Measuring, removing and recovering P: a parable of how innovation systems change and the challenges for establishing a circular economy

MAY 2018

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Dr. M.L. Blankesteijn

Faculty of Exact Sciences, dept. of Physics, section Science Business Innovation

De Boelelaan 1081, 1081HV, Amsterdam

M.L.Blankesteijn@vu.nl

+31 20 598 7636

Introduction

In 2014, the European Union declared the primary element phosphorus (P) to be a critical raw material. It is important to fabricate artificial fertilizer, which is in its turn crucial to meet the need for feeding a growing world population. However, formerly it was mostly treated as a pollutant, because if it enters the waterbodies, it causes eutrophication of surface water.

The value and status of P as a primary element thus remains notably ambivalent. Is it waste or valuable material? Currently, it can safely be stated that P is both, depending on for example the national context and regulations. In the Netherlands in particular, which provides the context for the case study presented in this paper, it is still seen as a pollutant due to its abundance in the soil as a result of overusing artificial fertilizers for many decades. As mentioned, on a global level, the shortage of phosphate is growing each year.

This sharp contrast shows the volatility of the status of raw materials. The volatility of status of P may well be comparable to that of fossil fuels, and maybe even already to biomass as a means to produce biogas, i.e. the burning of material to create energy instead of changing our need for energy on a more fundamental level. The changing status of P functions here as a parable - a short, succinct story that illustrates one or more instructive lessons or principles – for creating a storyline about fundamental changes in our science and innovation system from the nineteen sixties onwards.

There has been a lot of interests in phosphorus (P) recycling in the present industrial world as there are large amounts of P available in various waste streams from agriculture, sewage sludge feed and industries. Since regulations for discharge of P into the environment are becoming increasingly strict, these phosphate streams pose an increasing problem in the present world. The easiest solution, landfill, is increasingly inaccessible because of regulatory, social or economic pressures in most industrialized countries. Therefore, other possibilities have to be explored of disposal of these secondary phosphates. Recovery and reuse of phosphorus is a matter of great importance for Europe. How then to recover P as much as possible? A favorable R&D context, created by a supportive innovation system, is pivotal here.

A particular innovation system around P has already been developing since 1960. The constellation and dynamic of knowledge and innovation organizations, policy makers and private companies around the primary element P has thus up to a certain extent solidified already.

Currently the concept of circular economy within society is highly popular. Many policy documents and societal initiatives express the ambition to contribute to the establishment of a circular economy [refs here]. Within the context of the ambition to establish a circular economy and close the phosphorus loop, the resulting dynamic of the current innovation system creates specific challenges for the organization of R&D processes. The changing constellation of the innovation dynamic around the primary element P thus represents a rich and in-depth case study, shedding light on the nature of and concurrent challenges for the current innovation system as a crucial factor in the successful establishment of a circular economy. [intrinsic case study]

The innovation dynamic of this constellation cannot be captured under one denominator. It cannot be said to be solely lead by changes in thinking about fundamental versus applied science, or mode 1 to mode 2 science. The dynamic is in constant flux, and a singular perspective on how to conceptualize these changes does not cover the full magnitude of these changes.

The paper instead offers an in-depth and longitudinal analysis of the dynamic based upon a case study, to come to an understanding of the background and nature of the challenges that need to be tackled in order to establish a (more) circular economy. The analysis is informed conceptually by some dominant perspectives to understand the changing social contract between science and society.

The case study presented in this paper reconstructs the route the primary element P has created to develop and organize innovation for both scientists, policy makers, public organizations and the private sector. The case study does so by describing and analyzing three episodes on the route P has taken through science and society. It could be seen as a parable - in this case, on the changing and current state of our innovation system and its underlying knowledge infrastructure.

The three episodes of the parable center around *measuring* P, *removing* P and *recovering* P. The episodes are preceded by a short reconstruction of how P as a primary element became a topic of interest to scientists and policy makers in the first place. The case study mainly revolves around developments in The Netherlands, in the period from 1960 up till the present.

The structure of this paper is as follows. First, three influential perspectives on the changing role of science in society are discussed. They guide the analysis of the case study. The section is followed, secondly, by a section on methodology and method. Thirdly, the three episodes in the case study of making P measurable, removing P and recovering P are distinguished and analyzed. The analyses are conceptually inspired by perspectives on the changing role of science in society. They highlight the challenges that currently need to be faced in terms of innovation, technology and knowledge development in order to establish a circular economy. The conclusion will put these challenges into the broader perspective of our innovation system and innovation policies, thereby coming to conclusions and recommendations which are both relevant to academics with an interest in circular economy and innovation systems and policy makers that are faced with challenges in organizing innovation systems.

