The future of Waste Water Treatment: a Delphi-based approach

1. Introduction[1]

The Organization for Cooperation and Development (OECD) attested European countries such as Germany, Austria, Denmark, Finland, Netherlands, Sweden and Switzerland a very high rate of coverage by advanced sanitation services and especially by tertiary treatment. [*OECD,* 2009][2] The reliability of this infrastructure is of crucial importance for our society, as the *OECD* [2007] underlines: "The long-term future performance of OECD economies, and of the global economy, will depend to an important extent on the availability of adequate infrastructures to sustain growth and social development." This high level is financed in OECD and BRIC (Brazil, Russia, India and China) countries by current expenditures on water and wastewater services summing up to 405 billion US-Dollars ($bn) each year. Germany spends 17.932 $bn each year, corresponding to 0.75 % of its gross domestic product (GDP). [*OECD,* 2009] The recent report of the OECD expanded this work to the strategic transport infrastructure need and stressed the growing pressure to "balance long-term needs and the economic advantages of investing in infrastructure against short-term pressures and the costs and consequences of not investing." [*OECD*, 2013]

At the global level the water and sanitation sector is confronted by manifold challenges as identified by *the World Water Development Report of the United Nations World Water Assessment Programme (UNWWAP)* [2009] and the United Nations world water development report 4 [*UN-Water and UNESCO*, 2012]. Among the most important challenges are population dynamics such as growing or shrinking populations, changing age distributions, urbanization and mitigation, economic challenges such as globalization, food and energy scarcity, as well as social challenges and technological changes. The fourth Global Environmental Outlook of the *United Nations Environment Programme (UNEP)* [2007] describes the challenges with respect to water as follows: "The quantity and quality of surface- and groundwater resources, and life-supporting ecosystem services are being jeopardized by the impacts of population growth, rural to urban migration, and rising wealth and resource consumption, as well as by climate change." [*UNEP*, 2007] The Bonn Declaration on Global Water Security [*GWSP*, 2013] even states "In the short span of one or two generations, the majority of the 9 billion people on Earth will be living under the handicap of severe pressure on fresh water, an absolutely essential natural resource for which there is no substitute." [*GWSP*, 2013]

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1 This article was mostly inspired by three papers, *Dominguez et al.* [2006; 2009] and von der *Gracht and Darkow* [2010].

2 Most of the developing countries, especially in Sub-Sahara Africa, are not on track to meet the Millennium Development Goal to halve by 2015, the proportion of people without sustainable access to basic sanitation. Whereas rapid progress can be observed in domestic water supply in almost all regions of the world, sanitation still lags. That's why the UN General Assembly declared 2008 the International Year of Sanitation. [*WHO and UNICEF,* 2008]

In order to adapt to these dynamics, but also to maintain and replace the existing infrastructure, significant investments will be required. In the decade 2020-2030 the yearly expenditures in the OECD and BRIC countries for infrastructure networks expenses for the water and sanitation sector are expected to be the highest in the world among road, rail, telecoms and electricity. [*OECD*, 2009] In all OECD and BRIC countries it is predicted that the yearly expenses will increase from 405 $bn to 6,212 $bn by 2015 and to 9,003 $bn in 2025. In Germany the expenditures are expected to increase from 17.932 $bn to 23.38 $bn in 2015 and 35.84 $bn in 2025. For the specific expectations of the expenses per GDP share see Figure 1 [*OECD,* 2009]

