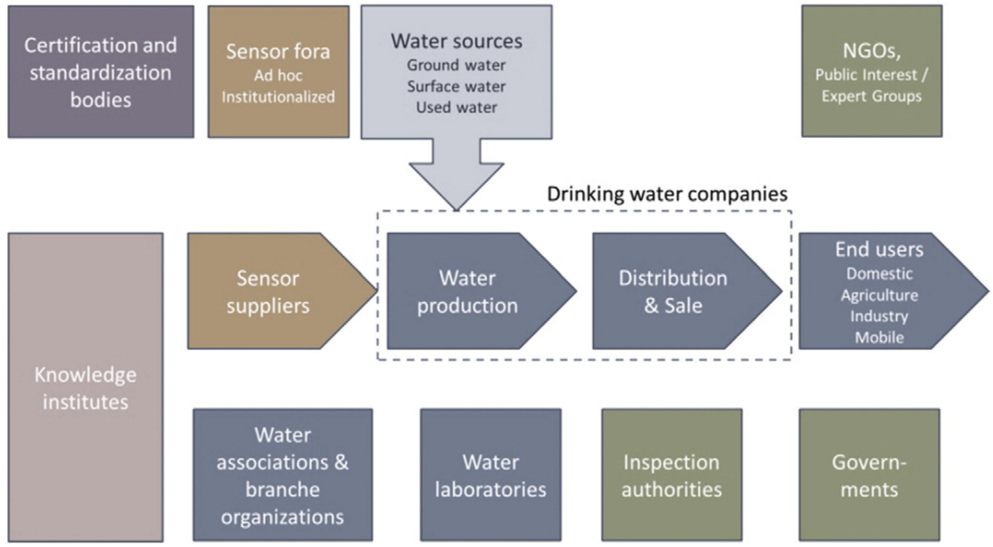

Fig. 1. Overview of the Dutch drinking water sector.

Currently, other technologies are explored to use sensors in distribution networks (rather than in water sources or in treatment plants), including sensors for monitoring the condition of water pipes (Liu and Kleiner, 2013). Emerging technologies in this area include hydrogels, lab-on-a-chip devices, fibre optics, and interferometry technologies (Banna et al., 2014). New sensor technologies enabled by micro- and nanotechnologies are expected to offer innovative solutions via miniaturization, high sensitivity and specificity, and speed of measurement (OECD, 2011b; Ahmed et al., 2014; Lagarde and Jaffrezic-Renault, 2011). In addition to the development of sensors, research is conducted regarding optimal placement strategies for sensors, data retrieval and handling (Banna et al., 2014; Storey et al., 2011).

In the Netherlands, several research projects have been conducted regarding the development and application of sensors for drinking water monitoring. Drinking water companies have been actively involved in such activities. While a rich case, it has particular conditions which can be expected to shape demand articulation processes in a specific way compared to other countries and therefore limit generalizability of our findings. In the Netherlands, the supply of high quality drinking water is largely taken for granted by customers and a majority of customers do not believe that quality needs to be improved (Van der Kooij et al., 2010). Given the relatively limited influence of consumers as captive consumers of products from water companies, and their high appreciation of water quality, one can expect that consumers' preferences do not act as a strong driving force for improvements of the production and distribution system via sensors. This constitutes an important framework condition which may motivate water companies to either maintain the high quality, or rather refrain from action as there is no outspoken urgency to do so. The latter case may impede the unfolding of sectoral demand articulation (e.g. little agenda building at collective level). Secondly, the production of drinking water is in public hands, concentrated in terms of companies and monopolized. The structural setup of the Dutch drinking water sector may support facilitation and co-ordination of demands relatively more easily compared to more fragmented and competitive contexts. Furthermore, knowledge institutes such as KWR Watercycle Research, with the water companies as shareholders, and WETSUS, offer arenas for co-ordination and mediation junctions for demand articulation processes. In more competitive and less co-ordinated areas, agenda-building and the construction of a shared repertoire may be more difficult to emerge. In Fig. 1 we offer an overview of the drinking water sector indicating the main involved actor groups.

3.2. Research methods

The research is based on a study of demand articulation processes as part of a broader project tasked with supporting ongoing demand articulation of stakeholders involved with novel micro- and nanotechnology enabled sensor applications. While the aims of the broader project (see also (Te Kulve and Konrad, 2017) are backgrounded for this paper, they informed the approach of the study and suggested the use of interactive research methods and a focus on contemporary data rather than for instance long term data collection and analysis. For the project we drew upon Constructive Technology Assessment (CTA) (Rip and Te Kulve, 2008a; Schot and Rip, 1997; Rip et al., 1995; Schot, 1992), a broadly acknowledged approach within the field of technology assessment studies. This approach was particularly suited for the project as it combines analysis and intervention-oriented approaches where dialogues between stakeholders and demand articulation play a key role, see also Schot and Rip (1997).[10]

For the study of local and field level demand articulation processes, the approach also implies some limitations. The use of interviews and workshops, as explained in more detail below, offers insights into preferences voiced by individuals and organizations, and indirect insights into the evolution of sectoral processes. Respondents' accounts of changes over time can be compared with other respondents' assessments and reports sketching long-term developments. However, a more systematic longitudinal research of documents revealing preferences of actors in the sector, or long-term observations of field level developments would supposedly yield a more comprehensive and more robust data set on local and sectoral demand articulation processes. Still, the methods used offer solid indications on the evolution of local and sectoral demand articulation processes which is appropriate for the explorative aims of this paper.