The changing social contract between science and society

The understanding of the role and concurrent organization of science in society has changed greatly in the last fifty to sixty years. Some authors have defined this as a changing social contract between science and society.

Following the American science advisor *avant la lettre* Vannevar Bush's influential 1945 manifesto on science policy 'The Endless Frontier', basic science was seen as a fundamentally different type of knowledge than applied science. Bush heralds the progress made in medical science due to the invention of penicillin, and progress in agricultural science to enhance the abundance of crops and thus to prevent famine. Both death of infectious diseases as well as death due to famine were all too familiar phenomena in the aftermath of World War II. Bush ascribes the successes of science to remedy these causes of death to basic science. Bush's position shows that basic, fundamental science 'without thought or practical end' enjoyed a higher societal status, as it was seen as breaking the ground for true invention.

In the 1980's, the distinction between basic and applied science gradually lost its meaning and influence on the organization of science. Being relevant to society as a scientist was no longer seen as something academically less worthwhile than producing fundamental knowledge on a particular topic. This shift has conceptually been captured by scholars studying the organization of science and innovation systems under the heading of a shift from mode 1 to mode 2.

In the age of neoliberalism, the character of many public services within society changed fundamentally. Innovation from science was seen as an important driver of economic progress – although some trace the origins of the term back to a much earlier date (Godin…). Science, one could say, was, as many public services, privatized up to a certain extent by the growth of the emphasis on the importance of cooperation with private companies.

The concept of triple helix analyzes this intertwinement of science, public organizations and the private sector. Triple helix as a concept is very influential, both in science studies as well as in policy discourse. The growing attention of science for cooperation with private parties grew in parallel to separate innovation policies, specifically aimed to stimulate this cooperation – next to an already existent science policy.

These three paradigms to understand the role of science within society have subsequently been highly influential in science and (later) innovation policy. They are still used interchangeably. However, their rise in scientific and popular discourse in respectively 1950, 1980 and 1990 signals a shift in itself in the perception of the organization of our science systems and the role of science in society, i.e. the social contract. As such, these schemes of thought about the social contract between science and society provide a conceptual background and guidance for the longitudinal analysis of the changing innovation dynamic in the case study.

Methodology and method

Longitudinal, in-depth case study based on interviews, desk research of primary and secondary sources. Intrinsic case study, aimed at generating empirical insight.

Measuring P – episode I		Removing P – episode II		Recovering P – episode III	
Desk research	Interviews	Desk research	Interviews	Desk research	Interviews
See ref list	See below	See ref list	See below	See ref list	See below

Prof. dr. H.
Saeijs
Middelburg 15 december
2005
Hoofd dienst milieuonderzoek
Rijkswaterstaat directie
Zeeland 1976-1982,
directeur-generaal
Rijkswaterstaat 1982-1994,
hoogleraar
Waterkwaliteitsbeleid en
Duurzaamheid, Erasmus
Universiteit Rotterdam vanaf
1994
Dr. G. Geldof en
drs. P. Lems
Deventer 12 februari
2006
Medewerkers adviesbureau
TAUW
Drs. P. Licht Lelystad 24 mei 2006 Projectleider Integrale
Inrichting Veluwerandmeren
(IIVR)
Ir. J. Leenen en

drs. B. van der
Wal
Utrecht 28 mei 2006 Voorzitter resp.
onderzoekscoördinator
Stichting Toegepast
Onderzoek Waterbeheer
(STOWA)
Dr. H. Havekes Utrecht 3 oktober
2006
Onderzoeker geschiedenis
Waterschappen
Mr. J. R. van
Dijk
Utrecht 11 oktober
2006
Secretaris Waterschap Regge
en Dinkel 1984-2007
Ing. H.
Hoefsloot
Joppe 25 oktober
2006
Voorzitter Waterschap Regge
en Dinkel 1981-1993
Drs. M.
Zonderwijk
Almelo 23 november
2006
Medewerker ecologie
Waterschap Regge en Dinkel
1983-heden
Ir. G. Verwolf Apeldoorn 10 januari
2007
Werkzaam bij
Rijkswaterstaat, huidig
dijkgraaf Waterschap
Veluwe, vml. ‘sparring
partner’ management
Waterschap Regge en Dinkel
Ir. P. van
Erkelens
Leeuwarden 16 januari
2007
Voorzitter Waterschap Regge
en Dinkel 1993-2003
Dr. D. Huitema Amsterdam 12 februari
2007
Onderzoeker Instituut voor
Milieuvraagstukken (IVM),
Vrije Universiteit Amsterdam
Ir. J. Deurloo Zwolle 19 februari
2007
plv. hoofd Technische Dienst
Waterschap Regge en Dinkel

