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Exploring the dynamics of water innovation: Foundations for water innovation studies

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ABSTRACT

The urgent need for innovation to address multifaceted and intertwined water-related challenges is becoming increasingly clear, acknowledged and responded to with cumulating sources and amounts of funding. Nevertheless, the water sector has been claimed to be less innovative than other sectors. This Special Volume on the dynamics of water innovation is based on the realization that, in general, there is a striking absence of academic studies on the dynamics of water innovation. This SV is therefore designed to lay the foundations for the field of water innovation studies, in an effort to integrate the emerging insights. Together, the contributions in this SV capture the current understanding of the dynamics of water innovation and provide insights into how the water innovation process can be fostered. The purpose of this introductory article is threefold, namely to frame the discussion on water innovation dynamics in order to contextualise the contributions of this SV, to provide systematic guidance for studying water innovation dynamics and to suggest the way forward for water innovation studies. It captures the extent of the field of water innovation studies with a review of the literature of the last three decades and frames water innovations. Based on five decades of innovation research and drawing on three areas (management, strategy and policy), we provide an innovation studies taxonomy that consists of four organising dimensions: type of innovation, stage of innovation, level of analysis and measurement. This taxonomy enables researchers to study the dynamics of water innovation from different combinations of conceptual and thematic angles, drawing on the field of innovation studies in a systematic fashion. Finally, we reflect on the way forward for water innovation studies with suggestions for future research.

1. Introduction

Water and the necessity for its sound management have been placed increasingly high on political and funding agendas. Access to water has been acknowledged as a fundamental human right by the United Nations General Assembly [see (UNGA, 2010)]. The need to take care of global freshwater resources and water-related ecosystems, to achieve universal and equitable access to drinking water and sanitation and to prepare for water-related disasters is firmly embedded in the targets of several of the United Nations Sustainable Development Goals (UNGA, 2015). The United Nations Secretary General and the President of the World Bank Group established the High Level Panel on Water[1] which called for "*a fundamental shift in the way the world looks at water*" (HLPW, 2016, p.1). Moreover, for the third year in a row, the World Economic Forum's annual Global Risks Report (WEF, 2017), which is based on the perceptions of world leaders and corporate decision-makers, placed environmental risks above economic risks, with water crises among the top three global risks. Already 10 years ago, UN-Water and the Food and Agricultural Organisation had argued

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[1] consisting of 11 sitting Heads of State and Government and one Special Adviser and charged to champion to ensure commitment for the implementation of the 'water goal' (SDG6) and the achievement of other SDGs that rely on the development and management of water resources.

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that the world was facing a crisis when globally roughly 1.2 billion people experienced water scarcity problems (UN-Water & FAO, 2007).

From the perspective of water utilities, water-related challenges are primarily related to scarcity, quality and the allocation of water (e.g. RobecoSAM, 2015). According to estimates by the United Nations World Water Development Report 2016 (WWAP, 2016), 78% of the jobs constituting the global workforce are dependent on water; some even argue that '*there is no human activity that does not depend on water*' (Savenije, 2002, p.742). The challenges facing water management are multifaceted and intertwined, particularly when conceiving water management broadly: there are interrelated *social challenges* (population growth, urbanisation, migration, changing lifestyles, provision of water access (rural & urban), provision of sanitation & hygiene, water consciousness to improve water use efficiency), *technological* (tapping novel sources of freshwater, smart infrastructure, waterless design to reduce system dependence on water, usage efficiency technologies, water reuse and recycling), *economic* (ecosystems services, energy supply, ageing infrastructure, virtual water (water footprint), climate adaptation), *environmental* (flood risk, persistent drought, groundwater depletion, agricultural productivity and climate resilience, ecosystem pollution, waste management), and *political challenges* (governance,[2] water stress,[3] utility ownership models, watershed cooperation, system vulnerability, water rights) (Luebkeman, 2015; Weerdmeester et al., 2017a; Water JPI, 2016; Dietz et al., 2014). Moreover, a sound knowledge base and capacity at different levels (water professionals, organisations, enabling environment and society) to address these challenges and to sustain and improve water management through change and innovation are lacking in many developing countries (Wehn de Montalvo and Alaerts, 2013).

Analysists estimate the global water sector worth 1 trillion USD per year by 2025 (RobecoSAM, 2015). These prognoses are based on expectations that the demand for innovative solutions will grow: solutions enabling more efficient use of available water resources, enhancing the quality of (drinking) water, and improving water resource planning to reconcile the conflicting trends of rising demand for water and finite water resources (Pinsent Masons, 2011). On top of these, further solutions are needed for water resources management more broadly, especially in view of increasing water-related disasters owing to climate variability and change. Strategic efforts to address these challenges via research and innovation stress the need to distinguish between different types of water,[4] different water users[5] and different water (re-)use, the value of water and the value in water (HLPW, 2016; Weerdmeester et al., 2017a).

The urgent need for water innovations is becoming increasingly clear, acknowledged and responded to with accumulating sources and amounts of funding. Examples in Europe include the Horizon 2020 programme (for research, development and innovation activities), the structural funds,[6] LIFE 2014–2020 (the EU's funding instrument for the environment and climate action), as well as grants for individual researchers by the European Research Council to undertake basic research. However, financial investment into the water sector is still far behind that of other sectors, such as the energy sector.[7] The water sector has also been reported to be less innovative than other sectors whereby innovation indicators suggest far less research and development (R&D) investment in the water sector[8] than other sectors (Ipektsidis et al., 2016). This image needs to be adjusted, given the sectoral patterns of innovation in the sector. The pattern of innovation in the water sector follows the natural path of sectors that are supplier-dominated (i.e. supply of equipment) and trading in bulk (Pavitt, 1984); in fact, its rate of R&D investment and valued added is higher than in other sectors with higher R&D intensity (Ipektsidis et al., 2016).

This Special Volume (SV) of the Journal of Cleaner Production (JCLP) is based on the realization that despite some efforts over the last two decades (e.g. Golay, 1988; Ferrucci, 1995; Garn, 1997; Gregg, 1989; Hon, 1993; Ishigure, 1991; Kiparsky et al., 2013; Krozer et al., 2010; Lobina, 2012; Martins and Williamson, 1994; Miller, 1990; Oka et al., 1996; Palfai et al., 1998; Partzsch, 2009; Peuckert et al., 2012; Robbins, 1998; O'Brien and Clemens, 1988; O'Loughlin, 1994; Hartman et al., 2017; Shupe, 1988; Njeru, 1995; Sirkiä, et al., 2017; Barripp et al., 2004; Bowmer, 2004; Chen, 1998; Matthews, 1997; Thomas and Ford, 2005; Daniell et al., 2014; Wehn and Evers, 2015; Mvulirwenande et al., 2017; Ngo Thu, H. and Wehn, 2016; Gharesifard and Wehn, 2016; Wehn et al., 2015; Pascual Sanz et al., 2013), relative to the scope of innovation studies, there is a striking absence of academic studies on the dynamics of water innovation, i.e. examining how relevant actors (fail to) interact to generate, finance, diffuse and apply water innovations and how these processes can be fostered, guided and steered; yet such insights are crucially needed in the face of urgent water-related challenges in developed and developing countries alike that require various types of innovation, both technological and non-technological: incremental improvements, adapted approaches as well as entirely new ways of interacting across stakeholders, basins, regions and related sectors. More than 50 years of research into the dynamics of innovation can provide existing insights about, models of and approaches for studying, innovation. These need to be applied carefully when studying the dynamics of water innovation, given the cross-cutting nature of water and the peculiarities of this sector - involving diverse stakeholders across multiple governance levels (Pahl-Wostl et al., 2010), sunk investments and risk averseness (Blokland et al., 1999), and monopolistic structures for the provision of water services and to safeguard water security.

This SV was designed to lay the foundations for the field of water innovation studies, as an effort to integrate the emerging insights regarding water innovations, both technological and other forms of innovations, and to bridge water and innovation-related research. The papers in this SV were selected from papers submitted to a competitive 'Call for Papers (CfPs) (Wehn and Montalvo, 2015), the authors of which argued that the cross-cutting nature of water as well as the urgent need to address the water-related challenges means that dynamic dialogue is urgently needed about water innovations to better inform and support the generation and diffusion of water innovations, globally. The contributions in this SV

[2] referring to how decisions related to water are made, by whom and with what degree of integrity, accountability, transparency and inclusiveness.

[3] demand for water exceeds the available amount during a certain period.

[4] rain water, surface water, ground water, brackish water, saline water, grey water, etc.

[5] typically distinguishing between agriculture, industry and households, which present 70%, 20% and 10% share of water use, respectively.

[6] to remove social, economic and territorial disparities across the EU while making the EU more competitive.

[7] For example, over the period 2000–2013, investments in clean energy have largely exceeded those in the water sector industry for all investment types (e.g., venture capital and corporate ventures, bank investment) globally (Ajami et al., 2014). It is estimated that, globally, clean energy attracted total investments of 139 billion USD of which 59 billion USD on capital investment (Ajami et al., 2014). In contrast, the water sector attracted 8 billion USD of total investments of which 5 billion was in capital investment. In the US, total investment in clean energy reached 69 billion (of which 41 billion in capital investment) while the water sector attracted 1.5 billion USD of which 1.4 billion USD in capital investment.

[8] referring to the collection and distribution of water only.

capture the current understanding of the dynamics of water innovation and provide insights into how the water innovation process can be fostered. The coherence of the papers in this SV stems from the fact that they draw from, and build upon, established literature and theories in the field of innovation studies and apply (and adjust) these to the study of water innovation.