To capture both local and field-level developments, including their interactions, we conducted semi-structured interviews and organized a stakeholder workshop on demand articulation & sensors. The interviews and workshop offered insights in the main dynamics at the time

[10] CTA aims at improving the reflexivity of actors involved in innovation processes. Typically this occurs through involving additional stakeholders in the innovation processes and including more perspectives and values. The involvement of and interactions with actors occurs on the basis of a close understanding of the dynamics of technology development and its implementation in society (Rip and Robinson, 2013; Te Kulve and Rip, 2011). For the analysis of technology dynamics CTA draws, among others upon evolutionary approaches (Schot, 1992; Rip and Te Kulve, 2008b).

and what was topical in terms of demand articulation for sensors in the drinking water sector. The field work was conducted from April to November 2013. 14 semi-structured interviews were held with organizations involved in sensor research & application in the drinking water sector, with each lasting approximately 1 to 2.5 h, see Table 1. The interviews inquired into the interviewees' requirements regarding future sensor applications. The interviews explicitly focused on organizations' considerations regarding these requirements, i.e. what they took into account when formulating requirements, whether this has changed and whether there have been specific developments in the water sector which influenced these requirements. A list of interview questions can be found in the Appendix A.

In order to be able to cross check field-level developments identified in the interviews with broader developments in the field, we gathered a set of reports and documents reviewing sensor developments in the drinking water sector. We examined scholarly reviews on sensor developments for water quality monitoring, and reports issued by water research institutes such as the Dutch national water research institute KWR and the globally oriented Water Environment Research Foundation. In addition, we attended conferences related to sensors and retrieved presentations from other conferences.

As part of the overall project a stakeholder workshop was organized to foster dialogues between participants representing the main actor groups in the drinking water sector. This was done in order to learn about different values and perspectives related to sensor applications as well as to formulate strategies to further demand articulation and innovation of sensors. While the workshop was designed to address the aims of the broader project, it also supported the analysis for the research in this study and was therefore included in our dataset. The discussions captured the existing agenda for sensors and in that way helped us to gain further insights into the dynamics of demand articulation by comparing them with what we learned from the interviews and document analysis. For instance, discussion questions were formulated which asked about priorities on the field level and their implications for requirements and future strategies regarding the implementation of sensors in the drinking water sector. In Appendix A an overview of the setup of the workshop can be found.

The workshop and 13 out of 14 interviews were recorded and transcribed. These documents, together with the field-level documents and notes of conferences, were examined with help of the software package Atlas.ti. We conducted a content analysis (Krippendorff, 2004) of these documents where we coded among others local demand statements, widely acknowledged demands, as well as considerations and drivers underlying these statements. In our analysis we aimed at identifying patterns in the data set and analyzed it drawing on the conceptualization in Section 2. For instance, do we observe indications for regime characteristics explaining a particular set of statements, do we see instances where statements are not aligned with regime characteristics and how are these dealt with? In this way we followed a 'directed content analysis' approach, that is, we used a prior conceptual framework to code the text, with the aim of 'validating and extending the framework' (Hsieh and Shannon, 2005). This analysis formed the basis for the construction of a rich narrative about what was happening in terms of demand articulation regarding sensors for drinking water applications in the Netherlands during the period of our empirical inquiry.

Table 1
Interviewed organizations.

Organization	# interviews
Drinking water company	4
Sensor company	4
Knowledge institutes (academic, private, semi-governmental)	3
Drinking water laboratory	1
Governmental agency	1
Non-governmental organization	1

4. Case study sensors for drinking water

In this section we present the main findings of our case study. Iterating between first readings and interpretation of our data and our conceptual framework, we zoomed in on two major developments in sectoral demand articulation in our case. We traced the emergence and effects of a collective repertoire and agenda regarding sensors, as well as the emergence of impasses and blockades in demand articulation processes.

4.1. On-line sensors moving on the agenda in the drinking water sector

Present day interest in sensor technologies in the Netherlands is shaped by a number of political and technological developments. These developments have contributed to a particular repertoire of preferences and requirements and moved sensors on the agenda of the sector. In this subsection we examine salient dynamics at the sector level which have contributed to the emergence of this agenda and repertoire since the 2000s.

Sensor developments can be traced back to developments in the 1960s and 1970s when sensors were first introduced as equipment in laboratories to speed up measurements (Van den Broeke et al., 2014). Later, these instruments were also used outside the laboratory to offer real-time data, without the need for sampling and analysis in the lab. Experiments with sensor technologies in the latter part of the 20th century were not always seen as successful. According to Van den Broeke et al. (2014) following early experiences with sensors, these have been considered as unreliable, complex and lacking in performance. This early assessment contributed to the widespread belief in the (international) water sector that sensors are not trustworthy. The large amount of data generated by these sensors, and challenges in handling and interpreting such amounts are also seen as challenges by water companies, who tend to highlight risks rather than opportunities (Van den Broeke et al., 2014).