1966-2002
Ir. T. de Jong Almelo 18 maart 2007 Ingenieur betrokken bij
Lateraalkanaalplan,
Bornsebekeplan en
Reggevisie, Waterschap
Regge en Dinkel 1975-heden
Drs. A. Demon Bilthoven 3 april 2007 Biologe/student milieukunde
betrokken bij project PIWAT
1988
H. Tienstra Telefonische
communicatie
25 mei 2007 Medewerker Provincie
Overijssel, betrokken bij
opstellen Integraal
Beleidsplan Bornsebeek
Dr. E.-J.
Houwing
Leiden 10 juli 2007 Teamleider
Hoogheemraadschap van
Rijnland
Ir. B. Hermans Utrecht 24 augustus
2007
Medewerker water Stichting
Natuur en Milieu
Drs. H. van
Hardeveld
Delft 13 november
2007,
12 september
2008
Projectleider 'flexibel
peilbeheer',
Hoogheemraadschap van
Rijnland
Ir. F. Schukken Aadorp 19 september
2007
Hoofd Technische Dienst
Waterschap Regge en Dinkel
1965-1989
Ir. F. van
Kruiningen
Leiden 25 september
2007
Hoogheemraadschap van
Rijnland
Dr. L. Giebels Amsterdam 20 november
2007
Onderzoeker en oudarchivaris
geschiedenis
Hoogheemraadschap van
Rijnland
Ir. J. van der
Does

Amsterdam 17 december
2007
Hoogheemraadschap van
Rijnland 1982-2005
Drs. L. Smeets Den Haag 3 januari 2008 Medewerker afdeling water
Provincie Zuid-Holland
Dr. G. van den
Eertwegh
Tiel 8 januari 2008 Projectleider flexibel
peilbeheer,
Hoogheemraadschap van
Rijnland 1997-2005
Drs. J. Kroes Wageningen 16 januari
2008
Onderzoeker Alterra,
ontwerper model FIWmultiSWAP
Dr. L. van Duin Leiden 14 februari
2008
Hoogheemraadschap van
Rijnland 1990-2009
C. Zonneveld
Piek
Tiel 7 maart 2008 Poldermolenaar Waterschap
Rivierenland
Dr. C.
Kwakernaak
Wageningen 16 mei 2008 Contactpersoon ‘Waarheen
met het Veen’ 2004-2009
Ir. D. van der
Schrier
Zwolle 8 juli 2008 Hoofd Provinciale Waterstaat
Overijssel 1963-1990
Ir. J. de Hoog Utrecht 18 september
2008
Projectleider Flexibel
Peilbeheer, Waterschap De
Dommel
Dr. S. Kuks Almelo 2 september
2008
Onderzoeker institutionele
ontwikkeling waterschappen,
voorzitter Waterschap Regge
en Dinkel 2007-heden
Dr. A. Schmidtvan
Dorp
Telefonische
communicatie,
Delft
3 september,
23 september
2008
Promovenda
Hoogheemraadschap van

Rijnland 1973-1976
Drs. J.
Gardeniers
Wageningen 4 september
2008
Deskundige
waterkwaliteitsbeoordelingen
Drs. F. Klijn Delft 9 september
2008
Begeleider vanuit Centrum
voor Milieukunde Leiden,
project PIWAT
Ir. F.
Goossensens
Rotterdam 19 september
2008
Projectleider Reggevisie
Ir. J. van Selm Almelo 29 september
2008
Hoofd Technologische Dienst
Waterschap Regge en Dinkel
1958-1990
Ir. B. Breunissen Apeldoorn 30 september
2008
Arcadis, betrokken bij
opstellen Integraal
Beleidsplan Bornsebeek
Ir. H. de Groot Warmond 7 oktober
2008
Hoofd Technische Dienst
Hoogheemraadschap van
Rijnland 1953-1987
Mr. H. Alberts Deventer 27 oktober
2008
Betrokken bij opstellen
PIWAT-plan vanuit functie
bij LNV Overijssel
Drs. L.
Nooteboom en
ir. B. van der
Veer
Delft 2 december
2008
Medewerkers
Hoogheemraadschap Delfland
Dr. H.
Golterman
Voorhout 17 december
2008
Limnoloog, directeur
Limnologisch Instituut
Prof. dr. R.
Feddes

Bennekom 25 maart 2009 Em. professor
cultuurtechniek, Wageningen
Universiteit
Ir. E. baron van
Tuyll van
Serooskerken
Heemstede 6 april 2009 Dijkgraaf
Hoogheemraadschap van
Rijnland 1984-2005
Ir. A. Overgaag Leiden 7 april 2009 Hoofd Technische Dienst
Hoogheemraadschap van
Rijnland 1987-1997
Drs. P.
Schroevers
Utrecht 6 oktober
2009
Deskundige op het gebied van
beoordeling van de
waterkwaliteit
Prof. dr. J.
Ringelberg
Putten 9 oktober
2009
Deskundige op het gebied van
beoordeling van de
waterkwaliteit

