THE GOVERNANCE OF MAJOR INNOVATION IN THE WATER CYCLE

EXAMINING THREE PROMINENT TECHNOLOGIES[1]

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Abstract

The growing absolute and relative waterscarcity requires drastic change in the water cycle in order to target an efficient and robust water supply. This article addresses the questions whether (1) the market is capable of adopting such radical changes needed, (2) which hindrances have to be navigated and (3) whether and how policy could help. These questions are elaborated by assessing the roles of three prominent new technologies in the water cycle in the Netherlands. First the three technological innovations are introduced and described, the first resulted in new technology for wastewater treatment plants (Nereda©), the second deals with a particular water pollution issue (Pharma filter©) and the third is about decentral sanitation (DeSah). This is followed by an analysis of the process of market adoption of each of them, including the emerged hindrances. Arguments for a more prominent watercycle policy are thereafter derived from literature on welfare theory and empirical observations. Finally an outline of stepping stones for governance strategies and conditions for such an innovation policy are provided. The water cycle consists of the production of water, wateruse, collection of waste water and its treatment. With regard to relevant policy domains we distinguish between research policy, innovation policy and sector policy. A balanced combination of research policy, innovation policy and sector policy is needed to address the challenges with reagard to future water supply. With regard to processes we distinguish the phases of research, development, market introduction and market adoption.

1. Introduction

Only 2,5% of the worlds water resources consists of freshwater, of which more than 60% is to be found in glaciers and ice. The growth in population, urbanization and welfare leads to a steep increase in the demand for clean water. This leads to absolute and relelative water scarcity. Both are rapidly growing around the globe. Relative water scarcity refers to economic scarcity, i.e. the situation in which many citizens cannot afford water of good

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quality. It is expected that the supply of good drinking water quality will fall short by about 40% by 2030 unless the international community improves water supply and water cycle management drastically. Demand for water is expected to increase by 55 per cent by 2050 while 20 per cent of global groundwater is already overexploited (Unesco, 2015).

Also for the Netherlands, where there is ample fresh water at first sight, scenario's indicate a 20% shortage in 2050 (Van der Aa, cs 2015). Relative water scarcity is in the Netherlands also an issue of concern, altough not so much with regard to the price of drinking water itself. Especially the related taxes/fees that have to be paid by citizens and companies are increasing rapidly. These fees have to be paid in order to cover the costs for collecting and treatment of waste water (Bressers and Lulofs, 2004). Nowadays compliance to water quality standards for aquifiers, lakes and rivers can only be reached at high costs. Contemporary and strict water quality standards and compliance are crucial. So vulnerability of fresh water supply is substantial and risks and resiliency of water resources represent key issues within water policy, also in a developed country such as the Netherlands.

National and regional Dutch authorities jointly committed themselves to reduce the expected increase in costs for the water cycle, to improve the quality of the water cycle, to reduce the vulerablility an avoid relative water scarcity (Bestuursakkoord Water, 2011). In the long run radical changes and innovations are needed, certainly in comparison with the often incremental steps taken in recent decades. In order to facilitate cost-effective delivery of water services, a more efficient and robust water cycle is called for. The water cycle consists of production of water, wateruse, collection of waste water and its treatment.

The progress in handling these challenges was monitored and analyzed in two national advisory committees to the Dutch minister of Infrastructure and the Environment. These committees explored the future of the water cycle in the Netherlands, concerning among others the appropriate roles of technological innovation, innovation policies and governance (Adviescommissie Water, 2015; Visitatiecommissie Waterketen, 2015). The committees had to assess why alternatives to reduce costs in the water cycle are neglected and why radical innovations in the water cycle to improve the quality, struggle with regard to market introduction and adoption.

In this paper we address whether (1) the market is capable of adopting such radical changes needed, (2) which hindrances have to be navigated and (3) whether and how policy could help. The questions will be elaborated by assessing the innovation paths of three prominent new technologies in the watercycle in the Netherlands. The selection of cases is non random, we selected the cases based on prior knowledge[2]. With regard to the process of these desired radical innovations we distinguish the phases of research, development, market introduction and market adoption (Schumpeter, 1942). With regard to policy domains we distinguish between research policy, innovation policy and sector policy.

[2] The analysis in this paper is among others based on membership and work of the authors in the referred to national advisory committees. These committees are the *Adviescommissie Water* that reviewed technological innovations and barrieres for market adoption and the *Visitatiecommissie waterketen* that monitored and facilitated change in the water cycle in the context of the agreement between national and regional governments.