The purpose of this introductory article is threefold, namely to frame the discussion on water innovation dynamics in order to contextualise the contributions of this SV, to provide systematic guidance for studying water innovation dynamics and to suggest the way forward for water innovation studies. Therefore, this introductory article is organised as follows. We capture the extent of the field of water innovation studies in Section 2 with a review of the literature of the last three decades. Section 3 frames water innovations while Section 4 frames innovation studies. Based on five decades of innovation research and drawing on three areas (management, strategy and policy), in Section 4, we provide an innovation studies taxonomy that consists of three organising dimensions (*type of innovation, stage of innovation and level of analysis*) as well as the cross-cutting *measurement* of innovation in evaluation and impact assessment terms. We contextualise the contributions of this SV in Section 5 and conclude with remarks on the way forward for water innovation studies in Section 6.

2. State of the field

In this section, the authors present a quick scan of three decades of information, based on the combination of the terms 'innovation' and 'water' found by Google Scholar (per year, 1987–2016). The total number of hits for all four decades was less than 1000. In comparison, searches for topics such as service, process or product innovation produced more than 35'000, 85'000, and 200'000 hits, respectively, over the same period. There are several aspects to highlight regarding the results of this review. First, during the early years covered by this research, there were very few hits per year (4–5 papers per year). During the first decade, the primary focus was on specific water technologies, calls for institutional innovation in the water sector and, above all, innovation in relation to water resources in agriculture and water resources management. Only a few papers referred to innovation and water utility performance. In 1997, there was a statement in one article, about the urgent need for innovation in the water industry (Matthews, 1997); the author did not have any impact though, indicated by the finding that this article has received only two citations. Nevertheless, 1998 marked the first inter-regional conference on environment with the topic of water, innovation and drainage [see (Kireycheva, 1998)]. In this year, there is the first mention of role of technology and innovation in the competitive strategies of water companies (Chen, 1998). The term 'water innovation' appears for the first time in the title of a publication in 2004 (Barripp et al., 2004; Bowmer, 2004). These publications refer to water innovation in terms of Australian leadership and achievement in water resources management. More recently, it has been recognised that there is a lack of innovation in water and waste water treatment (Thomas and Ford, 2005). In recent years (2014–2016), there is more engagement with the theories of innovation but the overall number of publications on water innovation was limited to less than 55 per year, which addressed topics such as frugal innovation, business models, service innovation, innovation systems, knowledge transfer and analyses of the adoption and diffusion of water innovations. However, in comparison to other sectors, during the last three decades, water sector researchers appear to have been reluctant to embrace the discourse and culture of innovation in terms of sectoral policy and strategy. This is documented in Fig. 1, for which we compared the number of publications and the number of citations for the most successful paper per year, for the water sector and the ICT sector (1987–2016).

3. Framing water innovations

Market analysts conceive the water sector to be comprised of i) water utilities (public or private) which provide treated *drinking* water and sanitation services for private end users as well as *untreated* water to agriculture and/or various water-using industrial sectors[9]) and ii) technology suppliers and equipment manufacturers for water utilities (Deloitte, 2012; Arup, 2015; Pinsent Masons, 2011). Taking a more comprehensive perspective of based on a water resources view, the United Nations World Water Assessment Programme (WWAP) which monitors the state, use and management of the world's freshwater resources and related issues, follows the definition of the United Nations Department of Economic and Social Affairs (UN DESA, 2008) and divides the water sector into three main functional categories, namely water resources management, water infrastructure, and water services:

i) **Water resources management** includes integrated water resources management (IWRM) and ecosystem restoration and remediation, aimed at ensuring the protection, sustainable use and regeneration of water resources by protecting ecosystems, rivers, lakes and wetlands and building the necessary infrastructure (e.g. dams and aqueducts) to store water and regulate its flow;
ii) **Water infrastructure** includes the construction, operation and maintenance of water-related infrastructure (natural and man-made) for the management of the resource as well as for the provision of water-related services, including the management of floods and droughts;
iii) **Water services** comprises the provision of services such as water supply, sanitation and hygiene, and wastewater management for domestic use as well as water-related services for economic uses, e.g. in the energy, agriculture and industrial sectors (WWAP, 2016).

Although these three functional categories overlap to some degree, they provide a comprehensive definition of the water sector, including the overall management of water resources, urban and rural supply and the use of water for various purposes (residential and productive) as well as water-related disasters stemming from too little or too much water. These three functional categories of the water sector can be associated with different types of innovations that may inevitably overlap to some degree and which - generally speaking - are designed to "*contribute to the continuous improvement of water management, in terms of efficiency and effectiveness.*" (Wehn et al., 2016). To this end, the water sector integrates a large number of technical and non-technical innovations from other sectors that often invest heavily in R&D and innovation. The water sector benefits from inputs and components that enable a high value added in monetary and services terms. These aspects of the water sector imply a strong innovation path dependency on other sectors such as ICTs, construction, specialised equipment, etc. Examples of innovation path dependencies (Pavitt, 1984), i.e. the knowledge flows embedded in technologies and practices acquired from other sectors as well as the knowledge accumulated in the water sector historically to absorb them, are illustrated in Fig. 2. This figure implies a distinction between stakeholders and organisations in the water value chain (along the

[9] mining, power generation, pharmaceutical, pulp and paper, upstream oil and gas, refining and petrochemicals, microelectronics, and food and beverages.

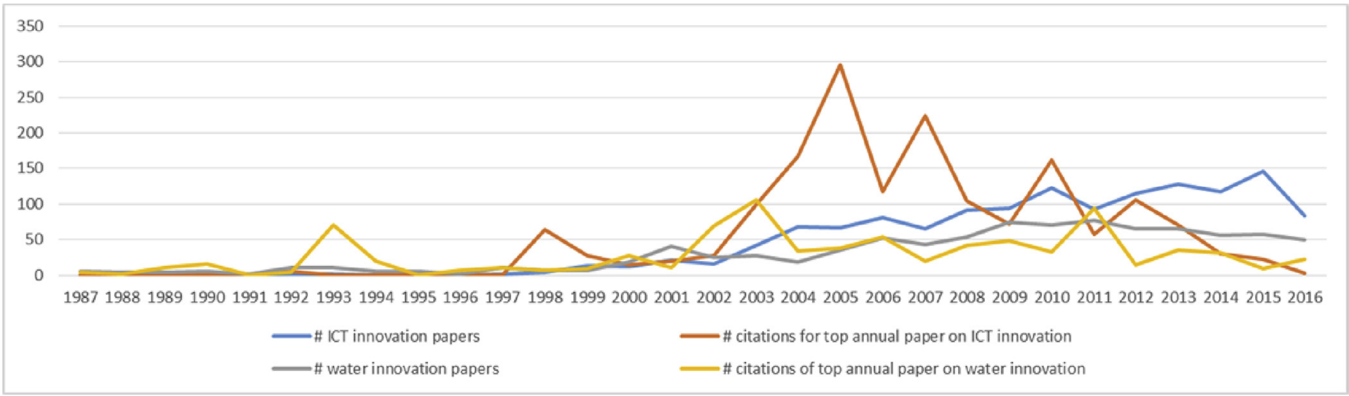

Fig. 1. Publications and citations for the most successful papers per year (Water sector & ICT sector).
Source: the authors

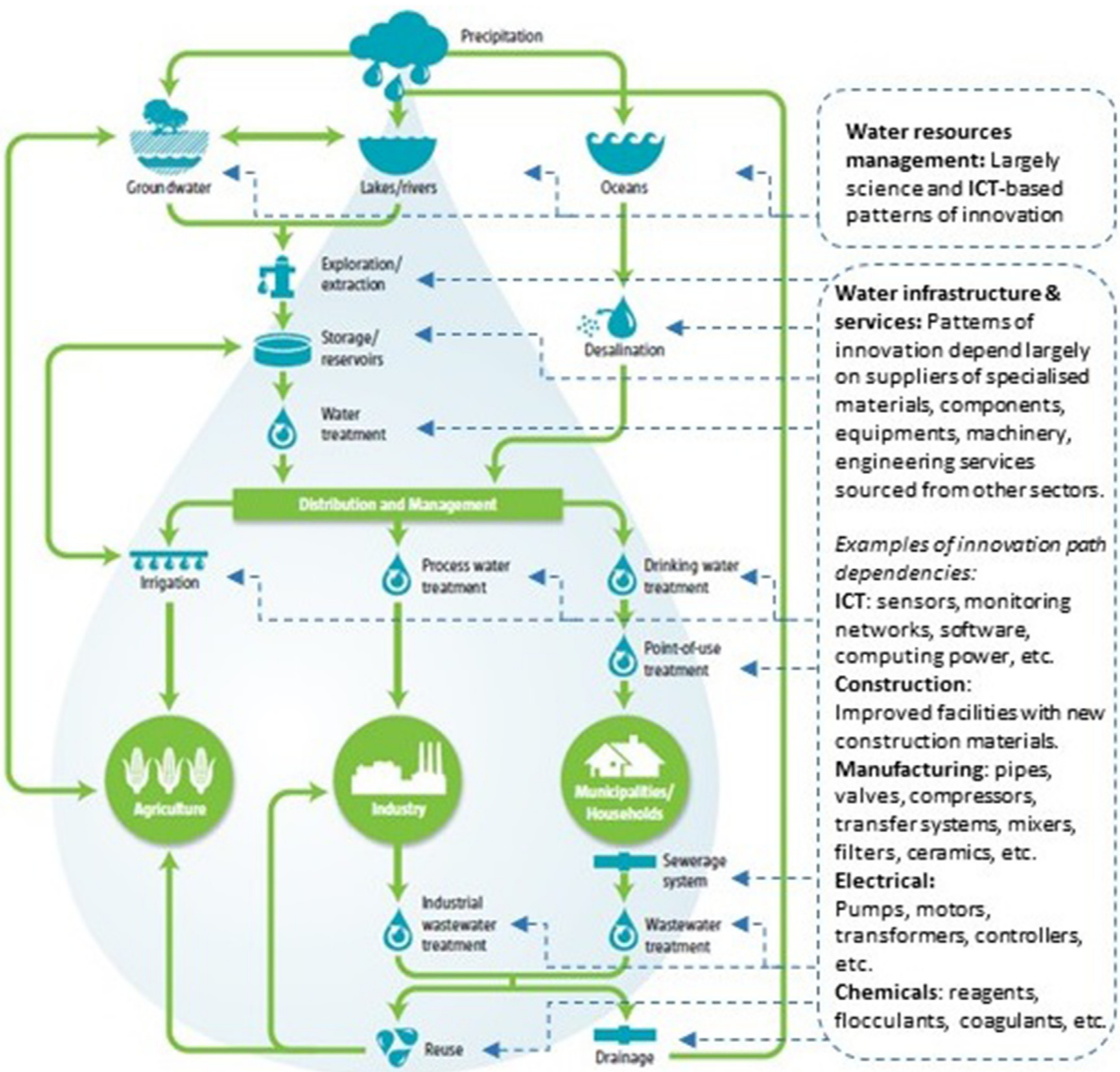

Fig. 2. Innovation path dependencies in the water sector.
Source: Based on (RobecoSAM, 2015)

green arrows, e.g. river basin organisations, emergency agencies, dam authorities, utilities, industrial users, agricultural users, household users, waste water treatment facilities etc.), on the one hand, and the technology providers and equipment manufacturers from other sectors (indicated by the dotted arrows). The latter provide the former with inputs and services to undertake their functions in the water value chain. The trade relations of the water sector with other sectors create interdependences that drive innovation in other sectors while creating a virtuous cycle of job creation and welfare. The specific dynamics of these innovation path dependencies in the water sector have been largely neglected in the water innovation research community.