Measuring, removing and recovering P

Prelude: Recognizing P as an academic and policy challenge 1960-1970

In the decades before 1960, the amount of P in surface waters was not recognized as a challenge for water managers in The Netherlands. Water managers were mainly occupied with issues related to getting the right amount of water in the right place – an effort that was mostly perceived as related to the interests of the agricultural sector. The agricultural sector was at that time the main driver of the Dutch economy. A lot of effort was put into the growth of the agricultural sector, since it was seen as the most important factor in economic recovery after World War II.

After the big flood that hit the south western provinces in the Netherlands in 1953, in which 1853 people and thousands of cattle drowned, an emphasis on water safety was added via, amongst others, a huge project called the Deltaplan to prevent such a disaster from ever happening again. Next to the issues related to water quantity and water safety, there was virtually no room for active attention to issues related to water quality from water managers. Water managers spoke of 'passive water quality management', which meant that measures were taken that were primarily aimed at issues of water quantity. If these measures were also beneficial for improvement of water quality, then that was seen as a nice side effect. Improvement of water quality never was the sole driver of policy measures or practical interventions in the water system.

Science did also not take a great interest in the matter of water quality. Some biologists were doing taxonomic research and research on the fish species eel for which water quality is important. Agricultural engineers occupied themselves with evaporation of ground water via crops. Limnologists performed fundamental research on chemical processes in ditches, which was quite far detached from the actual practice of water management and did not help in understanding the polluted state of surface waters in a more practical sense.

The lack of interest in the subject matter can be traced back to an ancient idea about processes in water, namely the idea of the 'self-cleaning ability' of water. It was believed that pollution as perceived now and then would solve itself via 'self-cleaning ability' of water, which is, up to a certain extent, a rightful assumption. Up to a certain extent, water can indeed keep itself clean. However, there is a certain tipping point, depending on the ratio between phosphates and nitrates in the water, at which water is no longer able to clean itself.

That self-cleaning ability reached this tipping point in the 1960s, when surface waters were literally foaming from the amounts of phosphates coming from detergents used in the modern invention of washing machines or were filled with toxic blue algae, killing all other flora and fauna in the water, as a result of a lack of oxygen and eutrophication.

Some pioneers in Dutch limnology who observed these phenomena took an interest in the matter and decided to do research on the causes of eutrophication in Dutch surface waters. It was generally known from Swiss and Canadian studies that both N and P could cause eutrophication, depending on the circumstances. What caused eutrophication in the Dutch ditches in the polder and lakes, could not solely be understood from the literature however, since the nutrient poor Swiss and Canadian lakes are something wholly different from the nutrient rich peat lakes in the west of the Netherlands. The Dutch geophysical condition, with its polders and peat soil grasslands is too singular to gain an understanding of it from the perspective of theory only. Empirical research was needed. With the rise of worries about the state of the environment around 1970, also policy makers developed a growing interest in the matter of water quality.

I. Measuring P: 1970-1990

Nowadays, national innovation systems are importantly aimed at doing research that is highly relevant from a societal point of view. The current system possesses inbuilt mechanisms to respond to societal needs. As logical as this may seem in first instance from our current perspective, this inbuilt capability to address societal challenges have not always been part of the science and innovation system. The initial lack of flexibility of the innovation system and an explanation from a conceptual point of view for this, will be elaborated upon in the next section,

The most important factor explaining this lack of flexibility is that the organization and institutionalization of science was based upon the discursive distinction between fundamental and applied science. The following section illustrates this stuttering and faltering innovation dynamic resulting from the institutional dominance of this distinction. The dynamic is characteristic for the first episode of the route of P through science and society.

Dutch limnology was eager for knowledge on the causes of eutrophication in the Dutch context. This is in itself interesting, as limnology in the Netherlands was originally a highly fundamental science – not aimed at Bush's 'practical ends'. It focused on pure science both in its content as well in its organization under the institutional umbrella of the Royal Academy of Sciences in the Netherlands (KNAW) – which at that time was solely interested in supporting pure science.

The first results of experiments of limnologists however showed no definitive results on the matter. Whereas strong signals pointed towards phosphorus as the so-called 'limiting factor', some doubt remained on the role of nitrates. Limnologists could not refer to earlier studies, as no research had been done up till then in the Dutch context in this domain. Assistance came from an unexpected corner of society.