The structure of this paper is that we start in §2 by describing the three technologies, the first focusing on installed secondary technology in waste water treatment plants (Nereda©), the second focusing on a particular water pollution issue (Pharma filter©) and the third focusing on decentral sanitation (DeSah). This will be followed by an outlook on market adoption of each of them and emerged hindrances. Arguments for a more prominent watercycle policy are derived from literature on welfare theory and empirical observations and are presented in §3. Finally in §4 an outline of stepping stones for governance strategies and conditions for such an innovation policy will be given.

2 Innovative technologies reviewed

With regard to waste water treatment in the Netherlands, like in other countries substantial efforts on cleaning polluted surface waters led, since 1970, to a grid of mostly large scale public waste water treatment plants. The plants are operated by regional water boards, an extra layer of governments in the Netherlands, with own taxation rights. In these plants waste water from households and companies and storm water is treated, the waste water is collected and transported to the treatment plant through the sewage system.

Installed technology in the relatively large Dutch public waste water treatment plants includes at least primary and secondary technologies. Primary treatment technology includes purification processes of physical nature such as filtration, centrifugal separation, sedimentation and gravity separation. Secondary water treatment includes biological routes for the removal of pollutants by microbes.

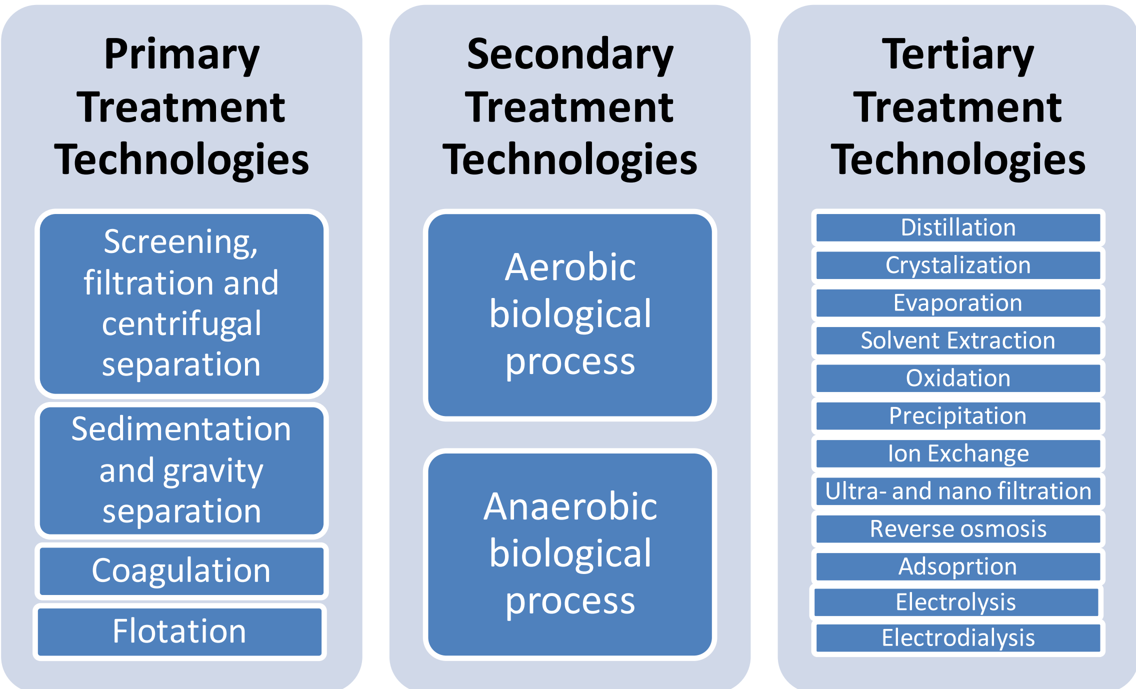

Figure 1: Classification of water treatment technologies

Source: based on Gupta c.s., 2012, page: 6381.

In recent years innovations were developed and installed in secondary treatment technology of plants for the biological removal of nitrogen and phosphates. These became necessary because otherwise it would be impossible to comply to strict water quality standards with regard to nitrogen and phosphates. Recently water boards also worked on issues such as process optimalisation and recovery of energy within treatment plants. Also the recovery of other valuable substances in waste water, substances that can be resold if recovered, is on the agenda of the water boards. Other recent challenges include the removal of micro-pollutants such as the residuals of medication, among which hormones. Still installed technology is predominantely primary and secondary technology.