4. Framing innovation studies

Similarly to framing water innovation, innovation research requires framing and positioning in order to enable entry points for research focus and problem definition in this, by now, vast area of research. In comparison to water innovation studies where there is little work at hand, innovation research offers close to four million scholarly titles as indicated by a keyword search for "innovation" in google scholar. This requires an organising heuristic for a taxonomy of innovation studies; in this we follow Rodriguez and Montalvo (2007) and complement the organising dimensions (*type of innovation, stage of innovation and level of analysis*) offered by Gopalakrishnan and Damanpour (1994). A fourth horizontal dimension relevant to the other three dimensions is the measurement of innovation (OECD-Eurostat, 2005; Adams et al., 2006; Bloch, 2005) in evaluation and impact assessment terms (Antonelli, 2014; Gago and Rubalcaba, 2007). The collection of papers included in this framing exercise comes from three areas of innovation research: management, strategy and policy. Selecting the focus along all four dimensions (*type, stage, level of analysis and measurement method*) serves for studying innovation in the different functional categories of the water sector outlined above: integrated water resources management, water infrastructure and water services. This enables researchers to study the dynamics of water innovation from different combinations of conceptual and thematic angles, drawing on the field of innovation studies in a systematic fashion. The joint consideration of all four dimensions serves to focus and frame such research. Fig. 3 indicates the structure and main categories within each dimension of this taxonomy. The literature in the field of innovation is organised according this structure which is further explained in the following sections.

The purpose of this taxonomy is not to provide an exhaustive review of the field of innovation studies, for this, see the compilations of Fagerberg et al. (2005) and Hall and Rosenberg (2010). Rather, the intention here is to provide systematic guidance for studying water innovation dynamics in terms of entry points into relevant literature in innovation studies. Given the breath and scope of the field of innovation studies, we inevitably have left out significant and influential work for some of the topics covered. Topics such as university-industry collaboration, property rights, innovation networks and foresight studies were not included in this review. Our review includes examples of early foundational classical papers for topics that have emerged recently. References include classical works of Schumpeter (1934) and Schmookler (1966) looking at the effects of innovation in the aggregated economy to the most recent upcoming topics including business models innovation (Osterwalder et al., 2005), behavioural approaches to innovation (Montalvo, 2006; Wehn and Montalvo, 2017) and innovation ecosystems orchestration (Valkokari et al., 2017), for example. We offer references to sound literature reviews for each specific topic so that the reader can dip into each of the topics, as needed.

In order to map and place each of the works included in this framing exercise, we present a taxonomy (see Fig. 4) with clear points of entry for each of the categories considered. Each category needs to be considered in order to fully frame an innovation research proposition. The reader is invited to consider the *type* of innovation addressed, in what *stage* of the innovation cycle it is located, at what *level of analysis* the research will be conducted and what *measurement* approach will be adopted. By turning to the respective, suggested authors in the respective sub-sections below, researchers of water innovation issues have a basic set of references that can help frame a research proposition.

4.1. Type of innovation

Innovation has been conceptualised in many ways depending on the context used but what is akin to all studies are the notions of the "new", and above all, "change" (Dosi, 1982; 1988; Gupta and Wilemon, 1996; Abernathy and Clark, 1985; Downs and Mohr, 1976; for a critical review, see Garcia and Calantone, 2002). One of the first questions researchers ask is 'What is new? What is changing or has changed?' This refers to the *type of innovation* that is the focus of interest.

4.1.1. Incremental vs. radical innovation

The innovation studies literature, primarily focusing on industrial or business activities, has considered whether the innovation is incremental or radical in nature taking as references established practice. Incremental innovation is characterised by marginal changes, occurs in mature industries or services, building and upgrading existing knowledge and skills, intellectual property rights are well defined and managed (see Ettlie et al., 1984; Normann, 1971; Dewar and Dutton, 1986; Henderson and Clark,

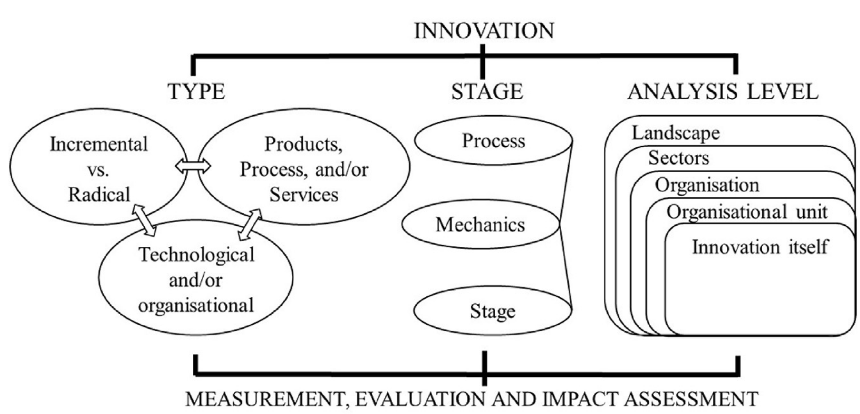

Fig. 3. Focus and research problem definition in innovation studies.
Source: the authors

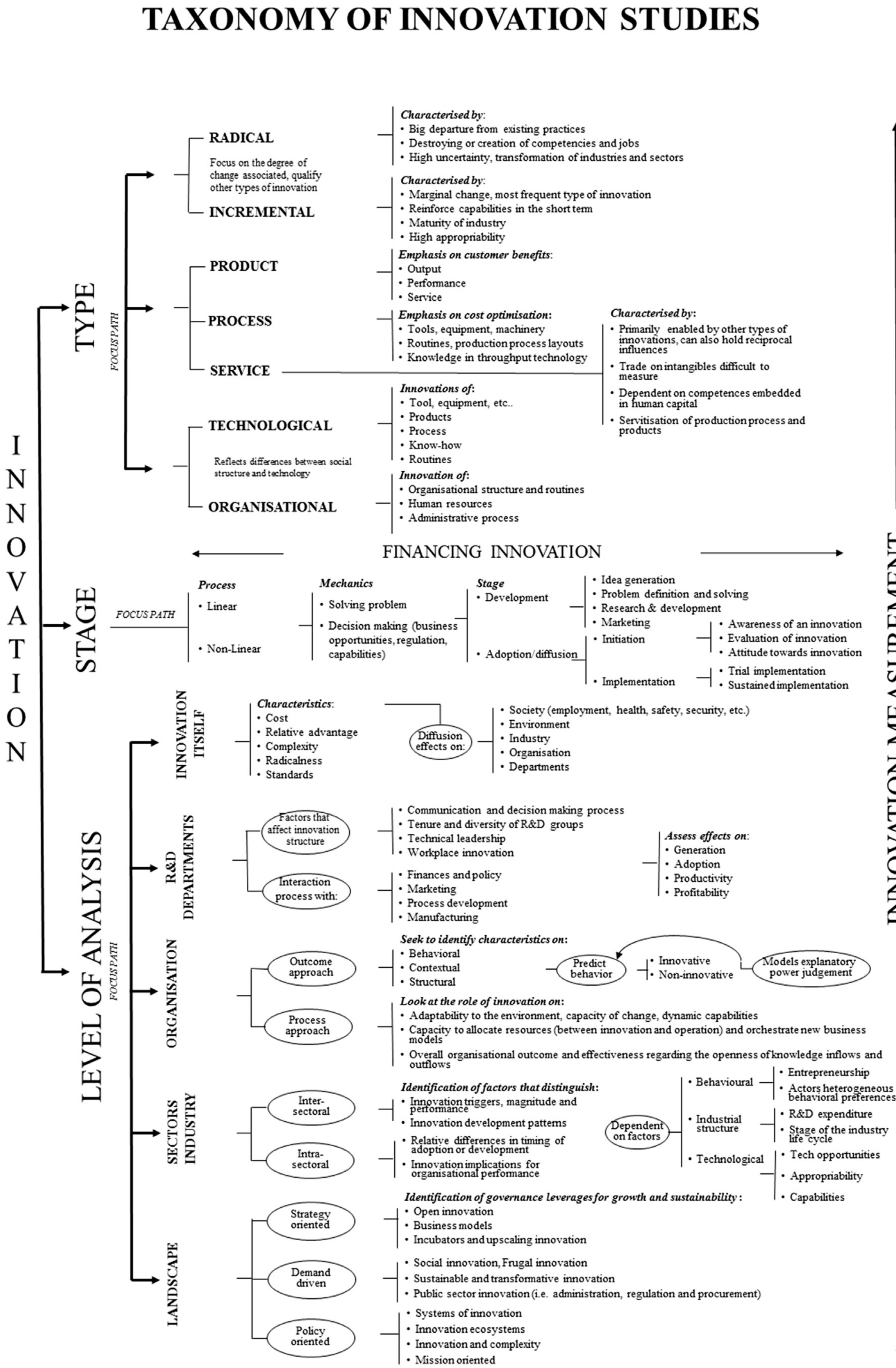

Fig. 4. Taxonomy of innovation studies.
Source: the authors

1990). In contrast, radical innovation is disruptive, transforming entire industries, pioneers depart from current practices and generate high uncertainty for established players, destroys and creates competences and jobs (see Christensen et al., 2006; Meyer et al., 1990; Normann, 1971; Tushman and Anderson, 1986; Coccia, 2016). Other types of innovation, that is, products, processes, and/or services, as well as organisational and technological innovation could be incremental or radical. These latter innovation categories have been primarily studied separately, although it is clear that changes in one can induce or imply changes in the other. These latter categories are used in influential manuals for innovation metrics such as the Olso Manual which offers internationally accepted definitions of innovation (OECD-Eurostat, 2005).[10] Typical questions in this research area include: What are the effects on employment and new skills requirements? Where will new competition stem from?