In the wake of environmental consciousness in the end of the nineteen sixties, a regional water authority in the west of the Netherlands (*Hoogheemraadschap Rijnland*) hired a researcher to investigate what the limiting factor was in the surface water for which they were, since 1970, lawfully responsible. The limnologist that was hired concluded, based upon bioassays, that nitrate was definitely the limiting factor.

This caused a schism in the community of limnologists, since they were, in the background, lobbying for policy to combat pollution via diminishing the amount of P in surface water. One of their proposals was to prohibit the use of phosphates in detergents. The outcome of the research for the water authority caused great confusion, harming the leverage of limnologists had been able to create in the policy debate. Their position here was already vulnerable, since these limnologists were treading into unknown territory already by trying to turn their knowledge into policy advice, to actually influence policy making processes.

Another threat loomed on the horizon for those in favor of policy measures to decrease the amount of P in surface water, namely one coming from the community of hydrobiologists. They were threatening the dominance of limnologists on the subject of water pollution and eutrophication as such by taking a completely different starting point to understand these processes. They found their starting point in a modern version of the 'the taxonomic style' (ref Add). This scientific paradigm assumes practically no causal mechanisms as explanations for the water quality. The chemical approach of limnologists is almost solely dedicated to identifying causal mechanisms. Hydrobiologists assumed that the interplay of organisms from a complex system's point of view matters most, in explaining the differences in water quality in surface waters.

Hydrobiologists claimed to be far more on the 'applied' side of the science system, thus increasingly occupying a more interesting position from the viewpoint of water managers than the fundamental scientists of limnology. The internal discussions in the limnological community on the cause of eutrophication, together with the competition of a completely different paradigm coming from hydrobiologists, meant that both groups could not create too much leverage in developing a useable, practical way of measuring P in first instance.

The institutional and paradigmatic divisions thus caused the impossibility of the science system to react timely, quickly and flexibly to urgent demands coming from society. This situation is characteristic for the innovation dynamic in the period between 1960 and 1985.

Eventually, in the beginning of the 1980s, ways to measure water quality were developed by using a combination of causal factors and the more systemic approach from hydrobiologists, namely the method developed by the German aquatic ecologists Caspers and Karbe. Both the limnological approach as well as the hydrobiological one are reflected in the theory underlying this method to assess water quality and put a temporary halt on debates, which method to use to assess water quality.

Scientists had by that time also shown that they could create an infrastructure via which their knowledge flowed into practice in order to give it practical importance. However, creating methods for measurements of P is one thing - developing an approach to eliminate P as much as possible from surface waters turned out to be a separate and wholly different challenge. Removing P became the next challenge and represents the second episode in the analysis of the route of P through our science system.

The involvement of scientists in removing P from surface waters signals a new understanding of their role. Eventually, their commitment to developing practical solutions for societal problems led to the introduction of a third step in the purification process of sewage water, in which phosphate was removed from the sewage water before it was brought back onto surface water.

II. Removing P: 1990-now

By identifying P as the main cause of euthrophication, several measures could be taken to reduce the amount of phosphate in surface waters. An important step was to include the removal of P from sewage water at waste water treatment plants. This step has been analyzed by Van der Poel [REF] as the entrance of biotechnology in water management.

Eutrophication caused a direct problem for the water quality of surface waters in the province of South Holland. Causes were identified in the historical accumulation of phosphate and nitrate in the soil due to agricultural activity in the region and the lack of connection of still many households to the sewage system until the nineteen sixties.

Water managers had long supported the agricultural sector by providing them via water level management with a high ground water level in summer, the growing season, and a low ground water level in winter. Basically this way of water level management entails that the natural dynamics of ground water levels is turned upside down – as, naturally, they are lower in summer and higher in winter. This was increasingly recognized as problematic, because it was recognized as one of the main causes of ongoing eutrophication. This increasing recognition was a result of the fact that the province designated a function to the area not only in terms of agricultural purposes, but also in terms of nature.

This form of water management causes increasing drought, which has negative consequences for the water quality in the area. Drought causes subsidence of the polder, which is slowly deepening the polder further. Also, it catalyzes the washout of phosphates from the upper soil layer of the banks of the ditches.

Increasing drought of the soil eventually necessitates the water level managers to add fresh water to the polders from other water systems with different water qualities, thus potentially enlarging the amount of nutrients in the water in the area again. Thus, this is not a favorable option.

Another unfavorable option was dredging the upper layers of sediment to remove the surplus of phosphates in the water. The regional water management authority preferably did not want to execute this. Dredging is an expensive and laborious solution. And even then, the problem would not be solved immediately because of the huge amounts of phosphates that have accumulated in the soil for many years.