If regulations will become even stricter new tertiair technologies have to be added or the system of treatment has to be changed drastically. Figure 1 illustrates that multiple tertiary treatment technologies are available focussing on a variety of issues and pollutants. And research and development still continious. If additional tertiary technology is needed the question becomes urgent where and how these can be applied most effective. Upgrading the effluent of the treatment plant by ultra and nano filtration is a likely and already tested addition. In large public waste water treatment plants such tertiary technologies easily become cost–ineffective due to large volumes of water and small concentrations of pollutions. So also other more cost effective alternatives are sought after. These might include a more integral approach to the water cycle and technology that connect multple segments.

In this context we will now describe the principles and market adoption of Nereda© (waste) water technology, Pharma filter© technology, and DeSah technology. These cases are non-random selected, the argument to select and present them is that each come with specific observations and lessons with regard to the now elaborated central problem statement and questions of this paper. So cases should be helpfull to assessing whether and under which conditions the market is able to create and absorb radical changes.

The principles of Nereda©

Installed technology in traditional Dutch large scale public waste water plants thus includes secondary technology. The aerobe, semi-aerobe and anaerobe biological treatment processes require multiple basins and a substantial amount of energy is needed for pumping. Futhermore the process of sedimentation in the basins takes substantial time which also adds to inefficiency. Finally substantial volumes of sludge are produced. In countries with contemporary waste management regulations this comes with high costs for waste management. The costs of operating the often 30-40 years old Dutch installations are steeply increasing, among others because of the referred to recent investments in additional technology for removal of nitrogen and phosphates. These older plants contain three subsequent basins in which respectively the anaerobe bacteria, the semi aerobe bacteria and the aerobe bacteria do their work.

Research on alternatives for this installed secondary technology started in the 1960s. It took a long time before the concept of Nereda© entered the phase of development. This sluggish process eventually led to the market introduction of the Nereda© technology. The radical change boils down to the fact that Nereda© bacteria grow in granules while traditionally the purifying bacteria grow in flocs. The granulate includes layers of aerobe, semi anaerobe and anaerobe bacteria, this implies that no longer three subsequent basins are needed in the water treatment plant. This implies that the process can take place in one basin instead of the multiple basins that are required by traditional secondary treatment processes, while additionally the sedimentation process proceeds extremely fast compared to the use of flocks in three subsequent basins. The process reduces the use of energy by circa 30% and recovery of nitrates and phosphates is relatively easy without using much chemicals[3].

Market adoption of Nereda©

The phase of development was based on the outcomes of a substantial research program and led eventually to the construction of a small pilot plant. During the test period the pilot plant performed better than expected and the Dutch water board water board Veluwe was convinced that it should act as launching customer. The waterboard Veluwe then acted as launching customer in the municipality of Epe for the first full scale plant.

Figure 2: The first full scale Nereda plant (the plant consists of three basins in a parallel order)

Source: Wikipedia (https://en.wikipedia.org/wiki/Aerobic_granulation)

The built full-scale plant proved to be substantially more efficient in terms of costs and space. Another water board (Rijn en IJssel) then decided to build the second plant. This second plant is located in the municipality of Dinxperlo and is embedded in an so called 'eco-water-garden'. In order to reach out for this an old land fill for municipal waste was restructured into a blue-green nature area that serves as natural after-treatment filter as well as recreational area. The strategy was to dig out and isolate polluted soil, followed by a transformation of the area into

[3] See for a video that explains more details of Nereda©: https://www.youtube.com/watch?v=P6fWCEHPt_0

a water garden, including walking tracks, which added some recreational space[4]. The project was planned, programmed and realized in cooperation with the municipality. In Dutch water cycle management, the municipality is responsible for collection of waste water and the sewage system.

A third plant followed soon and was built at Vroomshoop. This plant was engineered as a hybrid plant, a combination with an existing plant in which the active sludge secondary process remained in operation. The argument for the combination was derived from the varying supply of water, depending on precipitation. Though another strategy might be preferred for reasons of efficiency in the water cycle, being to reduce the amount of rainwater in the sewage system. This is also on the water cycle policy agenda but requires strong cooperation with the municipalities. In the Dinxperlo case the seedbed for such cooperation might be created, in the Vroomshoop case this was on short term not possible and the water board had to act alone. This limited efficiency and led to the choice for the hybrid plant.