Present interest in sensor technologies has been triggered by a number of critical events at the landscape level. Interviewees from a water laboratory and a knowledge institute pointed out that the aftermath of the attacks on 11 September 2001 ('9/11') contained a host of security measures in the United States which spilled over to other countries including the Netherlands. While arguably security has always been an important topic for the drinking water sector, one of the effects of '9/11' was the (heightened) attention for vital infrastructures such as the supply of drinking water. An indication for this was the establishment of a national project in 2002 to examine security of the drinking water production and distribution system. It resulted among others in improved physical security measures (fences, cameras). It also stimulated articulation of requirements regarding early warning sensors for contamination of drinking water quality with an emphasis on sensitive and specific measurements. The attention for possible malicious contamination of production locations and water distribution networks inspired many sensor research projects according to an interviewee, a project manager on safety and security of drinking water at a knowledge institute.

> That [start of interviewee's job] was about one year after 9/11, when the drinking water supply was identified as one of the sectors which

> could be threatened. […] Nowadays, they [drinking water facilities] are protected through fences and access security. […] Another question is, what if despite these measures the distribution network is contaminated? […] The usual procedure of sampling and lab analysis will not work of course. Then you need something which gives a rapid response, preferably in the range of minutes or even faster. And then you quickly end up in the field of sensors. […] Approximately ten, fifteen or twenty years ago this was not an issue […] That is, the question of security and sensors. […] Exactly because from the viewpoint of security, this [demand for sensors] has received a considerable boost in the sector. And this means that also from the sector this demand emerged and that various companies responded with the development of these technologies. *Interviewee 1, knowledge institute*[11]

This suggests that agenda building at the sectoral level indeed offered some guidance for more local articulations. The exact extent to which '9/11' has influenced already ongoing demand articulation for, and developments in, sensor technologies cannot be inferred from our data set. What is clear though is that these events, and associated agenda-building and repertoires, are used as a legitimization for the formulation of demands for novel sensor technologies at the local level.

Technological developments in sensor technologies were a further stimulus to demand articulation, showing the role of technology development in co-evolutionary demand articulation processes. An interviewee, an advisor at a drinking water laboratory, pointed out that there may not only be a growth of contaminants in real terms, but also a growth of known contaminants due to more sensitive analytical tools.

> I believe that this [trend toward sensors, online measurements] is due to the development of technologies. And due to the development of problems, problem materials. You can increasingly perform better measurements, also chemically. You can measure more substances and then find out that there always are more substances. And that implies that in some situations it may also be necessary to measure more frequently, measure better.*Interviewee 2, drinking water lab*

Interviewees noted that the emergence of novel sensor technologies for drinking water generated interest in exploring whether these technologies could be used for day to day operations in the drinking water sector and for more general quality monitoring purposes. Over time, using sensor technologies for monitoring drinking water quality has become firmly on the agenda, a 'need' which to some extent has become taken for granted in the sector. This is visible in the strong presence of sensoring aspects in the innovation themes of water companies and drinking water labs in the Netherlands (Kronemeijer et al., 2014) and in the attention for sensors in the knowledge and innovation agenda of the Dutch 'top sector' Water (Reitsma and Van der Hoek, 2015).[12] In fact, a number of sensors have already been applied in the field for some time in various stages of the drinking water supply chain (Van der Gaag and Volz, 2008). An interviewee, an advisor at a drinking water laboratory, observed a general trend towards sensors:

> For years and years we measure for example turbidity online, which we called field monitors. Now we call them sensors. […] Currently, the demand, the trend is to expand this portfolio of 4–5 parameters to 20 or more. The trend is that you want to measure more online. Preferably you have continuous insight in your water quality, everywhere. That is what you want."*Interviewee 3, drinking water lab*

A number of criteria which sensors are supposed to fulfill, have been formulated against the backdrop of a monitoring regime which has specific criteria and practices such as frequency and type of measurements as well as measurement methods. The existing regime thus influenced formulation of requirements and preferences. Major design criteria for sensors are sensitive, specific and robust (no false alarms) measurements, ideally also with little maintenance work, which support rapid interventions in and steering of water quality. Such criteria are in line with the current monitoring regime where measurements are done in sophisticated laboratory facilities and where great value is placed upon sensitive and specific measurements by actors across the sector. This holds particularly for sensors envisioned to play a role in 'normal' quality assurance, comparable to current lab capabilities. For sensors envisioned with an early warning role, requirements regarding sensitivity are different when considering water qualities which pose an immediate danger for public health (Tangena et al., 2011). The design criteria for sensors, in line with the present regime, have become part of the collective repertoire in the sector. In our interviews, reflecting earlier negative experiences with sensors (see above), actors clearly placed a lot of emphasis on robustness (no false positives/negatives) as a requirement for sensors. This was deemed essential before further steps could be taken to introduce novel sensors in the organization of water companies.