The only favorable solution that actually was seen, was the changing the usual way of managing water levels. The fundaments of water level management were therefore the subject of renewed research. Could another form of water level management be designed that did less harm to the water quality? The Wageningen University took up the challenge and came, together with water managers of the regional water authority of the lakes in which the above situation caused urgency, with a different form of water level management, in which the function of the area (in this case nature and agriculture) partly determined the way in which the water level was managed. This was captured in the term of 'flexible water level management'.

The regional water management was keen on experimenting with this new idea of water level management but was formally obstructed by the fact that the province of South Holland had a large say in how water level management was executed in the area. Initially, the province was inclined not to let the water authority experiment in the commercially important area of Nieuwkoop, Langeraarse Plassen and Reeuwwijkse Plassen.

However, eventually the Province decided, based upon a renewed assessment of the level of knowledge of the regional water authority and their acknowledgement of the fact that the level of knowledge lately, through bigger investments in research, hiring professional researchers as employers and the cooperation with Wageningen, has increased steaply. The Province acknowledged that the regional water authority could be trusted here because it seems to know what is was doing, based upon its steadily increasing specialist knowledge.

Thus, the regional water management authority emancipated itself from the province and took up a more steering role in the innovation system in water management. The regional water authority developed a strong role in steering the development of academic innovative knowledge in water management into a certain direction, and taking up a leading role in the governmental bodies with a responsibility in water management in the region.

However, the strong role the regional water authority developed for itself in the regional innovation system initially turned out to be impossible to maintain in the long run – simply because it is an expensive and time consuming route to take and other challenges also loomed on the horizon of water management, e.g. those related to climate change which is especially urgent in these low lying polders.

The next episode shows that even a smaller role of the regional water authority in the long term raises questions related to the cost, legitimization and legal task formulation of this governmental body.

III. Recovering P: 2007-now

The regional water boards developed a strong knowledge function and a prominent role in the innovation system in water management. It however also became clear that this prominent role raises questions about the nature of their activities as flag bearers of the regional innovation system in water managers.

The regional water authorities increasingly encounter new barriers as a results of their prominent role in innovation, related to 1. their legal task formulation, 2. to their lack of experience in commercializing their findings and products 3. to their lack of democratic legitimacy 4. The limitations due to their organizational form (EFGF is a network organization, regional water management organization is very old structure but needed to finance the activities of the EFGF) 5. Difficulties in upscaling their initiatives as a result of a lack of sufficient local and national policy support. These barriers are identified based upon the following episode of the route P has taken through our innovation system.

One key element of sustainable P management is closing the nutrient cycle by recovery and recycling. Although enabling technologies for recovery and recycling are already there, only some of them are economically viable under current conditions. Two typical examples of the type of organization that are trying to speed up the recovery of P from waste water, are the Dutch Nutrient Platform and the Energy and Raw Materials Factory.

Dutch Nutrient Platform

Its general aim is to spread awareness about the excess of P in the soil of this country and recover the P and put it into reuse by exporting it to the other parts of Europe where there is a deficiency in this critical element. The Value chain agreement in 2011 which led to the formation of this platform made its presence in the Dutch government too.

The formation of The Dutch Nutrient Platform in 2011 which operates on a national level throughout the P value chain and between parts of the 'triple helix', which consists the businesses, knowledge institutes/universities, governments and NGOs. The main goal is to create a sustainable market of P in the Netherlands ever since it has been formed, in which as many reusable P streams as possible will be returned into the cycle in an environment-friendly way and where recycled P will be exported to the fullest extent possible.

Dutch Nutrient platforms quotes that “establishing this sustainable recycled phosphorus market is not merely a question of the right technology. Moreover, it is a matter of creating the required demand and creating more insight in supply chain and market information. It is a matter of investing in the required processing industry, in forming new partnerships and in creating a sophisticated mix of market interventions by authorities”.

Energy and Raw Materials Factory

The Energy and Raw Materials Factory is a network organizations established from a cooperation of regional water management authorities. It focuses on the retrieval of energy and raw materials from waste water. Currently the focus is mostly on the retrieval of raw materials such as bioplastics, cellulose, alginate and phosphate. The ERMF is currently most successful in the retrieval of phosphate in the form of struvite from waste water treatment plants. It is basically a nuisance for managers of WWTPs, since it clogs the pipes of the WWTP and thus needs to be removed anyway. The challenge for the organization is to sell it with a profit.

However, both the Nutrient platform as well as the ERMF encounter several barriers to recovering P from sewage water.