Meanwhile Nereda© had proven its market potential, especially its flexibility and robustness caught attention. It is not that Nereda© is a solution for all treatment issues, but its strength is that it functions as stand-alone system, consumes little space and energy and can perform far more efficient than the conventional active sludge process. This enabled access to the world market. At the moment there are 20 Nereda© plants on 4 continents[5]. Many perceive the fact that the technology (its patents) were bought by a large worldwide operating consultancy company as the key to connecting to the worldwide markets. Nevertheless, an evenly influential factor in the Dutch context was that effluent limits in permits became stricter. Those for nitrogen nowadays are often lower than 5 mg per liter, those of phosphate 0,5 mg per liter. It made decision-makers receptive to alternatives. This was in the Netherlands an important driver to update some older public water treatment plants, and made the Dutch water boards acting as "launching customers" creating showcases for the technology and proving its technological soundness.

The principles of the Pharma filter©

Relatively new on the water pollution agenda is the issue of residuals of medication, which in fact threaten the quality of water resources (Metz, 2015). For instance micro pollutants such as antibiotics could lead to resistant bacteria which might endanger human health. Removal of these substances in large public water treatment plants gets extremely costly if technology for these micro pollutants is installed. Nereda© does not solve this, neither can tertiary treatment technology in large scale water treatment plants do this at acceptable costs. Cost effectiveness of removal is extreme low due to the large volumes of water and low concentrations of pollutants.

Therefore another strategy was chosen and the Pharma technology was developed as a decentral sectoral water treatment package for hospitals. As such it was inspired by decentral industrial waste and water treatment technology, that often aims at relatively concentrated pollution loads. The Pharmafilter© is a package that can deal with all hospital waste. A special feature of the Pharmafilter© is that it offers a combined package for water treatment and

[4] See for a video presentation: https://www.youtube.com/watch?v=whbKKTICVBI

[5] See http://www.royalhaskoningdhv.com/nereda

management of solid organic waste. Organic hospital waste, among which leftovers from food, urinals and bed-pans is shredded in the so called Tonto.

Figure 3: Tonto at the hospital Reinier de Graaf Gasthuis in Delft

Source: M.V. Batelaan c.s., 2013: 16

This replaces the traditional sanitation washers and uses the existing hospital sewage piping infrastructure to transport the shredded organic waste, together with the waste water from showers, toilets and sinks. It also works well to remove harmful bacteria and viruses at the source in hospital waste streams.

In the purification unit the solid waste is separated from wastewater on the hospital site. Subsequently the solid waste is reduced by anaerobic digestion. By this the Pharmafilter also plays a role in solid waste management. It reduces the volume of solid waste by 90%. The produced biogas is used for powering the plant. The wastewater is purified and harmful substances are eliminated including hormone disturbing substances. Pharmafilter uses different purification steps to clean the waste water.

The first waste water stage step takes place in the bio reactor where activated sludge removes heavy metals, nitrogen's and phosphates. During the next step innovative membranes take out viruses and bacteria. Only water can pass through these porous straws. The third cleaning step is the treatment with multiple advanced oxidation processes among which an ozone contact tank. The dissolved remains of micro pollutants will be taken care of here. Finally the water is treated with activated coal-carbon filtration. The last traces of medicines, endocrine disruptors and x-ray fluids liquids are adsorbed. The purified water is very clean as an extensive evaluation study proved and can be reused as process water, for example for flushing the toilets, closing the circle once again (Batelaan c.s., 2013) [6].

Market adoption of Pharmafilter

Also without immediate regulatory pressure a hospital acted as launching customer, the 'Reinier de Graaf Gasthuis' hospital in Delft did so. The initiator worked with the hospital to improve the kitchen and food waste logistics. Tests at the small scale test facility and at the full scale pilot plant proved to clean the water from substances such as medicines residuals, germs, cytostatica, röntgen contrast residuals and other harmful substances such as hormone disturbing elements below their detection limits. The full scale pilot also indicated improved hygiene in handling hospital waste benefits. There is for instance less human contact with contaminated waste.

The concept proved a positive business case, though the payback time would be considered too long for commercial purposes. The hospital acted within their corporate social responsibility policy and choose to become the launching customer. The Pharmafilter© development was also supported by the water board and some other organizations, the pilot plant project was co-financed by the European Union. The effluent of Pharmafilter© can flow into the sewage system. The effluent is extreme clean, the hospital does not need to pay effluent charges for biodegradable pollution (in the Netherland very high with some 55 Euro per pollution unit, which is estimated to be equal to the organic pollution of one person). This tax saving is an important part of its business model, next to restricting the amount of labor needed for internal waste logistics.