> Thus on the one hand you are looking for sensors that are sufficiently sensitive. That is always the balance: they need to be sensitive and robust. They should not generate false alarms. That will eventually determine reliability.*Interviewee 3, drinking water lab*I would like to keep the attention fixed on robustness and reliability of sensors. I believe that that is also an important aspect.*Interviewee 5, drinking water company*

Even if actors recognize the agenda and its repertoire such as on-line measurements in the distribution network, not all actors in the sector agree. An interviewee, a director at a drinking water company, noted differences in opinion regarding sensoring and offered some critical reflections. This interviewee emphasized the use of sensors in the production of drinking water rather than in the use of sensors in the network. Sectoral demand articulation may offer directions but does not determine local demand articulation processes:

> Everybody has his own ideas. Personally I do not believe in sensoring in the distribution network. But I do believe in improved sensoring in production locations because one can immediately intervene in these locations. As for the distribution network, well, what are you going to do [in case of contaminations]? Are you going to shut down the water supply, is the sensor malfunctioning? In the end you are only left with questions. And what is the problem that we need to solve? Is that only about data gathering? […] A terrorist attack in the network, to mention something? If you start to calculate on this… I do not see this happening, but you never know.*Interviewee 6, drinking water company*

Developments inside and outside the drinking water sector then have contributed to agenda-building regarding sensor technologies. Secondly, they have contributed to the emergence of a repertoire of functional requirements regarding sensor technologies (e.g. reliable, enabling interventions), which is broadly recognized in the sector, though not necessarily shared by all. In Table 2 we offer an overview of major events and developments, responses of the drinking water sector and their effect on demand articulation for sensor technologies.

4.2. A new trajectory in demand articulation

Sensors for monitoring quality and safety are by now established on the 'demand agenda' of the drinking water sector. General design criteria such as sensitivity and specificity are recognized as important.

[11] The quotes were translated into English by the authors.

[12] In 2011, the Dutch government launched a new policy to stimulate the Dutch knowledge economy. Part of the policy is the selection of 9 domains, 'top sectors', including water, as focal areas.

Table 2
Building of a field-level agenda and collective repertoire on sensors.

Category	Description	Coping strategies in the water sector	Effects on demand articulation for sensors
Critical event at landscape level	Perceived terrorism threat (particularly in early 2000s, now less prominent)	Physical security measures (gates, fences) Monitoring source and distribution network contaminations via sensors Physical security is sufficient, threat is marginalized	Encourages exploration of requirements and possibilities of early warning sensors at source and sensors detecting anomalies in distribution network For others :no urgency to articulate new requirements
Emerging technologies/ materials in the sector	Ongoing production and introduction of new materials. Novel measurement technologies enable detection of (new) contaminants	Reconsidering priority list monitoring contaminants Developing sensors to monitor effects, detect anomalies No additional monitoring actions ('we're doing fine')	Difficulties to determine which for parameters to be measured on-line, at which levels of sensitivity Develop requirements for increasingly sensitive biomonitors Develop requirements for 'fingerprint' sensors For others: No urgency to articulate new requirements
Institutional changes in the sector	Impracticality of measuring all possible parameters, and difficulties to measure sensitive and specific. Thinking in terms of infection risks rather than monitoring compounds and organisms.	Calls for and implementation of water safety plans by water companies, possible up take in EU drinking water regulation	Opens up new ways of thinking about water quality management which may lead to exploration of requirements and possibilities of sensor applications
Critical events in the sector	Unexpected contaminations of water sources	Developing regulation, measures to prevent incidents (e.g. improve surface water quality, prevent *Legionella* outbreaks). Development of sensor technologies to detect specific contamination such as *Legionalla*	Encourages exploration of requirements and possibilities of sensor technologies for (early) warning
Emerging technologies (in niches)	Negative experiences with using novel sensors in the past	Distrust sensors Emphasis on experimentation and validation.	No urgency to articulate sensor requirements (because of lack of trust Emphasis on robustness as major design criterion
	Advances in novel sensor technology developments in water sector and other sectors areas generates interest in exploring possibilities	Experiments with novel sensor technologies Initiating R&D projects	Encourages exploration of requirements and possibilities of variety of sensor applications

Table 3
Demand trajectories of water quality sensors[a].

Demand Trajectory	Guiding principle	Functional requirements	Examples	Challenges for further specification of requirements
Parameter-based process monitoring	Enhanced process steering at lower operating costs	Sensors used to optimize production and distribution processes.	Monitoring pH, water hardness and oxygen during purification.	• Validating functionality and robustness • Demonstrating business value (costbenefits)
Parameter-based water quality monitoring	Rapid intervention in case of quality issues	Sensors that measure legally required parameters.	Monitoring basic parameters such as pH, turbidity, conductivity and specific chemical and biological parameters in the distribution network.	• Sensors not comparable to lab analysis • Certification and regulatory acceptance • Demonstration of value • Choice of parameters
Deviation-based water quality monitoring	Rapid intervention in case of quality issues	Sensors that monitor toxicological effects of contaminations in water and provide an early warning function.	Monitoring trends in basic parameters or fingerprints of water quality and the detection of anomalies in experimental settings in the Netherlands and Singapore.	• Acceptance of sensor principle and interpretation of results • Demonstration of value • Certification and regulatory acceptance • Implications for response protocols
Effect-based water quality monitoring	Rapid intervention in case of quality issues	Sensors that monitor water quality trends and provide an early warning function	Biological monitoring devices for water intake such as via *Daphnia*-toximeter, *Algae*-toximeter.	• Validating functionality and robustness • Implications for production process and response protocols

[a] Adapted and modified from Te Kulve and Kronemeijer (2014).