Barriers to recovering P from sewage water

The following issues can be seen as a challenges and hence referred as barriers to the wide-spread implementation of technical P recovery and recycling options:

1. ***Good business case is lacking: Technology transfer gap between product development and market:*** P based products and raw materials obtained from primary sources like fossil fuels from phosphate mining are very low priced and hence challenge the economic viability of many recovery technologies, especially when these technologies do not provide operational benefits and yield recovered materials that are not directly marketable. If there is no prospect of profits, investors will spend their money in other sectors and markets. Here realistic recovery targets could motivate or even enforce recovery and recycling. It is important not just to enforce P recovery, but the recovered materials need to find a market. Otherwise, and as a worst case scenario, recovered materials ends up as waste and have to be disposed of as such. This is a true example of “crossing the valley of death” (Markham, 2002) for P recycling technologies.
2. ***User involvement: Communication gap between P recycling technologies producers and P recycling technology buyers:*** Many technologies which are mainly developed without the direct involvement of potential users are more complicated than necessary and in some cases comparable to the reinvention of the wheel. Current market deployment reflects this and results in implementation of only those technologies that provide operational benefits for their users.

3. ***Path dependency in technology development: Variation in input streams for the recycling technologies and various outputs:*** Technologies and recovered materials which cannot be integrated into existing infrastructure and markets have to cope up with strong competition within established structures. Therefore the more varied the ways in which the recovered product can be used, the better. In the case of P, white phosphorus P_4 or phosphoric acid (H_3PO_4) are the most promising materials. But it is not only the downstream market potential that determines the vulnerability of a technology or value chain. The security of supply of the raw material is also crucial. The more versatile the technology is in terms of input material, the better. For example, a technology that can process various fossil and/or secondary P sources is less vulnerable compared to a technology depending on, for instance, sewage sludge ash alone.
4. ***Current EU regulations:*** The legal framework is tailored for existing structures and is very slow at adapting to future challenges. In relation to resource efficiency and sustainability, we are still a long way from implementing what is being discussed. For example, the upgrading of recovered material from being treated as a waste to being considered a product is proving to be a challenge. The re-definition of *End-of-Waste criteria* is a tough process but is a prerequisite to enable value chains to bridge the gap between recovery and recycling, and making a circular economy really happen. Therefore, the revision of the EU fertilizer regulation (EC 2003/2003) needs to be progressed to provide a level playing field for fertilizers, irrespective of whether they are produced from fossil or secondary sources. (Hukari et al., 2015). Another issue that needs to be considered is the application of appropriate products for use in organic farming, for instance by adding recovered struvite to the list of approved fertilizers in EC 889/2008. Excess of P in the Dutch soil coupled with formation of the Dutch Nutrient Platform makes the Netherlands a very good case study to analyze the several factors acting as drivers and barriers in recovering and reusing P. This case study can also provide effective strategies to advance the growth of P sustainability in Europe where the law is still to be changed. This research will address particularly the key variables influencing the wider implementation of P recovery technologies with a national law that allows selling of recovered P in order to gain understanding and provide recommendations on how to overcome challenges and enable opportunities.

5. ***Lack of pragmatic approach to existing technologies, focus on already developed P recycling technologies:*** In some cases decision-makers focus only on the 'highest hanging fruits', instead of starting with the 'lowest hanging fruits'. A new market for material including P from secondary sources cannot be developed if the already viable options are ignored and non-feasible options are favored. A market starts with a product, that is available and of use to someone. The same applies to the technology itself. Market penetration and replication will only happen with full-scale demonstrations. Instead of broadening the range of technologies, the focus should be on setting up full-scale demonstrations of the most promising options. This should be augmented by making the most out of the existing infrastructure.

6. ***Lack of legitimacy of supporting organizations***

Regional water authorities lack democratic and legal legitimacy to be truly innovative

The water authorities counter the arguments of opponents of their strong role in innovation by developing initiatives that aim to create viable business cases, such as the retrieval of raw materials from sewage water. These business cases are meant to show that on the long run, it can help the regional water authorities to keep the costs of water management manageable so that taxes do not have to rise that much, and do something good for the world in terms of sustainability.

Technical knowledge is advancing with proven efficiency including a positive assessment of the potential value of recovered product (struvite). At the same time, a quantity equaling 15% of Europe's mineral P demand is being wasted as disposed sewage sludge and its ashes. Technologies enabling P recovery from the wastewater stream have developed tremendously in the past few years and are able to overcome limitations to direct sewage sludge application on arable land (Kabbe, 2013). These barriers show the current limitations of triple helix like cooperations to recover P. They are currently not sufficiently able to tackle technological barriers. They lack the know-how to build a successful business case. The market currently is still very competitive. The quality of the recovered P from waste water is still doubtful, which reflects in stringent national and supranational regulations to reuse it and a public bias against raw materials gained from waste water more generally.