4.1.2. Product, process and services innovation

Product, process and services are intrinsically linked (Utterback, 1994). Process innovations generally refer to changes in one or several aspects related to production activities such as tools, machinery (and associated software), layout of production systems, and accompanying knowledge and expertise (Utterback, 1994; Tushman and Anderson, 1986; Rosenberg, 1982; Davenport, 1993; Utterback and Abernathy, 1975). Innovations in production processes have generally been enabled by changes in discrete parts of the production layout. This type of innovation enables innovation in products and often has implications for organisational innovation and logistics. Most process innovation at the production system level in any given sector is incremental and primarily focuses on the optimisation of costs for consumer products and quality and performance for high end products. Having said that, over the last decade, innovation for environmentally friendly behaviour have been gaining legitimacy (Boons et al., 2013; Rennings, 2000; Geels, 2004; Montalvo, 2008; Montalvo and Kemp, 2008). *Product innovation* arises from new knowledge, materials or the recombination of other innovations. This often requires the modification of, or is enabled by, new production processes. Product innovation is oriented to fulfilling client preferences by increasing product performance, lifetime, service, quality or enabling new lifestyles and experiences (Utterback, 1994; Capon et al., 1992; Rosenberg, 1982; Souder, 1986; Suarez and Utterback, 1995; Gold, 1983; Anderson and Tushman, 1990; Manders et al., 2016; Dangelico, 2016). Regarding *service innovation,* according to Gallouj and Weinstein (1997), the production of a service concerns an action, or a protocol application that leads to a change of state, not the creation of a tangible artifact (e.g., a product). Furthermore, services are characterised by their intangibility, heterogeneity, inseparability, and perishability. Based on this, service innovation has been defined as changes affecting one or more innovation types and/or inherent competences (Gallouj and Savona, 2009; Miles, 2000; Snyder et al., 2016; Carlborg et al., 2014). Service innovations are generally enabled by new applications of existing products or process. Although primarily enabled by other types of innovation, service innovations often hold reciprocal influences. Evidence of such influences are seen in current trends of 'servitisation' of products and production processes (OECD, 2005; Sawatani and Fujigaki, 2016; Howells, 2006) and the R&D process itself (Lin and Lin, 2012; Dix and Ganz, 2013).

4.1.3. Organisational and technological innovation

Both types of innovation – organisational and technological - occur in the sphere of organisations in the private and public sectors (Farris, 1988; Van de Ven, 1986; Van de Ven and Rogers, 1988; Dosi, 1982). These innovations can have an incremental or radical character affecting organisational structures, human resources competences, and/or administrative processes (Kimberly and Evanisko, 1981; Kimberly et al., 1981; Damanpour and Evan, 1984; Wolfe, 1994; Baldridge and Burnham, 1975; Nonaka, 2008; Leonard-Barton, 1995). Such innovative changes can demand or can be originating in technological change in areas such as new technological standards and regulations (Hawkins et al., 2017) or from technological changes in tools and equipment, products, process, and/or knowhow (Damanpour and Evan, 1984; Utterback, 1971; Daft, 1982; Hartman et al., 2017).

4.2. Stages of innovation

The stages of innovation refers to the cycle of the creation of 'the new', from idea generation to wide diffusion, decline and replacement of those ideas embodied in protocols, standards, artefacts, machinery, equipment or systems with the new. This cycle has been considered a process (King, 1992; Saren, 1984; Leonard-Barton and Sinha, 1993), characterised as linear (Kline, 1985; Robertson, 1974; Ettlie, 1980) or non-linear (Rosenberg, 1982; Kline, 1985; Poole, 1981, 1983; Schroeder et al., 1989), depending on the *level of analysis* adopted by researchers (see section on the level of analysis below). Despite the early recognition that the innovation process occurs in cycles [see (Utterback, 1994)] the staged model has been dominant in scholarly works.

In general, two clusters of stages can be distinguished: the development (or technology push) and the adoption (or market pull) of innovations. These have different actors, the producers developing and championing innovations and the adopters using those innovations. Some authors have pointed out the messiness of the innovation process and the existence and importance of feedback loops as well as multi-actor systems; feedbacks, iterations and loops between stages which is relevant for innovation management (Kline and Rosenberg, 1986). For practical matters of analysis, strategy and policy, the staged model has been used to focus specific interventions, for example supporting R&D on specific health issues or supporting the scaling up of strategic industries.

4.2.1. The development of innovations

The development of innovations stems from specific problems or social demands that might generate business opportunities and benefits for entrepreneurs championing and relevant stakeholders supporting them. Two intrinsic mechanisms that limit the initial stages of any innovation (Utterback, 1971; King, 1992) are: the actual capacity of problem solving and integrating knowledge (Ettlie et al., 1984; Nonaka, 2008; Leonard-Barton, 1995; Gassmann, 2006) and the decision making process and structure (Poole, 1981, 1983; Harvey et al., 1970; Montalvo, 2006). The development of innovations comprises the following stages: ideation, definition of priorities in problem solving, conducting basic research, then applied research for prototyping and testing, testing feasibility of manufacturability and upscaling, upscaling production and marketing (Suarez and Utterback, 1995; Kimberly et al., 1981; Anderson and Tushman, 1990; Manders et al., 2016).

The success of an innovation occurs with the emergence of a dominant design and standards that enable its wide diffusion (Rogers, 2010). All activities prior to the production stage are oriented to reduce uncertainty concerning potential sunk investments

[10] In addition to the innovation types listed, the Oslo Manual has traditionally also considered the following types of innovations: industrial relations, marketing, designs, logistics and distribution channels. In recent waves of the Community Innovation Survey, the measurement of eco-innovation and social innovation have been included as well. See EUROSTAT Community Innovation Survey.

and expected returns of innovation (Leonard-Barton and Sinha, 1993; Schmookler; Howells, 2006). Typical questions in this research area include: What are the characteristics of entrepreneurs? What drives the decision to innovate? A second pervasive question type refers to where innovations come from, who champions and supports them from idea creation and experimentation to standardization supporting their diffusion and decline.

4.2.2. The adoption of innovation

The adoption of innovations broadly comprises, as already outlined above, the phases of acquisition by and integration in users' behaviour, service and support and wide use. It is in these stages where the effects of change brought by innovation are experienced: 1) in organisations in terms of new skills requirements, destruction and creation of jobs, new organisational layouts, loss or gain of competitive positions in sectoral markets, the creation of new services, etc.; 2) at the broader societal level it is possible to see changes in behaviours, consumption patterns, lifestyles, employment and, in general, structural change across economic sectors (Ipektsidis et al., 2016; Antonelli, 2014). The effects of the diffusion of innovations is one of the most studied topics in the field. From the strategy and policy perspectives, research has looked into the factors that drive adoption at the company level or consumer preferences looking at the decision process that triggers innovation adoption (Damanpour and Evan, 1984; Kimberly et al., 1981; Poole, 1981; Ettlie, 1980; Van de Ven and Rogers, 1988; Montalvo, 2006). Others investigate how to promote the diffusion of new technologies as a means to solve societal problems (Smith et al., 2005; Montalvo and Kemp, 2008; Mansell and Wehn, 1998; Matthews, 1997; Montalvo et al., 2011; Yu et al., 2016; Nagel et al., 2017; Annala et al., 2017, Hartman et al., 2017). From the management perspective, researchers have aimed to identify factors affecting the implementation of innovations at the organisation level and resulting performance (Tornatzky and Klein, 1982; Wolfe, 1994; Black and Lynch, 2001; Black and Lynch, 2004; Bresnahan et al., 2002; Shefer and Frenkel, 2005; Howaldt et al., 2017; Thamhain and Wilemon, 1987).

4.2.3. Financing of innovation

The topic of financing innovation cuts across all types of innovation and innovation stages and concerns the availability of capital for innovative activities. Financing of innovation has been considered a critical factor dating back to the times of Schumpeter (Arrow, 1962; Christensen, 1992). The topic has received considerable attention in the literature of innovation studies (as well as by water sector practitioners) over the last few decades and continues to be reported as the most important factor in the upscaling of innovations. Scholars in this area of innovation studies have considered the role of innovative capabilities interacting with sufficient funding (Hottenrott and Peters, 2012; Brown et al., 2012); the different sources and modalities of funding for R&D projects (Hall, 2002; Hall and Lerner, 2010; Van Bavel et al., 2010; Bakker, 2013; Howell, 2017); the relative importance of internal versus external financing of R&D in small businesses (Bougheas, 2004); financing the risk of innovation via financial markets (Kerr and Nanda, 2015; Nanda and Rhodes-Kropf, 2016; Berglund, 2007); and the role of intermediaries (Howells, 2006).