[6] The process description of Pharamafilter is based on M.V. Batelaan c.s. 2013.

Figure 4: The first full scale Pharmafilter plant at Reinier de Graaf Gasthuis te Delft

Source: M.V. Batelaan c.s., 2013: summary

The plant produces biogas, this is reused to power the plant. In Terneuzen a second plant is taken into operation. A number of other hospitals are meanwhile in the process of considering the Pharmafilter concept. The investments, for instance by the Erasmus Medical Centre in Rotterdam, a large academic hospital, are calculated at circa 10 million Euros. The hospital expects a return on investment in 10 years, mainly because the fee they have to pay for the waste water in the Netherlands will be reduced strongly. Also benefits in logistics, waste minimization and water use contribute to the business case. For smaller hospitals the investment is calculated at circa 2-3 million Euros[7]. While sometimes changes in the internal piping system in the hospital are required, installation in new or renovation buildings is easier than in a fully operative hospital, which is sometimes a hindrance for its dissemination. Another difficulty is that the role of water boards is often passive. They accept that they receive less fees (for the biodegradable pollution), but do not want to invest themselves in this innovative improvement of water pollution with other substances. Neither do the big health insurance companies want to co-invest in the health improvement results. Positive is that the installation in Delft has acted as a showcase and a proof for the soundness of the technology (Adviescommissie Water, 2014).

Pharmafilter is a startup that now has a worldwide patent on this technology. In 2015 Pharmafilter worked on three large installations, it is expected that many will follow in the

[7] Source: http://fd.nl/ondernemen/1095883/erasmus-medisch-centrum-investeert-miljoenen-in-recyclingsysteem-van-start-up

Netherlands, within Europe (Germany, Ireland, England, France) and outside Europe. Though whether this optimism is justified will depend on factors such as the regulatory pressure and perceived hot-spot situations.

The principles of DeSaH

The acronym DeSah stands for Decentral Sanitation and Re-use (Decentrale Sanitatie en Hergebruik). Other than Nereda and Pharmafilter, DeSaH was developed to additionally serve the agenda to reduce the use of freshwater. And is thus an example of a relative integral approach to the issues in the water cycle. As mentioned, even the Netherlands, characterized by abundancy of fresh water, is expected to be confronted with fresh water scarcity in 2050. The DeSaH network developed decentral infrastructure that enables reduction of water use by circa 60%. Its decentral character makes it a more drastic innovation than the Nereda concept. The strategic choice is made to separate heavily polluted water (blackwater) and lightly contaminated grey water.

As a species of the family of new sanitation concepts it is based on source separation, collection and treatment. The blackwater stream starts at the toilet and organic waste from the kitchen is added and flows to the black water treatment technology. Grey waste water is collected from the washing machine, the shower, bathtub and washbowls and flows to the grey water treatment technology. To reduce furthermore the amount of black water a vacuum toilet is used. The organic household waste is added by a shredder installed in the kitchen. This reduces the amount of water needed to flush by more than 80%. The collected grey water from showering, washing, washing machines, and sinks can be treated in different ways, this is relatively easy. The water can be re-used.

Various techniques were developed and tested to find the optimal treatment concept for concentrated black water and grey water (Leal c.s., 2010). The black water is treated by fermentation, this process produces biogas. Adding the shredded organic material to the fermentation process increases the amount of biogas being produced. More than 95% of the nutrients are subsequently removed. Ultimately this treatment process produces energy and the volume of sludge is reduced by 80% compared to conventional treatment. An additional option would be to for instance add an oxidation step to remove micro pollutants from medication and substances that influence hormones. This can be done at relatively low costs, because the volume of water to be treated is less than 5% of the volume in large scale plants and the pollution load is relatively concentrated. Whether these additional options will be applied in the near future depends on factors such as the regulatory pressure and perceived hot-spot situations.

Market adoption of DeSaH

After extensive research this new method for the collection of waste water has been installed in 60 rental accommodations in the city of Sneek (Adviescommissie water, 2014). The Sneek pilot learned that the produced biogas can be used by some of the connected houses. The nutrients are used for agricultural purposes. The system is however still expensive when large scale treatment is readily available. Thus it is especially useful for new districts, remote dwellings or when superior quality of effluent is needed.