Discussion and conclusion

Timeframe, episode	**Starting points for developing innovative knowledge**	**Innovation system characteristics**	**Conceptually close to dynamics of innovation described in theory that highlights…**
1960-1985: Measuring P	Limnology, hydrobiology, aquatic ecology	Staggering and faltering towards innovation, divided science system focused on either applied or basic science, no inclination to work on solutions on the ground, high level attempts to influence national policy. Lack of experience to create leverage in policy arena.	Mode 1, applied versus basic science
1985-1995: Removing P	Environmental sciences, Interdisciplinary research fields	Focus on solving societal problems, aimed at cooperation with practitioners (mostly public). Gaining experience with policy advice. New	Mode 2, interdisciplinarity in science, central role practitioners, democratization

		interdisciplinary fields in science emerge. Interdisciplinary cooperation to solve interconnected ‘wicked’ problems. Central role for regional and central governments in the creation of eco-innovation in water management.	
1995-2015: Recovering P	Inter- and transdisciplinary cooperation across and outside disciplines	Strong role of government in innovation is increasingly questioned. Focus on creating commercial value via cooperation with private parties. Dispersion of knowledge production in networks consisting of public and private parties. Knowledge production in networked organizations. Dominance of universities and academic institutes in research decreases. Partial privatization of knowledge production via private R&D labs and consultancy bureaus.	Neoliberalism, triple helix, valorization, new public management.

We have seen the following dynamic of the innovation system unfold, based upon reconstructing the route P has taken in the innovation system around water management. In the beginning, it was staggering and faltering movement towards innovation to be able to measure P in the first place. The highly divided science system focused on either applied or basic science. This causes a lack of incentive to work on solutions on the ground, for real time societal problems. On the higher governmental levels, attempts were made to influence national policy. However, there was a sincere lack of experience to create leverage in policy arena.

The second phase shows that a focus came into being on solving societal problems, aimed at cooperation with practitioners (mostly public). Scientists were gaining more experience with giving policy advice. New interdisciplinary fields in science emerged. Interdisciplinary cooperation was stimulated to solve interconnected ‘wicked’ problems. Central role for regional and central governments in the creation of eco-innovation in water management.

The third phase shows that the strong role of government in innovation is increasingly under siege. The focus shifted towards creating commercial value via cooperation with private parties. This resulted in a dispersion of knowledge production in networks consisting of public and private parties. Knowledge production was hence done in networked organizations. Dominance of universities and academic institutes in research decreases. There is a partial privatization of knowledge production via private R&D labs and consultancy bureaus.

Challenges for circular economy are thus on the level of:

- Cooperation across disciplines and paradigms
- Policy support – European level
- Technological development – path dependency and lack of pragmatism
- Organization of knowledge development interdisciplinary
- The development of solid business cases
- Getting actors and organizations aligned in their goals, commitment and ambitions: user involvement

Taking these results to a tentative answer on what they mean on a more general level- the lessons and principles that can be deducted from the parable - it can be said that the current innovation system is on the verge of entering a new phase, whereby the aim is to combine commercial outlook embedded in innovation system via innovation policy, with an outlook to create societal value. This creates its own challenges, as market driven innovation, without central role of a governmental agency to subsidize the initiative, is often mostly aimed at creating commercial value and not social value.

Thus the current initiatives around recovering P lay bare some weaknesses in our current innovation system – which formally acknowledges the need to combine commercial with societal value but in practice is not sufficiently able to combine the two goals.

This parable shows the shortcomings in the roles of the diverse actors. They lack room to move. Companies are very much aimed at safeguarding their own competitive position. The market is not sufficiently able to take over highly innovative and promising initiatives, because of some systemic lock in effects created by institutional inertia. New business models are sought for via e.g. the platform economy, but they still have to prove themselves on the long run.

Knowledge institutes are highly enthusiastic to contribute to the design of new technologies and new business models, but eventually the interdisciplinary cooperation that is needed to be able to be truly innovative is hampered by the fact that the science system is still very much aimed at disciplinary core problems instead of interdisciplinary solutions for societal problems. Valorization remains a daunting task for Academia.

Governments are locked up in the legal formulation of their tasks and their facilitating role towards business and society. The emphasis on this role creates an information asymmetry – society and business know more about sustainability then governments. This makes it difficult to steer via policy upon sustainability. Central governments lack specialist knowledge to be able to assess the viability of truly innovative technologies and developments. They are always behind with regulations and laws. They have to take into account the fact that neither they, nor their regional counterparts can sell materials themselves, but that the market does not feel the same urgency as the government to contribute to making P from sewage water into a viable business case. On a policy level, this creates a wicked policy problem.

Current focus is on how to combine result of marketization and privatization, via a loose interpretation of institutional roles via making use of project based working, network organizations and other organizational forms reflecting the basics of platform economy.

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