Yet further specification of these criteria and functional requirements regarding their implementation in drinking water companies and the sector more broadly is lacking. Different perceptions on the need for sensors, challenges in the development of sensors and the processing of big data generated by sensors will most likely interfere with formulating requirements. Here, we highlight the puzzles on the sectoral level which contributed to impasses in demand articulation.

For a long time sensor research focused on "ever more specific and sensitive sensors" (Van den Broeke et al., 2014: 187). Since a few years, a number of sensor researchers and water companies have departed from the major design criteria in the collective repertoire regarding sensitivity and specificity, and point out that they do not believe in this route of requirements (Kronemeijer et al., 2014). A new demand trajectory has emerged around 2008 (Volkers, 2012) which added a new storyline to the collective repertoire. Instead of developing sensors to measure new parameters and reach higher levels of sensitivity, research efforts have shifted towards developing sensors to measure deviations in water quality (Van den Broeke et al., 2014). This new, deviation-based trajectory is recognized, though not shared by all actors. This is not surprising considering that this new option departs from the existing regime which emphasizes sensitivity and specificity. Instead of the earlier fit-strategies in demand articulation, this approach deviates from or 'stretches' the current regime.

This diverging demand trajectory draws on discussions in the water sector about the parameters which should be measured (at all) and how unknown contaminations should be handled. There is a dilemma insofar as the choice for measuring specific parameters excludes monitoring other contaminants, which might just be the contaminations which are spreading through the water distribution network. A further and major reason behind the emergence of this novel trajectory is the expectation that sensor technologies that can detect all contaminants, and detect them at very low levels will be very difficult to achieve, if at all. Current sensor technologies are 100–1000 times less sensitive than required by regulation. This will pose significant challenges for the introduction of sensors meant to replace existing approaches as authorities would require evidence that the new sensors perform equally or better than conventional approaches (i.e. as done within the labs).

The deviation based trajectory is an alternative approach to monitoring water quality with sensor technologies rather than with lab-based equipment. There are further approaches to use sensors in water quality monitoring in addition to the parameter or deviation-based approach. We already mentioned using sensors in order to measure water quality for improving and optimizing water purification processes. A fourth approach is the use of biosensors to measure effects of water quality. Biosensors use organisms such as bacteria, fish, algae or water fleas and have been developed since the early 1980s (Lechelt et al., 2000). In the Netherlands such biosensors are used as early warning instruments for the intake of surface water (Van der Gaag and Volz, 2008). They are used as indicators for possible contaminated water and are not prescribed by legislation. They constitute an interesting category of sensors as these types of sensors are focused on (toxic) effects of drinking water quality rather than measuring particular compounds.

Thus, while the main objectives, that is the 'guiding principles' (Smit et al., 1998; Van de Poel, 2000), underlying the application of sensors (rapid interventions, optimization and steering of water quality) are still broadly shared, the functional requirements as to realize these objectives differ, which leads to different trajectories. We can speak of different trajectories because of different logics structuring the preferences and the consequences they have for specification of requirements. Sensors cannot be generic and specific at the same time, and requirements regarding the application of sensors in a distribution network are quite different compared to those used to monitor intake water (for instance in terms of number of sensors, and data handling and interpretation of multiple sensors compared to single instances). So, there are strong indications that demand articulation processes in the drinking water sector are splitting up and that different trajectories may co-exist for some time. Table 3 offers an overview of the demand trajectories we identified.

While the overall demand articulation process has led to a novel trajectory, further specification of this trajectory and the more conventional parameter-oriented approach proved to be difficult. In the interviews and the workshop this was mentioned several times which indicates that this struggle is sector-wide rather than limited to individual actors. The following excerpt from a discussion in the workshop illustrates this struggle.

> What I perceive [in the contact with launching customers and potential end-users] is the lack of clarity about the essential sensor requirements. 'How low is enough? How fast is enough? Which specs are must-have and which are nice-to-have?*Workshop participant 1, sensor company*I think that, first, it is very important to be clear about your application, what do you really want?*Workshop participant 2, knowledge institute*Yes, and here things immediately go astray, because we do not know this. Therefore we first need to demonstrate and try out things, and then we know what we want. Because we know that we would like to measure online, real time, but we do not know what we want. […]*Workshop participant 3, drinking water company*This sounds as an impasse. Research says 'we can do a lot, but what do they want?' and the water companies say 'we know that we want something, but what exactly is unclear.'*Workshop moderator 1, knowledge institute*Well, I think that drinking water companies can say in general terms…at a fairly abstract level, but when it becomes more concrete then… […]*Workshop participant 4.*We do not know it very precisely. That is really astonishing. If you visit the drinking water companies, we do not know it precisely. That is really true.*Workshop participant 3, drinking water company*

So, we can speak of an impasse in demand articulation regarding the further specification of functional requirements, especially for application of water quality monitoring applications in the distribution network. This impasse is partly due to uncertainties regarding the application of sensors such as choice of parameters and/or measurement approaches, sensitivity and specificity requirements, and number and positioning of sensors. Uncertainties regarding the organizational implementation of sensors, such as how to make sense of the data, sensors' embedding in protocols and organizational routines also contribute to the impasse. Implementation is now becoming more and more of an issue according to interviewees working at sensor companies:

> During the last years we have reached the level that there are quite a number of sensors available which are suitable to be deployed. That was much less ten years ago. While there have emerged no new big technologies, the existing technologies have matured. So, you see that presently one can look at their deployment. […] How to react at signals [generated by these sensors]? […] How can you automatically verify that this is also reliable data? […] What does this data tell me? That is the second question. And the third question is, if I know this, how do I respond? That is the stage we have currently arrived at, that are questions of current interest. We were aware of them ten years ago, but they were not urgent at that time.*Interviewee 7, sensor company*I feel that sensor developments have passed through a number of stages. It started with technology development, prototyping, validation. We are currently in the phase of "what are the organizational implications of using sensors. How and where do you position them, that is fairly practical. But also what are response protocols, how do you respond to output [of sensors]? I see it developing more and more into an organizational than a technological innovation. […] We have actually moved from the sensor research & development to the application and what are the practical barriers which need to be overcome. […] And what needs to be changed in terms of organization with [drinking water] companies."*Interviewee 8, sensor company*

A third set of uncertainties which contribute to the impasse relates to rules and regulations regarding drinking water quality monitoring. In our interviews the role of regulations in the demand articulation and innovation process was often mentioned. New sensor technologies have different measurement principles compared to those currently accepted in regulation. New sensor technologies then need to be accepted by regulatory authorities in case they will replace existing approaches or new regulations need to be developed. The latter is more challenging as it requires modifications in regulation, which is complex in its own right and because of linkages between national and European legislation.

One of the conclusions of our workshop was that introducing new sensors would require rethinking the current 'paradigm' (participants wording) in the drinking water sector. Such rethinking, which would question the current monitoring regime and affect demand articulation at the sectoral level, was deemed necessary in order to formulate requirements regarding new sensors. This diagnosis by participants supports our suggestion that regimes need to be taken into account in conceptualizations of demand articulations.

> What I hear you telling is "We find it very difficult because we have our paradigm, if I understand it correctly, and are tied to the existing infrastructure with drinking water labs, we find it difficult to image how, with actually obvious end parameters, namely well produced, healthy, sustainable, safe and guaranteed delivery of water, to arrange measurements differently." […] This re-thinking is what you have done insufficiently yet, is that a great challenge?*Workshop moderator 1, knowledge institute*Indeed, that is a really great challenge.*Workshop participant 3, drinking water company*

Regulation, including standardization, is of key importance for innovation. During interviews and the workshop, standards were also mentioned as important to support introduction of sensor applications. Discussions on regulations and standardization, which play at the level of the sector, become entangled with discussions on requirements, and will contribute to further demand articulation at sectoral and local levels. Uncertainties regarding the relation between regulation and sensor applications thus add to impasses in demand articulation.

5. Discussion

Through the lens of our general conceptual framework a sectoral agenda and repertoire regarding the use of sensors in the drinking water sector became visible and we showed how this affected local demand articulations. Developments inside and outside the drinking water sector were conducive to the emergence or re-emergence of sensors on the agenda of the drinking water sector. Part of the emergence of

Table 4
Driving and guiding forces in demand articulation.

	Actor constellations	Institutions	Technologies
Existing patterns	Actor constellations and specific inter dependencies between actors such as within value chains, networks and socio-technical systems offer directions and boundaries for formulation of demands.	Rules and learning from experiences, the socio-technical regime, agendas and repertoires, offer directions and boundaries for formulation of demands.	Existing technological options, technological alternatives offer directions and boundaries for formulation of demands
Changes, new patterns	Changes in actor's backgrounds or involvement of new actors trigger formulation and unfolding of demands.	Critical events in society or in the sector, which challenge existing approaches and institutions in the sector, and changes in institutions, trigger formulation and unfolding of demands.	Emerging technologies and associated expectations trigger formulation and unfolding of demands

this agenda was due to the co-evolution of emerging demands and emerging technologies. Attention for sensor applications led to the development of sensor technologies. The development of sensor technologies and the assessment of their performance led to new ideas on requirements for sensor technologies. This agenda was accompanied by a collective repertoire emphasizing rapid interventions and sensitive and specific measurements, which fits with the existing monitoring regime in the sector. We found that changes on the landscape level, a specific and stringent monitoring regime as well as emerging technologies were important shaping forces in sectoral as well as demand articulations.

Our exploratory case study also highlighted other dynamics which were not explicitly included in our initial framework. In our interviews, learning from earlier experiences was visible in local demand articulations. Water companies learned about sensors by using them in practice, 'learning by using' (Kamp et al., 2004). Earlier experiences with sensor applications made some interviewees skeptical regarding sensors and led them to underline the importance of robustness of sensors. This supports studies that understand demand articulation as a learning process (Boon, 2008; Boon et al., 2011). Literature on Strategic Niche Management for instance links learning on technologies, with learning about user needs (including questioning existing preferences) as well as learning on regulatory requirements (Hoogma et al., 2002). This resonates with our understanding of demand articulation as being distributed across a variety of actors in a particular sector. More generally, learning is considered to be a key element in innovation (Lundvall, 1992). Various studies into technological change have used concepts of learning (Edquist, 1997; Quist and Tukker, 2013; Hekkert et al., 2007).