Figure 5: Sneek pilot in new sanitation
Source: SLO, NLT4, p. 87

At this moment the ambition is to deliver water that meets the requirements of the European Water Framework Directive. Research still goes on and it is apparent that decentral sanitation could also meet even stricter future legal standards. Concentrated black water and grey water collected in Sneek is used in research labs to elaborate further options. Supplementary treatment processes and techniques have to be balanced to the costs they require in terms of investments and operational costs. Compared to conventional large scale water treatment the costs related to the use of energy and the costs for the environmentally responsible processing of the sludge are dominant. DeSaH reduces these costs significantly. In international perspective the rules and practices with regard the treatment of sludge are influential. In some countries sludge from waste water treatment can be used as fertilizer, in a densely populated low delta country as the Netherlands this would be particular harmful, therefore this practice is forbidden. The sludge has to be burned in either waste incineration plants or energy plants. Both options are expensive due to the required end-of pipe equipment. The costs of energy use required can also be considerable reduced by alternatives like Nereda©, though if the aim is to reduce energy costs only, there are other options in the water cycle. The investments done in large scale sewage systems and large scale water treatment plants hinder market adoption of technologies such as DeSah that span boundaries between various waste streams and energy and nutrient re-use (Bressers and Lulofs 2010a).

3. **The governance of non-incremental change in the water cycle**

In this section the arguments for interference by the government will be presented in sections 3.1 and 3.2 and afterwards we will elaborate some outlines for the governance aspects of research policy, innovation policy and sector policy. Frequently science or research policy is considered central with regard to new ideas, new concepts and invention. Innovation policy refers to public efforts with regard to the creation of innovation alliances, R&D programs, transition experiments, and alignment of innovation policies to transition goals. Sector policy is described as niche development (through for instance procurement, regulations or the use of economic incentives), the removal of barriers to the research, development, market introduction and market adoption (Kemp, Loorbach and Rotmans, 2007: 83). If we take these three types of public efforts and our cases into consideration, the observations are as follows:

3.1 The arguments for research and innovation policies

Drastic change in the water cycle requires several steps once initial ideas and concepts popped up (Schumpeter, 1942). Considerable efforts in research and development are often needed, these were really substantial and time consuming in the case of Nereda©, and also quite substantial in the case of Pharmafilter© and DeSah. This calls for *research policy* that facilitates investing in research without being hindered by a market oriented return on investment time horizon. However when the invention is done and efforts in the field of development are successful, it gets important that no technical, economic or legal arguments should hinder application. Market introduction nevertheless often hampers. Finding a launching customer is often not easy and even then adoption by the market is not guaranteed. The question is relevant whether government has a role in this, if so efforts in *innovation policy* are required and legitimate. In most cases the required processes take more time than markets take into account, and require larger investments than markets are willing to finance. According to some authors in welfare theory the return on investment period is exceeded and actors fear that they will not be able to gain the full profit of their investments (Jaffe, Newell and Stevens, 2004).

During the process it remains unclear whether performances of new technology will be convincing and ultimately will lead to profits. While large investments are called for, the risk of failure is substantial and the expected return on investment period far too lengthy. There is also another issue on the minds of executives that have to decide upon whether to invest or not, the fear that other companies that did not invest in research and development and market introduction will benefit by capturing the technology. Realized patents might offer some protection, in international perspective not everywhere the system of patents is respected (bis, 2004). The system might work rather effective for new medicines, but in this field of water treatment technology it proves hard to prevent free-riding. This leads to a situation in which from the perspective of societal welfare, markets tend to underinvest in research and development aiming for drastic change beyond 'the low hanging fruit'. Though this might be acceptable from the perspective of static efficiency in welfare economics, it certainly is not from the perspective of dynamic efficiency. The principle of dynamic efficiency focusses upon the future welfare, in this to operate a more efficient water cycle in the future to avoid relative and absolute water scarcity. For instance options to abate more pollutants at lower costs or to need less water for the same level of consumption and production. From the perspective of societal welfare it is required from governments to compensate for this tendency. This can be done by applying innovation policy to increase investments in research and developments and market introduction. When these policies focus on development and market introduction these are often referred to as *innovation policies*.