4.3. Level of analysis

In general, the level of analysis refers to an instance where researchers consider diverse aspects of the governance of innovation in reference to the context and level of aggregation where change takes or has taken place. Here, innovation is placed within a process of governing undertaken by a department within an organisation, a formal or informal organisation, the market in an industry, or within specific territory. All of this relates to an interdependent process of decision making and collective action that leads to the creation of the new reinforcing or changing reference models, standards, social norms and institutions. In the following, we outline the type of research efforts that have characterised the different levels of analysis addressing the governance and impacts of the new.

4.3.1. Level of analysis: innovation itself

Researchers addressing the nature of innovations, looking at the ***innovation itself***, have concentrated on the features of innovations such as the novelty (disruptive technology), level of complexity, relative advantages in terms of cost, functions and performance (Evangelista and Savona, 2003; Leonard-Barton, 1992), the implementation of standards (Manders et al., 2016; Hawkins et al., 2017) and how these features relate to the speed and scope of diffusion across organisational boundaries, industries, and ultimately welfare and growth. The effects of the diffusion of innovations have also received a great deal of attention. For example, at societal level, on employment, health, safety and security (Hirsch-Kreinsen, 2016; Gulati and Soni, 2015; OECD, 2005; Schumpeter, 1934; Schmookler, 1966; Evangelista and Savona, 2003; Acemoglu, 1998); new skills requirements (Daniell et al., 2014; Wright, 2012); on the environment (Adams et al., 2016; Lima and Navas, 2012; Corral, 2003); across industries (Lima and Navas, 2012; Sirkiä et al., 2017; Davis et al., 2017; Gambardella and McGahan, 2010; OECD, 2005; Sawatani and Fujigaki, 2016; Lin and Lin, 2012; Dix and Ganz, 2013; Schumpeter, 1934; Hobday and Rush, 1999) etc.

4.3.2. Level of analysis: R&D departments

Concerning innovation research at departmental level, ***R&D organisational units*** as a level of analysis have received most attention. Focal points have been the exploration and identification of barriers and drivers of innovations, how the R&D process is organised and its effect on company performance. More specifically, for example, decision making in teams and at department level (Katz and Allen, 1982), interaction and communication across departments (Souder, 1986; Gordon et al., 1991; Khanagha et al., 2017; Katz, 1988), leadership and diversity in research teams (Farris, 1988; Gassmann, 2006). Recently, studies have focused on how innovations affect the workplace (Bresnahan et al., 2002; Oeij et al., 2017; Morris et al., 2010) and how innovation in the organisation of the workplace, including tenure of researchers, affect departmental and company productivity (Howaldt et al., 2017; Oeij et al., 2017; Morris et al., 2010; Manu and Sriram, 1996; Greenhalgh et al., 2004; Hirsch-Kreinsen, 2016). Further studies have focused on how R&D interacts and is affected by availability of funds (Bakker, 2013; Hall, 2002; Abernathy and Clark, 1985) and policy cycles (Feldman and Kelley, 2006; Bakker, 2013; Guellec and Van Pottelsberghe De La Potterie, 2003; Radicic and Pugh, 2016), its interaction with marketing departments and costumers (Khanagha et al., 2017; Brockhoff, 2003; Gupta and Wilemon, 1996; Dix and Ganz, 2013) and with manufacturing operations (Sawatani and Fujigaki, 2016; Lin and Lin, 2012).

4.3.3. Level of analysis: organisation

Regarding innovation research focused on the ***organisation***, this provides insights into what was called in the late 90's the learning organisation (Nonaka, 2008; Crossan and Apaydin, 2010). This concerns an organisation's capacity to quickly learn and adapt to changes in its operating environment; the capacity to source, generate and integrate resources into new knowledge, knowledge that would affect overall its performance (Nonaka, 2008; Leonard-Barton, 1995; Van de Ven and Rogers, 1988). According to

Gopalakrishnan and Damanpour (1997), organisational innovation studies take a process or outcome approaches to innovation. Research taking a process approach looks into the capacity to source knowledge, to generate capacity to change and how the firm react to changing framing conditions. The capacities to change and quickly adapt are conceptualised as dynamic capabilities (Ettlie, 1980; Tornatzky and Klein, 1982; Burns and Stalker, 1961; Kirchmer et al., 2017; Van de Ven et al., 1989; Panda and Ramanathan, 1996; Teece et al., 1997; Teece, 2007; Tidd et al., 1997). Recent works have looked into the process of alignment of different organisations, seen as interacting agents of change, whereby the innovation outcomes depend on the capacity and willingness to align expectations, goals and resources across organisations (Montalvo, 2007; Wehn and Montalvo, 2017) and across organisational boundaries (Wehn de Montalvo, 2003). Such alignment is closely related to the openness of internal and external knowledge flows to accelerate innovation and create new markets (Chesbrough, 2006; Dahlander and Gann, 2010; Annala et al., 2017). Researchers taking an outcome approach have looked into behavioural (Montalvo, 2002; Montalvo, 2006; Montalvo, 2007; Lortie and Castogiovanni, 2015; Wehn and Montalvo, 2017; Lima and Navas, 2012; Sirkiä et al., 2017), structural (Antonelli, 2014; Gulati and Soni, 2015; Davis et al., 2017) and contextual aspects of an organisation (or organisations) to explain innovative behaviour and corresponding performance (Kimberly and Evanisko, 1981; Poole, 1981; Gatignon and Robertson, 1989; Burns and Stalker, 1961; Kimberly and DavisAssociates, 1986; Hirsch-Kreinsen, 2016; Gulati and Soni, 2015; Brockhoff, 2003). Models used in analyses of variance often aim to distinguish a set of factors that explain innovative and non-innovative behaviour and the respective performance of organisations.

4.3.4. Sectoral or industrial level of analysis

Innovation research conducted at ***sectoral or industrial level of analysis*** is closely related to industrial economic research approaches. The innovation research field has taken approaches that resemble an intra- and inter-firm focus in industrial economics.[11] Here we take this differentiation to cluster innovation studies at the sectoral level into intra- and inter-sectoral. These came to complement approaches of innovation systems at the national level that said little about innovation at sector level (e.g. see Nelson and Winter 1982; Lundvall, 1992). Concerning the cluster of research on ***inter-sectoral*** innovation research has received the most attention over the last three decades (Christensen et al., 2006; Pavitt et al., 1989; Acs and Audretsch, 1990; Scherer, 1984), strongly marked by the works of Pavitt (1984) and Pasinetti (1983) on the structure and patterns of innovation at the sectoral level. Research looking across sectors intends to map innovation patterns (i.e., knowledge flows embedded in technologies) across sectors and how such patterns affect structural change and growth (Mansell. and Wehn, 1998; Ipektsidis et al., 2016; Antonelli, 2014). Regarding ***intra-sectoral*** innovation research looked into how innovation differentiates the performance in companies within a sector (Dewar and Dutton, 1986; Yu et al., 2016; Mansell and Wehn, 1998; Greenhalgh et al., 2004), how changes in standards and regulations can foster or destroy market niches (Hawkins et al., 2017; Montalvo et al., 2011; Pasinetti, 1983; Lee and Malerba, 2017; Alonso et al., 2016), companies of what size are the most innovative (Acs and Audretsch, 1990; Scherer, 1984; Shefer and Frenkel, 2005), and how the timing of pioneering development or adoption of innovation affects the economic performance of companies (Dewar and Dutton, 1986; Alonso et al., 2016). Highly influential over the last two decades is the concept sectoral innovation systems (e.g. Malerba, 2002; Weber and Schaper-Rinkel, 2017). One of the main premises of the concept is that innovation systems are sector-specific, that is, these face a differentiated knowledge base, technologies, inputs and demand, thus strategies and policies seeking to support innovation must consider these sources of heterogeneity. As noted at the outset, there is very limited research on the specificities of the water (sub) sector(s) innovation systems. Both approaches (i.e., inter- and intra-sectoral) intend to explain innovation and economic performance in terms of behavioural, industrial structure, institutions or technological factors. *Behavioural factors* examples include entrepreneurship (Lortie and Castogiovanni, 2015; Pinchot, 1985; Morris et al., 2010) and heterogeneous preferences (Montalvo, 2007; Wehn and Montalvo, 2017); *industrial structure factors* include the level of R&D expenditure (Guellec and Van Pottelsberghe De La Potterie, 2003; Pavitt, 1984; Perez, 1983; Pasinetti, 1983; Antonelli, 2014; Ipektsidis et al., 2016; Fagerberg, 2000) and industry life cycles (Pavitt, 1984; Gambardella and McGahan, 2010; Barripp et al., 2004); and *technological factors* like technological opportunities (Hall and Sena, 2017; Pavitt et al., 1989; Kagermann, 2015; Phillips and Wright, 2009), appropriability conditions (Hall and Sena, 2017; Hurmelinna-Laukkanen et al., 2008; Pisano, 2006) and technical and organisational capabilities (Panda and Ramanathan, 1996; Teece et al., 1997; Teece, 2007) have been considered crucial to understand sectoral patterns of innovation.

4.3.5. Level of analysis: landscape

Innovation research looking at the ***landscape level of analysis*** has sought to identify governance leverages to best devise strategies and policies to support growth and sustainability. This type of research is clustered into three topics oriented towards strategy, demand driven and policy oriented studies. The set of studies presented in this section hold particular importance for any type of innovation. To a large extent, they are related to what some authors have called behind-the-scenes struggles amongst stakeholders defining the fate of specific innovations (Wehn and Montalvo, 2017; Osborne and Radnor, 2016; Page and Kaika, 2003; Frenken, 2017; Daniell et al., 2014). These topics have a large degree of overlap in their orientation as their underlying motivation, i.e., governance of the innovation process, can gear advice towards strategy and/or policy. Here we present some of the lasting classic and influential concepts of the last 30 years as well as emerging topics that could well become a fad over the next years.