Even more salient in our study was the ambiguous role of the sectoral demand repertoire. The repertoire did not in a simple way support or constrain actors' demand articulations and interactions. In retrospect, the agenda and repertoire generated by sectoral articulation has paradoxically both supported and constrained formulation of preferences and requirements regarding sensor options. First, as a field-level agenda it turned sensor technologies into legitimate and relevant options for further inquiry. In addition, the agenda led some actors to initiate

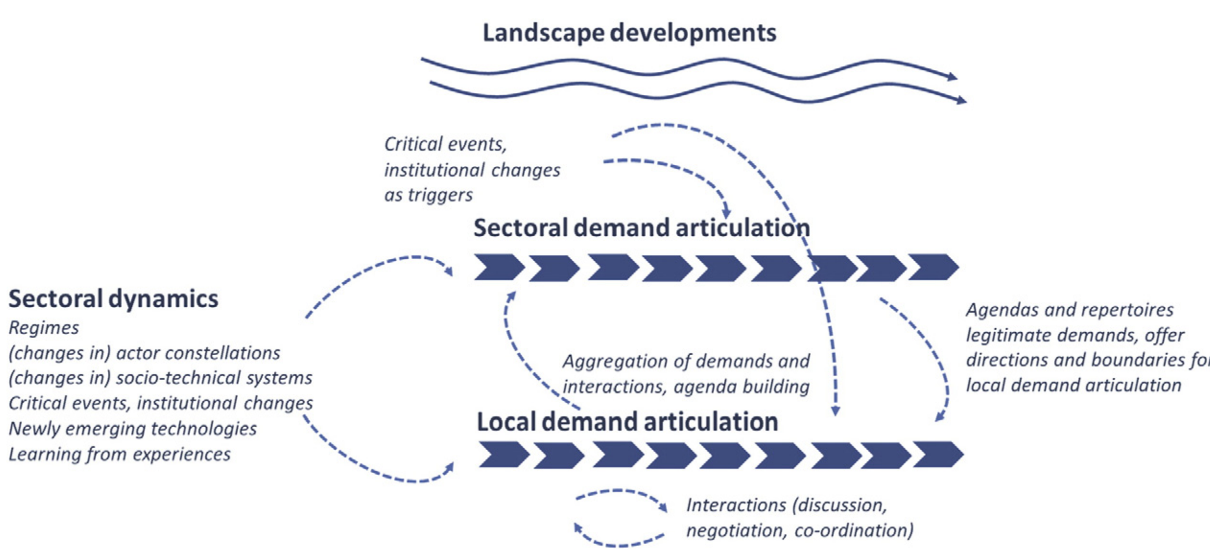

Fig. 2. Process model of demand articulation.

articulation activities to formulate requirements in that specific area. Clearly, it did not convince all actors to do so. Secondly, the repertoire and agenda offered a set of directions regarding the use and societal embedding of novel sensor technologies in the drinking water sector. This repertoire then guided actors to further specify these broadly formulated functional requirements.[13] However, the repertoire did not lead to a single specific demand articulation trajectory. We found multiple trajectories with quite different functional requirements which led to different products and prototypes. In that sense, there does not exist a dominant trajectory or 'dominant design' and multiple demand trajectories or paths can co-exist as shown earlier by Bergek and Onufrey (2014).

Being rooted in the current monitoring regime, the agenda and repertoire also impeded further articulations. Firstly, current and anticipated performance of novel sensor technologies did not fit with the collective sensor repertoire. Secondly, there are unclarities regarding implications of novel sensors for organizational routines and for existing relations with other actors such as drinking water laboratories and authorities. Alternative requirements (deviation measurements) were developed which stretched the current monitoring regime. Further development and demand articulation of sensors will most likely require dedicated work at the sector level in order to support the innovation process and the embedding of sensors in user organizations and society more broadly.

From this we infer that sectoral demand articulation and its outcomes do not determine or shape local demand articulation processes. Instead, sectoral demand articulation offers guidelines, cues for action and symbolic resources to support arguments, cf. Swidler's (1986) notion of culture as repertoires offering tools to use in action strategies rather than ends.

Striking in terms of actor involvement was that the sectoral demand articulation process was predominantly carried by interactions between sensor companies, knowledge institutes and representatives from water companies and water laboratories who are interested in innovation of monitoring technologies. Other actors such as inspection authorities, policy makers, consumer representative organizations or public interest groups were not involved, i.e. we found no evidence indicating otherwise. This is understandable in the Dutch context with a high standard of drinking water quality, where consumers are not involved (and not much motivated to be so) and authorities largely leave matters to the sector. More generally the Dutch drinking water sector has favored bottom-up collaboration between companies rather than top-down induced cooperation (Hegger et al., 2011). This may be quite different in other countries which struggle with issues in water quality monitoring or where consumers are otherwise more engaged in issues around drinking water quality.

More generally we argue that the context, i.e. the particularities of a sector, will play a major role in not only individual (local) demand articulation, but also in collective (sectoral) demand articulation processes. The actors involved constitute an important element in the overall dynamics. For instance in cases with prominent public interests at stake, such as debates on nuclear power or use of genetically modified organisms, public voices will play a stronger role in shaping the direction of sectoral demand articulation. In a parallel study on sensors for the food industry we also found sectoral demand articulation to be important (Te Kulve and Konrad, 2017). There, interactions between actors along the agri-food value chain were much more prominent in shaping demand articulation compared with our study in the drinking water sector (Table 4, Fig. 2).