In the Nereda case regional water authorities acted as launching customers, enabling a full-scale showcase and further development. With Pharmafilter also a regional water authority played a role, while the hospital took the lead in the full scale pilot. This also provides arguments for *innovation policy*. A launching customer that (co-)invests takes at least two risks. First the performances of the technology can disappoint. Second, when the technology functions well the early mover might still be disadvantaged. After the market introduction a learning process will take place that enables both the supplier of the technology and the later clients to do even better, at lower costs. So it makes sense that also the launching customer is compensated for playing such a role. Launching customers also might have other arguments to be the first mover and establish a showcase. Often being entrepreneurial is appreciated and being a first mover profiles a launching customer as being innovative. Also corporate social responsibility might play a role in a decision to go for it. These factors played a role in the decision of the hospital in Delft to take the role of launching customer in the case of the Pharmafilter. The residues of medicines and medical substances, including viruses and bacteria in water resources and water supply due to ineffective removal might influence human health. Since this concerns the core of the medical business it is considered an urgent issue to think of alternatives. So these provided for the hospital the arguments to act as launching customer for the Pharmafilter. CSR arguments played a role in the decision. Being in the market of human health, it was felt as appropriate to act as launching customer. This was felt even though there still was uncertainty, the return on investment period was really expected to be long and it was well known that the learning process would proceed. Also it was one of the reasons why the regional water authority stepped in as a partner in this launching customer ship. The argument was that water quality would benefit from this technology next to that it might save them costs in the future when stricter rules for micro pollutants would be set. This example clarifies that appropriate research policy and innovation policy following principles of good governance do not emphasize finance only, but look also at the allocation of potential wins and losses, and thus at the potential of creating cooperation across demarcation lines (Lulofs and Bressers, 2010). This brings us to the issue of market adoption.

3.2 The arguments for sector policies

With regard to the market characteristics the water cycle is a sector with considerable assets, in other words there are substantial investments at stake. Regional water authorities invested huge amounts in large scale waste water treatment plants (circa 1000 Euros per citizen), transition to decentral sanitation infrastructure would imply to write off of investments early. Municipalities have invested huge amounts in large scale sewage systems, circa 4000 Euro per inhabitant. And both water boards and municipalities are renewing their domain, optimizing processes and taking good housekeeping measures. The problem pressure they perceive is about costs, efficiency of operations and effectiveness of waste water treatment and priority topics. To the latter Pharmafilter connects, to the first Nereda.

This might hinder change, there might be lock-in positions, both in terms of invested capital and in terms of organizational aspects of the management of the water cycle. This has noticeable consequences: New technologies are picked up and absorbed by the market that fit in the existing water treatment infrastructure and in the process of maintening and updating existing infrastructure. This was already described in literature long ago. When research and development are promising, it is often still hard to find market entrance, a first commercial introduction, not to mention the need for upscaling and thus diffusion (Schumpeter, 1942). In modern times Paul Reitner, director of IWA, concluded that once locked-in technological positions have emerged, markets renew themselves within these settled system boundaries. Only if external threats become urgent new innovations will be developed that span those boundaries. The key to success is to seek where the new technology connects to local problem definitions and pressures (Tuijn, 2010).

This explains the differences between the Nereda technology, an example within settled system boundaries, Pharmafilter, an example that spans some boundaries, under a realistic external threat and DeSah that is still hampered by not willing to write off investments and to change allocation of authority with regard to the water cycle. Ambitions with regard to reduction of water use and those with regard to waste water collection and those with regard to waste water treatment remain allocated over several actors. Having those actors to span their temporal, sector and spatial boundaries is a prerequisite for moving forward (Bressers and Lulofs, 2010b).

The invisible hand of the market tends to fail in cases like this. Like negative externalities have to be included in the market price of a product, also the positive knowledge externalities have to be included in the market mechanism or compensated by government intervention. If pollution is not included in the price, the market tends to produce too little of abatement. In the case of positive externalities the market tends to produce too little. This is reinforced while also mentally cognitions and motivations of actors tend to reproduce the boundaties of technological change. This calls for *sector policies* to handle these biases.

Economists might emphasize that financial instruments should be used to repair the welfare theoretical inefficiencies, our position is that also an open eye should be on the institutonal aspects, like the organization of the water cycle, and on influencing the boundary definitions of actors.

3.3 Some governance principles

Without touching upon all details there are a some rules of thumb how these programs should be governed to optimize efficiency. The issue here is the considerable uncertainty whether an idea will live up to expectations. So careful selection is needed, but who to involve for a balanced selection? There is the tendency in recent years to include governments, knowledge institutes and the private sector. That is a good idea, while in the first period researchers and developers will be dominant, and as development proceeds market parties that have to take over will become dominant. The development of the Nereda technology offers a showcase in this. It took decades before the original scientific idea was developed into the first pilot plant.