Concerning ***strategy oriented research,*** innovation studies advance structural approaches (Mintzberg, 1989) adopting more dynamic approaches where interactions amongst stakeholders and knowledge flows play a key role to accelerate innovation. Examples of this include the new research concept and approach of *open innovation*, that provides insights into how companies use knowledge inflows to accelerate internal innovation and knowledge outflows to expand and diffuse innovation in targeted markets (Feldman and Kelley, 2006; Chesbrough, 2006; Dahlander and Gann, 2010; West and Bogers, 2014; Randhawa et al., 2016; Annala et al., 2017; Enkel et al., 2009; Bogers et al., 2017). Closely related this, the concept of *business models* has advanced, providing ontologies and archetypes to orchestrate new sets of relationships in a value network around a new value proposition (product, process, service, etc.). According to this approach, innovation in business structures that affect entire value chains in and across sectors can occur in the following dimensions: value proposition, relations with target customers, distribution channels, value configuration, core competencies, partner networks, cost structure and the revenue model (Osterwalder et al., 2005; Teece, 2010; Boons et al., 2013;

[11] 'Intra' refers to phenomena (activities, trade, research, regulations, etc.) occurring with one sector (in the literature also called vertical analysis) and 'inter' refers to phenomena occurring across sectors (also known as horizontal analysis).

Lüdeke-Freund and Dembek, 2017; Amit and Zott, 2012; Comes and Berniker, 2008; Gambardella and McGahan, 2010). Over the last decade, in Europe there is growing concern about the disparity of the levels of R&D and innovation investments and the level of new business creation, known as the European paradox (Dosi et al., 2006; Radicic and Pugh, 2016). This has given rise to a body of research looking at the ways and *strategies to upscale research and innovation* projects to the market (Lalkaka, 1996; Smilor and Gill, 1986; Hansen et al., 2000; Hackett and Dilts, 2004; Campbell et al., 1985). Amongst the instruments used to this aim since the mid 80's are incubators (Smilor and Gill, 1986; Fry, 1987; Lalkaka, 1996; Peters et al., 2004; Nowak and Grantham, 2000; Patton et al., 2009), including virtual, internet-based ones (Nowak and Grantham, 2000), which – if set up well – serve to 'nurture' firms, help them survive the start up phases and generate positive outcomes through the provision of a range of services, following the careful selection of incubated firms.

With regard to ***demand driven innovation research***, this stream of research stems from the fact that most innovation research conducted over the last decades had focused on the production side of the economy. The notion of demand driven innovation stems from the insight that the State and citizenry can play a salient role in innovation cycles. Key recent concepts include frugal and social, sustainable and transformative, and public sector innovation. Research on *frugal innovation* originally focused on the large numbers of consumers who move from the bottom of the pyramid (BoP) segments to the middle class in emerging markets, thus becoming potential customers (Zeschky et al., 2011; Soni and Krishnan, 2014). More recently, this stream of research has focused on the economic use of resources throughout the entire innovation process and the extent to which this results in products, services, and systems that are environmentally sound, of high quality and affordable for resource-constrained customers (Bhatti, 2012; Radjou and Prabhu, 2015). Closely related to this, research into *social innovation* has been characterised by two distinct schools of thought: those who argue that social innovation has an immaterial structure represented by new social practices that aim for institutionalization and social change (Mulgan, 2007; Cajaiba-Santana, 2014), i.e. implying 'all things social' as opposed to technological innovations; and those who use social innovation as a lens through which collective and societal needs that are not met by market mechanisms alone move into focus (OECD, 2011; Moulaert et al., 2013). In sum, similar to research on frugal innovation, this research considers both, the innovation process as well as its outcomes. The concept of social innovation is gaining interest in the context of the complex and cross-cutting challenges that need to be addressed in the field of water and Climate Change - and which likely will not be met by relying on market signals alone.

Sustainable and transformative innovation research is a vast area of inquiry that looks at the demand side (consumption) and supply side (production) and their potential effects on the sustainability of society. Building in concepts of systems of innovation, scholars have offered frameworks to describe potential patterns of the governance of innovation (Adams et al., 2016; Rennings, 2000; Geels, 2004; Smith et al., 2005; Carrillo-Hermosilla et al., 2009; Montalvo, 2008; Montalvo and Kemp, 2008; Schot and Steinmueller, 2016; Hekkert and Negro, 2009; Montalvo et al., 2011). Adams et al. (2016) offer a recent review on sustainability oriented innovation. In particular, scholarly works found in the Journal of Cleaner Production have made a significant contribution to the understanding of the role of innovation supporting sustainability and welfare e.g (Boons et al., 2013; Montalvo, 2008; Montalvo and Kemp, 2008). Demand driven innovation research has also looked into *public sector innovation* concerning the role of government promoting sustainability and growth. Some authors examined innovation in government and public services (De Vries et al., 2016; Brown et al., 2016; Osborne and Radnor, 2016). This interest stems from the realisation that governments have three major means of leverage to support R&D and innovation, namely regulation, public procurement and fiscal instruments (De Vries et al., 2016; Selviaridis, 2016; Edler and Georghiou, 2007).

Policy oriented research Innovation policy oriented research arises from the realisation that technical change has an effect on growth and welfare (Schumpeter, 1934). Since then, we have seen concepts guiding research that have evolved from descriptive models to more sophisticated ones that aim to account for more granular analyses at the national level, to the regional/sectoral and to networks and ecosystems. Akin to all approaches are knowledge and resources flows, the roles of actors and their interaction and mutual influences. Here we account for the most influential concepts like systems of innovation (national, regional, sectoral), innovation ecosystems and networks and recently upcoming innovation and complexity and mission oriented research and innovation.

Research into *systems of innovation* stems from the seminal works by Freeman (1987), Nelson and Winter (1982) and Lundvall (1992). This literature considers innovation as a process of interactive learning that improves the competencies of actors so that value of socio-economic benefit for society can be created from knowledge. According to this system-level view, knowledge is created and distributed among each country's institutions (Gu and Steinmueller, 1998). The widespread and rapid diffusion of ICTs have increasingly accelerated the process of knowledge creation and diffusion from the 1990s onwards (Mansell and Wehn, 1998). With a strong focus on the role of institutions (Soete et al., 2010), this line of policy-oriented research aims to produce analytical tools to study the functions of innovation systems (e.g. Hekkert and Negro, 2009), processes and mechanisms (Rip and van der Meulen, 1996) and the quality of relationships between innovation system actors, among others (Weber and Truffer, 2017). The scope of innovation systems research has also been extended to tackling questions of development and debated the applicability of the innovation system concept to developing countries (Lundvall et al., 2009; Morrison et al., 2008; Dutrénit and Sutz, 2016; Bell and Pavitt, 1997). The realisation that national systems could not account for intersectoral differences in the patterns of innovation, Malerba (2002) introduced the notion of sectoral innovation systems, a concept that aimed to account for sectoral specificities. Similarly, others have focused on the regional specificities of innovation (Howells, 1999; Cooke et al., 1998).

Seeking to find leverage to create new value chains enabling new products and services, scholars turned to the idea of *orchestrating ecosystems of innovation* (Dhanaraj and Parkhe, 2006; Valkokari et al., 2017). A concept that naturally evolves from regional and sectoral innovation research, fertilized with conceptualisations of innovation networks (Camagni, 1991; Tsai, 2001; Pittaway et al., 2004), business models innovation (see sections above) and incubators (see sections above), seeking to upscale new technological opportunities to create new markets. A new stream of research is looking in more detail into heterogeneous preferences and endowments of different actors in a given ecosystem that gives rise to innovations. Arguably, innovation is both a guided endeavour at the local level with emergent properties at the aggregated level. This fact leaves research and policy making with the peculiar challenge of trying to find leverage points to steer a complex social phenomenon that by definition is non-governable (see Montalvo, 2007; Davies and Brady, 2000; Hobday and Rush, 1999; Frenken, 2006; Rycroft and Kash, 1999; Frenken, 2017; Marks and Gerrits, 2017; Poutanen et al., 2016).

In turn, *mission oriented policy research* to a large extent overlaps with demand driven innovation concerning the role of the State promoting innovation. The mission orientation stems from the need to address grand societal challenges, such as climate change, environmental degradation, water scarcity, energy provision, healthy living, aging of population, etc. The underlying notion of this policy approach is that investments into innovation can yield a double dividend. That is, while aiming to tackle societal challenges via innovations, new solutions can underpin the creation of demand for new products and services. For example, demands to reduce CO_2 in the atmosphere is triggering subsidies to support the demand for electric vehicles, thus creating new markets (see Weber and Schaper-Rinkel, 2017; Wright, 2012; Sampat, 2012; Veugelers et al., 2015; Anadon, 2012; EC, 2011; Hall et al., 2003; Foray et al., 2012; Edquist and Zabala-Iturriagagoitia, 2012; Fagerberg, 2017).

4.4. Measurement, evaluation and impact assessment

This last dimension of innovation studies is of a horizontal nature and thus relevant and applicable to all other three dimensions. The importance of innovation measurement is already implicit in the early theoretical and empirical works of Arrow (1962) and Schmookler (1966) who analysed the impacts of invention on welfare. Measurement is required to check the spread of innovation diffusion in markets (see Rogers, 2010) but also to establish the validity of theoretical propositions made in terms of the effects of innovation, what factors affect innovative activity and performance and welfare derived from innovation. To this end, the evolution the Oslo Manual over the last two decades has offered a set of harmonised indicators in use in OECD member states (see OECD-EUROSTAT, 2005). One of the most comprehensive collections of indicators related to innovative activity and relative performance is offered by the European Commission (2014). Scholars conducting research on this topic have addressed issues such as measuring the impact of innovation on productivity, employment and growth (OECD, 2005; Gago and Rubalcaba, 2007; Mansury and Love, 2008; Atrostic, 2008; Vallejo and Wehn, 2016); some have attempted to develop unifying frameworks for the measurement of innovation management, so far without empirical testing (Adams et al., 2006). Despite these comprehensive efforts, the frameworks and data infrastructures available show some limitations (Bloch, 2005; Van Bavel et al., 2010; Bain and Kleinknecht, 2016). Future directions for innovation measurement are indicated by Hipp and Grupp (2005), Bain and Kleinknecht (2016), incl. the challenges that new concepts such as complexity of innovation pose as well as the availability of Big Data sources that are vastly untapped (Still et al., 2012; Alexander, 2016).