6. Conclusions

By differentiating between sectoral and local demand articulation and the development of a process model incorporating both, we contributed to a better understanding of the dynamics and evolution of demand articulation. In particular, we showed that collective patterns, such as institutional changes and regimes played a major role in shaping sectoral and local demand articulation. We found that broader societal changes created momentum for sectoral demand articulation and that the current monitoring regime influenced the content of these requirements. Sectoral demand articulation generated attention for specific technologies and their applications by creating an agenda, and generated a repertoire with ideas, preferences and requirements which actors can draw upon. It also became clear that actors recognized the sector-wide attention for sensors, but interpreted it quite differently for their own situation. In fact we identified multiple co-existing demand trajectories with different functional requirements regarding sensor applications. Sectoral demand articulation thus influenced but did not determine local demand articulation processes.

The specific findings in our case study on the concrete dynamics and requirements cannot be generalized directly. The particularities of a case will influence which patterns play a role in sectoral and local demand articulation. Whereas regime dynamics played a prominent and dominant role in setting directions in our case study, this may not necessarily be the case in other countries where consumers are more engaged in issues with drinking water quality. In other sectors of industry, with complex actor constellations such as the food & beverages industry, demand articulation may be more dependent on the interactions and negotiations among actors at different positions in the value chain. Our process model which differentiates between sectoral and local demand articulation and emphasizes the sectoral context, offers fruitful avenues for further examining and explaining demand articulation processes and their dynamics.

A major implication of our study is that in policy making as well as in strategy development of innovation actors, sectoral demand articulation is a key area for intervention. Challenges in demand articulation are not just fueled by design and/or adoption problems. Lack of specified demands and the impasses observed in our case, cannot be fully solved at the level of individual organizations because some of the challenges are intertwined with interactions and patterns such as the monitoring regime, which are located at the level of a sector. Also the broader environment of users and suppliers of novel technologies needs to be included in order to stimulate formulation of requirements and exploration of promising options. In our case of drinking water we highlighted the importance of regulation and to some extent also standardization. Demand articulation processes can be stimulated by supporting users, in interaction with producers, but as this paper suggests, also through involving a broader range of stakeholders in furthering field-level demand articulation.

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[13] In general, subsequent (more-specific) formulations of demands are likely to draw upon earlier formulations. It will increasingly become difficult to deviate from these earlier formulations, without setting in motion an alternative trajectory. Teubal (1979) and Clark (1985) captured this logic in the form of what Clark called a 'hierarchical structure' in demand articulation.

Appendix A

Guiding questions for the research interviews
Introduction research interview.
1). Which needs should sensors fulfill? What drives these needs and how did they come about?
2). Which requirements need to be fulfilled before these sensors may be purchased?
3) What is unclear to you regarding the use of sensors? How do you deal with these uncertainties?
4). Have your ideas on sensors changed over time? How did these changes come about? What would make you rethink the role that sensors should fulfill in your organization?
5). Which organizations are involved with the development and use of sensors by your organization? What is their impact on (your vision regarding) the use and implementation of sensors?
6). Do other organizations in the drinking water sector have similar or different ideas and requirements regarding the use of sensors for monitoring drinking water quality?
7). Are there specific rules, regulations or practices in the drinking water sector which affect the use and implementation of sensors? Which and what is their impact exactly?
8). By way of conclusion, does the use and implementation of sensors need further stimulus? What needs to be done according to you and by whom?

Workshop Design "Sensoring Demands" November 2013	
Workshop objectives	1. Formulating requirements and their underlying considerations regarding the application of sensor technologies; 2. Supporting participants in becoming aware of other actor's perspectives, possible future developments in the sector and underlying socio-technical dynamics 3. Discussing strategies to further the development and implementation of sensor technologies that address these requirements.
Event setting	Event hosted plenary and parallel sessions (Sensors for the drinking water sector, sensors for the food & beverages sector). Location: conference center in the Netherlands.
Participants	35 representatives from knowledge institutes, drinking water suppliers, food & beverages companies, sensor companies, governmental agencies and organizations involved in standardization and certification.
Documentation	Participants received prior to the workshop a report with background material on sensor applications in the case of drinking water and food & beverages, a detailed program of the workshop and a set of scenarios exploring how the involvement of a broad set of actors may affect articulation of preferences and requirements, in order to stimulate discussion and reflection.
Plenary session I	• Introduction by organizers • Key note on the application of sensors for industrial processing and improvement of product quality
Parallel session I	Discussion round focusing on the following main questions: • What is your vision on the value and relevance of real-time sensors/ rapid detection systems for quality and safety issues in the (drinking) water sector? • Which future developments in the water sector do you expect that influence or might modify this vision? • What are key requirements and organizational practices to ensure effective and efficient implementation of this vision at a user organization? The discussion was kicked off by prepared commentaries from two workshop participants.
Parallel session II	Second discussion round focusing on the following main questions: • What are key challenges which need to be overcome in order to advance the development and innovation of preferred (from session 1) and other sensor applications? • What is your recommendation on how to advance these and other sensor applications? Which initiatives should be taken, by whom, and what should be taken into account? The discussion was kicked off by prepared commentaries from two workshop participants.
Plenary session II	Final session exploring options to advance sensor applications across the domains of (drinking) water and food & beverages.

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