For a long time research institutes, research programs and scientists were dominant. Later also Nereda development took place in the context of a research and development program. In this program participating actors had to co-finance the efforts. This prevents that companies can capture a new technology and bring it to the market without contributing. What especially can be learned from the Nereda case is how during the process its potential was monitored. Though it was not aimed at for a long period, at a certain moment one of the involved partners bought all involved patents and rights and brought it to the market. This case tells the lesson that different actors play different roles in the innovation process, and each bring specific competences.

The Nereda case also provides some ideas how to finance the governance of innovations. With the partner that bought all patents and rights and brought it to the market and commercialized Nereda©, it was agreed that the partners that invested in financing research and development should be reimbursed every time Nereda technology is sold. This enables them to share in turnover and profits. In this way also governments that invest in research programs can be compensated, creating some kind of revolving fund. In the Nereda innovation regional water authorities acted as launching customers, enabling a full scale showcase and further development.

Pharmafilter was established as a startup company to get the market to adopt Pharmafilter© technology. The history of this technology is comparable to Nereda. There are however differences, since Pharmafilter© is a patchwork of technologies already on the market or developed especially for application in hospitals. The trajectory therefore took less time, but was also financed from research and innovation programs. In this case the European Union (Life+) was one of the financers. Similar to the launching customer concept in Nereda also in this case there was a coalition engaged in the market introduction. It involved among others the regional water authority, the hospital and the STOWA, which runs the research and innovation program of the associated Dutch regional water boards. The start-up company Pharmafilter meanwhile grew into an established company. Nevertheless Pharmafilter© is still just in the process of being accepted and adopted word-wide. Compared to Nereda this slower process might be partially explained by the fact that Nereda is marketed by a large globally active consultancy. A start-up company does not have similar resources. Though more likely is the explanation that context is more important, like the present lack of micro pollutant regulation and perceptions about hotspots.

Our findings with regard to the water cycle are mirrored in literature on socio-technological co-evolution. This stance of literature proclaims that for significant steps to a sustainable future socio-technological co-evolution is required. It assumes that successful non incremental technical change co-evolves with institutional change and change in social systems. Linking long term issues and perspectives to short-term action is then needed. Some prominent authors in transition literature expect that frequent forward and backward reasoning provides an important element in a more effective governance strategy with regard to non-incremental technological change and its relationships with research policy, innovation policy and sector policy. Forward casting refers to trend analysis, forecasting, scenario building etcetera. This then could be followed by short term actions, research and development programs, experiments and pilots and effort on market introduction and market adoption. This links long term and short term problems and issues, elaborates possibilities and alternatives and aligns them in short term and long term perspective. Back-casting may help monitoring, feedback, identification of crucial issues and experiments and may help to align long term and short term goals. If this is not done adequately, there is a danger that lock-in positions emerge and continue that are not optimal from a longer term perspective (Kemp, Loorbach and Rothmans, 2007).

4. Conclusions

Our conclusion is that there are indeed major concerns on the governance of the future water cycle. First, without proper governance only the low hanging fruits might be picked. This might lead to lock-ins in technological trajectories, just focussing on short term interests and not paying sufficient interest to long term perspectives like "circular economy". Second the allocation of management-, user- and ownershiprights might play an important role. Large scale water treatment is in the Netherlands the most common practice. Rivalry between vested interests in large scale central waste water treatment and new technologies that lead to decentral solutions occur. Technological lock-in positions, vested interests and sunk costs (early write offs) have to be dealt with.

Furthermore there is no one ideal model for the governance of innovation in the water cycle. With regard to the governance of follow up steps such as research, development, market introduction and market adoption the lesson should be that one should be receptive to long term quests for transition. It is obvious that the existing segmentation of roles, tasks and responsibilities with regard to the Dutch water cycle, hampers drastic change.

The examples of Pharmafilter and Decentral Sanitation indicate that the long term strategy should include decentral treatment capacity with regard to urgent issues. The potential of decentral treatment in the coming decades will likely grow because of its flexibility in tailor made combinations of primary, secondary and tertiary treatment technology and to span traditional boundaries over segments in the water cycle. It could lead to a "hybrid" system of water treatment (Adviescommissie Water, 2015). This all calls for balancing research policy, innovation policy and sector policies by a process of forward and backward thinking and coordinating both on strategic and operational level.

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