5. Themes of the papers in this Special Volume

The contributions of the authors included in this SV cover water innovations in all three functional categories of the water sector: integrated water resources management (Duijn, 2017; Grotenbreg and van Buuren, 2017), water infrastructure (Bikfalvi et al., 2017; Kreijns et al., 2017), water services (Tutusaus et al., 2017; Garrone et al., 2017; Sousa-Zomer and Cauchick Miguel, 2017; Tanner et al., 2017; Wehn and Montalvo, 2017; Bichai et al., 2017; Gabrielsson et al., 2017; Annala et al., 2017; Worm, 2017) and cross-cutting (Nagel et al., 2017; SchmidtBauer et al., 2017), whereby the highest number of contributions notably falls into the water services category. Together, these contributions cover case studies from different continents and regions around the globe. Moreover, this SV contains a number of 'Notes from the Field', i.e. practitioners' accounts of their initiatives to foster water innovation. It is noteworthy that some of these initiatives do not squarely fall within one of the functional water sector categories but cut across two or all three. We discuss all contributions in turn below.

5.1. The innovation knowledge base: competencies and capabilities

Thematically, the paper by Bikfalvi et al. (2017) is related to products and services in the water infrastructure sector. They describe and test an organisational innovation in water education (*type*). Their empirical evidence stems from 18 international, competence-based internships that are piloted (*stage*) as part of a pan-European project in Austria, Belgium, Germany, the Netherlands and Spain and that are embedded in a knowledge alliance in the water sector (*level*), involving students in R&D. This multi-stakeholder international collaboration between universities and companies has the aim of training the future workforce better trained for business needs by reducing the gap between graduate-*acquired* and employer-*required* competences. As part of their assessment of the competencies required and practiced in water innovation projects, they find that the companies involved in the collaboration prefer and award development priority to generic rather than water-specific competencies.

Duijn (2017) examines the value and impacts of providing facilitated reflection on professionals' innovation practice (*type*), namely reflecting on innovation in public policy for water management in The Netherlands. Driven by the recognition that 'normal policy making' will no longer suffice given the challenges for water management induced by climate change, professionals of the Dutch ministry of Public Works and Water Management were involved in an innovation program (*stage*) as a community of practice to promote durable and novel solutions. Based on an action science approach, facilitated reflection was provided for the professionals involved in the water management innovation program to deliver specific insights on their individual and collective innovation practices. Using the generated insights, interventions could be designed to promote change in this community of practitioners, thus enhancing the community's capacity to learn. Duijn (2017) finds that the impact on individual innovation practice was stronger than at the collective level; the achieved impact at the collective level was nevertheless important since the program's substantive focus was realigned during its implementation. Duijn (2017) suggests that facilitated reflection helps to identify the possibilities for policy change and improvement and guides their actual and targeted implementation in practice.

Grotenbreg and van Buuren (2017) examine how local authorities (*level*) employ their administrative capacities (*type*) in spurring innovation (*stage*). They compare four cases of attempts in the Netherlands to realize integrated energy and water works (type), i.e. infrastructure that combines water safety and sustainable energy generation. As such, they focus not only on public-private interaction in the innovation process but, thematically, also on the water-energy nexus. Despite broad support for such innovative, multifunctional works, in the Netherlands they have had varying degrees of success. Distinguishing four administrative capacities, Grotenbreg and van Buuren (2017) find that all four have to be employed to realize integrated energy and water works: *regulatory* capacity to adjust policies and regulations; *delivery* capacity for financial resources; *analytical* capacity to provide the necessary information; and *coordination* capacity to bring together relevant stakeholders. The four capacities do not have to be employed by one single public actor; rather, different authorities can complement each other as long as there is public alignment. Importantly, they find that while public authorities have a salient coordination role in the innovation process, contributions such as 'bringing actors together' and 'facilitating their collaboration' are found to be insufficient.

Finally, Wehn and Montalvo (2017) apply a behavioural approach to innovation in their study of Water Operator Partnerships (WOPs). WOPs are peer-based partnerships (*level*) between water operators (utilities) to strengthen the capacity (individual competencies and organisational capabilities) (*type*) of the mentee operator. While the other papers in this SV apply innovation studies to examine the dynamics of water innovation in detail, Wehn and Montalvo (2017) use WOPs as salient cases to contribute to theory building, testing their multi-disciplinary approach to studying knowledge transfer (*stage*). Innovation systems theory stresses the central importance of knowledge and the transfer of knowledge between the different actors of an innovation system but lacks approaches to systematically analyse the dynamics of such relationships. The approach by Wehn and Montalvo (2017) makes use of insights from the behavioural sciences in order to explore the dynamic interplay of the conditions under which a knowledge provider would be more likely to engage in knowledge transfer and the conditions that might limit and determine the willingness and ability of 'potential knowledge recipients' to gain access and internalise new knowledge. Although Water Operator Partnerships are conceived to share best practices via knowledge transfer, their findings based on empirical evidence indicate clear points of consensus as well as issues of conflict in the dynamics of knowledge transfer between water operators engaged in such partnerships.

5.2. Innovation selection and adoption

The paper by Garrone et al. (2017) focuses on the adoption (*stage*) of new, environmentally-friendly wastewater treatment technologies (*type*) by utilities and investigates why stringent environmental regulations are not sufficient to foster it. The adoption of advanced wastewater treatment technologies is complicated by the sunk nature of highly specific infrastructure and the consistent exposure of utilities to political and institutional influences. In addition, various actors (utilities, suppliers, contractors) are directly involved and distinct and unaligned stakeholders (communities, business users, citizen associations) exert their influence. Garrone et al. (2017) examine two dimensions (*level*): (a) the role played by firm-specific characteristics, i.e. technological and organisational capabilities and managerial professionalism; (b) the influence of community-level factors, i.e. the pressure exerted by local stakeholders, including citizens. Based on their investigation of 11 wastewater utilities in North Italy, they suggest that firm-specific resources can spur wastewater utilities into the adoption of innovation, even in adverse institutional environments. Nevertheless, their analysis also shows that residents and local private sector actors are able to mobilize resources and exert pressure to either drive or hinder the adoption of these water innovations.

Tutusaus et al. (2017) also examine the adoption of innovation (*stage*) in the water services sector, namely information and communication technologies (*type*). Although ICTs in principle have the potential to increase productivity, improve efficiency and eventually raise the quality of water services, there is great variation in the way water utilities adopt ICTs. Examining environmental, organisational and individual factors (*level*) to explain technology adoption, the paper pays particular attention to the idiosyncrasies of the water services sector which influence this process: the social and economic importance of water supply, the monopolistic nature of the sector and increased commercialization of public water utilities. Similar to the findings by Garrone et al. (2017), the results of their empirical research in three case studies (a municipality in Greece, an airport in Italy and a water utility in the Netherlands) suggest that the drivers of technology adoption appear to be somewhat ambiguous in the water services sector, in that they impact adoption differently in diverse locations. Moreover, they suggest that the importance of the factors that determine adoption is dynamic and changes over time.

The paper by Tanner et al. (2017) examines the factors that influence the development and adoption of innovations (*stage*) in the investment process (*type*) by utilities concerned with water and sewerage service delivery (*level*). They documents the process of innovating the infrastructure investment process in a large, privately owned UK water and sewerage utility. For UK utilities, the capacity to innovate capital investment processes and consequent performance outcomes is essential for their efforts to deliberately change infrastructure to improve the sustainability of service delivery within a comparatively regulated framework. The findings by Tanner et al. (2017) suggest that the development and adoption of innovations in the asset investment process tend to be skewed in favour of opportunities that align with (i) UK and European Union legislative and regulatory drivers; (ii) the utility's mission policy and goals; (iii) innovation cost advantages over a prescribed period of time; (iv) perceived risks to service provision associated with the introduction of the innovation, and; (v) the extent to which the organisational processes and cultures, which serve to increase the absorptive capacity of the utility to the proposed innovation, are already functioning.

Bichai et al. (2017) employ a cross-sectoral model that draws on theories of technological innovation systems, system dynamics, transitions of socio-technical regimes, and evolutionary theories of technology, to diagnose implementation barriers (*stage*) for water recycling (*type*) in arid regions. Cases from three water-scarce countries with distinct political economies (Australia, the United Arab Emirates and Jordan) are used to document the dynamics of innovation in the water recycling system (*level*) and identify policy solutions. Despite important differences between these countries, the analysis by Bichai et al. (2017). suggests that major barriers across all three countries occur at the same key stages. With developed wastewater treatment facilities, Australia faces less 'production' barriers than the two Middle Eastern countries, but existing centralized water supply and sewerage systems create a path dependence barrier at the 'selection' stage. In the U.A.E., oil-based wealth as well as subsidies favour desalination at the selection stage as opposed to more sustainable practices including recycling options, creating another form of path dependence. Significant political barriers to effective water recycling implementation in both Middle Eastern countries also exist at the selection and 'initial adoption' stages, namely due to a lack of enforcement of existing guidance for non-potable reuse. They suggest that rather than a 'mere' crisis, the implementation of water recycling requires coordinated, long-term planning with a collective vision and complete economic assessment.

5.3. Demand-driven innovation: co-production and sustainable business models

Annala et al. (2017) examine the claim that frugal innovation, with its promise to increase affordability, assures social impact in resource-constrained environments (*level*). They do so using the case of low cost household water filters using reverse osmosis technology (*type*) in Ahmedabad, one of the fastest growing cities in India. They confirm that the active role of citizens as co-producers in the innovation process (*stage*) allows local small scale entrepreneurs to customize their products and services to the needs and price expectations of their customers. They find that the co-production process, facilitated by the proximity of the local entrepreneur with the end users, has not only reduced costs typically borne by the users; the involved entrepreneurs have also more successfully met the diverse needs of their end users than their more expensive counterparts have been able to do. Nevertheless, while the private value created by this frugal innovation is applauded, Annala et al. (2017). recommend that the social implications of this contested and unregulated technology require further examination.

De Sousa-Zomer and Cauchick Miguel (Sousa-Zomer and Cauchick Miguel, 2017) argue that while technologies in the water sector have been advancing over the past few decades, complementary innovation in business models (*type*) is needed to support the adoption of these technologies. Specifically, their paper explores the role of sustainable business models to support the adoption (*stage*) of technological innovation for water quality improvements. Their case study in Brazil focuses on a community-scale water treatment system (*level*) that employs a reverse osmosis process and which is installed at commercial establishments, thus providing common access after re-treating the water provided by the centralized public supply network at the point of use. They compare the sustainability potential of this setup with the provision of bottled water which is widely used in the region (due to a lack of trust in the quality of water from the public supply network) but considered unsustainable due to the practices involved in drawing on water from an underground spring. Their results demonstrate that consumer acceptance, risk perception and confidence in decentralized water supply technologies can be improved by suitable a business model in which the value proposition closely matches customer demands.

5.4. *Fostering innovation via incubation, acceleration and demonstration sites*

Gabrielsson et al. (2017) explore the promotion of technological water-related innovations (*type*) through networked acceleration (*stage*) in their analysis of the Water Innovation Accelerator (WIN) for the water and sanitation sector in Sweden, a virtual network-centred incubator model (*level*). WIN offers a virtual community that supports SMEs by providing a market arena, tailored business coaching and assistance with financing. Informed by theory and research on open innovation, incubation models, and entrepreneurial networks, Gabrielsson et al. (2017) provide an overview of the WIN design, management and organisation and assess its performance in relation to its purpose to aid the development and market uptake of water-related innovative solutions via its networks. Their findings suggest that the benefits perceived by SMEs are highly dependent on the stage of their innovation in the process (i.e. better for those close to commercialization) as well as geographic proximity to the incubator network.

Nagel et al. (2017) report on the VIA Water incubator for water innovations in Africa in their 'Note from the Field'. VIA Water is a Dutch programme (*level*) designed to stimulate and support the co-creation (*stage*) of innovative solutions for water problems in African cities. To be considered for support, the idea needs to focus on one of the seven VIA Water countries and on one of the twelve 'pressing needs' in an urban context that VIA Water had identified. These needs are related to IWRM, water infrastructure as well as water services. VIA Water supports innovations that have just come out of the research phase (*type*) and which require a piloting period focusing on all aspects of business development rather than mere testing of the technology. A key component of the programme is the knowledge exchanges that are facilitated among the incubatees, via an online and F2F learning community.

The 'Note from the Field' by Kreijns et al. (2017) reports on efforts to foster the uptake (*stage*) of technical delta innovations (*type*) via thematic demonstration sites (*level*). Although such radical, technological innovations are urgently needed as solutions for effective and impactful water management in vulnerable delta areas, their adoption is characterised a) by the perceived high risks and high costs in the face of unproven and typically long term benefits and b) the difficulty for the SMEs providing such innovation to break into 'the old boys' network' of water managers trusting existing solutions. Kreijns et al. (2017). reflect on their own, practical experience with setting up and running thematic demonstration sites as a means to overcome these obstacles and to help speed up the uptake of innovative products in the market. They suggest four essential aspects for success: an independent promoter of the site; involving three major parties: local and regional government, academia and private sector actors (a range of small and large companies as well as start-ups); sufficient initial funding and, although perhaps obvious, an openness for testing innovative solutions.

The 'Note from the Field' by Schmidt et al. (2017) reports on the approach and interim results of the European Innovation Partnership on Water (EIP Water) which is an experimental, demand-driven and flexible initiative (*level*) within the framework of the EU 2020 Innovation Union; its overall objective is to facilitate the development (*stage*) of more innovative solutions to water challenges (*type*). This initiative cuts across all three functional categories of the water sector. The EIP Water has identified the removal of persisting barriers and bottlenecks to innovation in the European water sector as an urgent action, prioritising changes in funding schemes, public procurement, set up of partnerships, regulation and improved dissemination.

Finally, the 'Note from the Field' by Worm (2017) reports on the work of the Technology Approval Group (TAG) (*level*). The fundamental values of utilities, namely continuity of service, limitation of risks, and cost efficiency, can be conflicting with the essence of testing and applying innovative technologies. Moreover, water utilities need technologies (*type*) to be more efficient, limit environmental impact, comply with increasingly stringent legislation and meet with the continuously changing customers' demands and expectations. The TAG identifies and preselects (*stage*) the most relevant innovative technologies for more than 150 municipal and industrial TAG-members worldwide. As such, it enables its members to share the risks and costs of testing while allowing solution providers to gain their initial references and enter the market.

6. Way forward for water innovation studies

This SV was designed to lay the foundations for the field of water innovation studies. To this end, the review of the literature of the last three decades found that during the first reviewed decade (mid 80s-mid 90s), there were very few publications on the topic of water and innovation, that the term water innovation appeared in publication for the first time less than 15 years ago (2004) and that the limited number of publications since then has barely engaged with the field of innovation studies and had very limited impact. As mentioned at the outset, recent years have seen large strategic efforts on water innovation, by different types of funding mechanisms (e.g. in Europe: Horizon 2020, the Water JPI (Water JPI, 2016) and associations (the Water Supply and Sanitation Platform (WssTP) (Weerdmeester et al., 2017b)) to identify research and innovation gaps in view of water-related short and long-term challenges. Yet our understanding of the dynamics of the innovation path dependencies in the water sector is still limited. Given the scope and nature of the contributions included in this SV that were introduced above, in this section, we reflect on the way forward for water innovation studies with suggestions for future research.

As we noted above, most of the contributions in this SV fall within *one* of the **functional categories of the water sector**, namely the water services category. The other functional categories of the water sector (water resources management and water infrastructure) have attracted far fewer contributions, also outside this SV. Additional attention should therefore be paid to dynamics of innovation in these functional categories of water management (and their subcategories, e.g. water for production and hydropower, urban and rural water supply and sanitation, water-related disasters).

Another axis concerns water innovation studies research on **the demand and supply sides along the water value chain**. Among the water users, interestingly, the agricultural sector – the largest water user in most countries – has long attracted the attention of innovation studies and has been explored from a systems perspective of agricultural innovation systems (e.g Hall et al., 2003). Studies are still required to examine the water innovation dynamics related to industrial water users as well as households. Moreover, one of the most acclaimed challenges facing the sector across all three functional categories - but water services in particular - is related to water governance, i.e. how decisions related to water are made, often with varying degrees efficiency, effectiveness, and trust and engagement of all stakeholders (OECD, 2015). Both technological and non-technological innovations may present opportunities for much-needed changes. Digital transformations in particular *can* enable new forms of stakeholder engagement, participation in decision making and even governance structures but will not do so automatically. Given the multi-stakeholder setting prevalent in many areas of water management and advocated by the paradigm of Integrated Water Resources Management and water governance principles, the water sector may be more prone to derive such positive outcomes from digital transformations. Nevertheless, as other innovations, ICTs entail opportunities as well as disruptions and barriers. Action research is required to steer these technologies in desirable ways and to derive their social innovation potential.

We suggest that both types of water innovation studies are required: studies with a focus on the specific water sector subfunctional categories as well as cross-sectoral approaches – referring to interactions and interdependences of the water sector with other sectors supporting and/or creating social and resources trade-offs, i.e., at the Water-Energy-Food Nexus, considering the interoperability of technologies, institutions and networks.

From another perspective, it is also noteworthy that the contributions to the field of water innovation studies (in this SV and elsewhere) thus focus far more on the **demand side of innovation**, i.e. the adoption of innovations by water managing organisations, what hampers the diffusion and utilization of water innovations and what can be done to overcome such impediments. Yet equally important are the **innovation supply side dynamics** at play for the solution providers of monitoring equipment, decision support systems, infrastructure construction, pipe manufacturing, pumps and electronics, chemicals, etc. Questions here concern the process of technology development within and across value chain networks, approaches to customer and needs identification, competitiveness of these companies within and across countries, national specialisation and whether and how this is related to the water security situation in the host country.

The effects **ICT-based innovations** for water-related activities are likely to extend much beyond current improvements in sensing, monitoring and smart metering, citizen observatories, hydroinformatics and modelling, and robotics. Digitization will continue to affect processes related to the management of water quantity and quality. Water innovation studies should examine the Industry 4.0 developments that are reshaping other sectors (i.e. the combination and convergence of sensor technologies and robotics transforming industrial systems and manufacturing) and their implications for the quantity and quality of water-related employment opportunities (i.e. changes to relevant knowledge, skills and capabilities), thus supporting the sector in shaping what Water 4.0 (GWP, n.d.) means in practice.

Water innovation systems, i.e. the learning, innovation and competence building systems for improving the competencies of actors so that value of socio-economic benefits for society can be created from knowledge, require due attention to enable the transition towards water smart[12] or water wise[13] societies. Managing individual and organisational learning processes to ensure that they result in the (improved) application of knowledge by individuals and in collective changes such as improved organisational routines and procedures, as well as innovation, is crucial. Research should examine how these processes differ for water managing and water using organisations and from organisational learning and knowledge management in other areas and how they can be effectively addressed.

Finally, indicators, tools and methods are required to **measure water-related R&D and innovations** at appropriate levels of detail and to analyse sources of structural changes and their impacts on competitiveness, employment, productivity, economic performance in helping to ensure equitable, short and long-term water security.

The definition of water innovation, the taxonomy of innovation studies provided in this paper and the reflections presented here suggest a concrete way forward for studying these dynamics of water innovation, to accompany the implementation existing strategic efforts to foster water innovation for a water secure world.

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[12] As envisaged by the WssTP.
[13] As envisaged by the International Water Association.

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