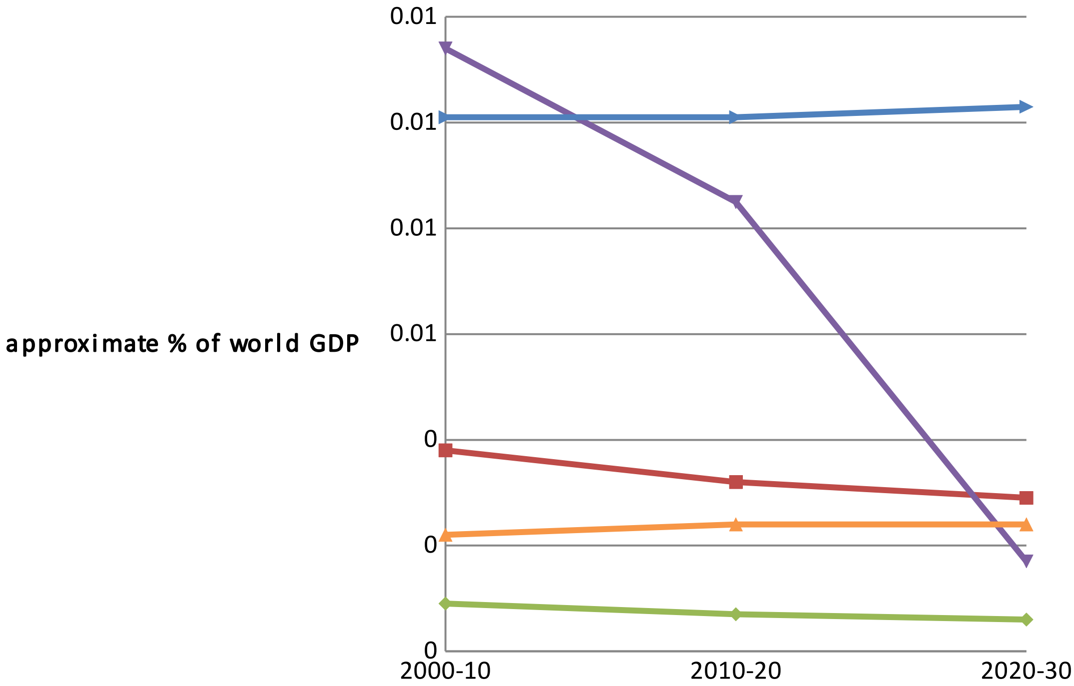


Figure 1. Share of current expenditures of gross domestic product (GDP) in OECD and BRIC countries for road, rail, telecoms, electricity, and water and sanitation infrastructures

The major challenge "capital intensity" of the current status of the sanitation sector involves a high degree of fixed costs and low rates of return. [*OECD*, 2009] In combination with the long useful life especially of the sewer system of more than 80 years and in some cases of even more than 100 years [*Baur and Herz*, 2002; *Kaempfer and Berndt*, 1999; *Lemer*, 1996] the sanitation sector is especially vulnerable to path dependency [*Pierson*, 2000] and sunk costs [*Kirkpatrick et al.*, 2006; *Rees*, 1998] as discussed by *Hiessel and Toussant* [1999], *Huitema and Meijerink* [2007] as well as by *Ingram and Fraser* [2006].

In view of the long term impacts that go along with infrastructure investments, strategic planning approaches that can deal with such determining, long range decisions and the involved uncertainty caused by changing environmental conditions seem to be indispensable. But as *Dominguez and Guyer* [2009] underline, decision-makers in the sanitation sector are not aware of the long-term dynamics of the system and mostly rely on forecasts and the assumption that the future can be predicted based on extrapolations of past trends. This "*capability gap*" [*Dominguez et al.*, 2009] to deal with long range challenges has also been identified by the *OECD* [2007], which recommends the strengthening of strategic planning capacities by supporting long range planning approaches to infrastructure planning. The OECD Environmental Outlook 2050 stresses the importance of planning in water management, too [*OECD*, 2012].

In Germany the planning deficit has become obvious in the context of demographic changes. Whereas in most regions of the world demographic change implicates a growth of the population [*UNDESA*, 2007], in Germany the population is shrinking and ageing. [*Federal Statistical Office of Germany*, 2010] In East Germany, demographic change was reinforced by structural and economic changes initiated by the reunification process. Additionally, important parts of the East German sanitation system needed to be modernized to the high standards of the Federal Republic. At the time the newly installed infrastructure was designed for growing populations and "*blooming landscapes*", a term used by the former chancellor Helmut Kohl. But the contrary turned out to be true in most of the East German regions, leading to oversized wastewater systems and, as a consequence, rising wastewater fees due to the high degree of fixed costs. [*Hillenbrand et al.*, 2010; *Hummel and Lux*, 2007; *Nowack et al.*, 2010; *Schlör et al.*, 2009]

Scenario planning is one of the most promising long range planning approaches that support decision-makers to bridge this gap and overcome the difficulties of traditional planning instruments. [*Miller and Waller*, 2003; *Phelps et al.*, 2001; *Schnaars*, 1987, 2001; *Schoemaker,* 1991, 1993, 1995; *Schwartz*, 1998; *Slaughter,* 2002a; *Slaughter*, 2002b] Originally developed for military purposes such as possible causes for a nuclear war by the RAND Corporation in the United States during the Cold War it was later adopted by the civil sector. [*Bradfield et al.*, 2005; *Wack*, 1985; *Cornelius et al.*, 2005; *Royal Dutch Shell*, 2005; *Shell International*, 2010] Since then, scenarios have been used by multiple planners, researchers and practitioners and adopted to their specific needs, which has resulted in a "*methodological chaos.*" [*Martelli*, 2001] Several authors place emphasis on systematizing and structuring the existing body of methodological scenario literature and applications. [*Bishop et al.*, 2007; *Bradfield et al.*, 2005; *Börjeson et al.*, 2006; *Chermack et al.*, 2001; *Godet*, 2000; *Lempert et al.*, 2009; *Malaska et al.*, 1984; *Mietzner and Reger*, 2005; *Nowack et al.*, 2011; *van Notten et al.*, 2003; *Varum and Melo*, 2010]

In this article we consider a scenario as ""*storylines" or narratives that describe conceivable future developments of the world water situation*" and adopt thereby the definition of *Alcamo et al.* [2000]. Very often the term scenario is used as a synonym for a set of specific values of different assumptions, especially in more natural scientific oriented studies. Often these studies are much closer to predictions than to strategic planning scenarios in the sense of *Wack* [1985]. Scenario planning is consequently the entire decision-making process that develops and analyzes scenarios and derives the necessary consequences for today's decision. [*Bishop et al.*, 2007; *Chermack et al.*, 2001] We follow Bishop's approach that consists of two phases which are characteristic for a complete scenario planning study: in the first phase a set of possible futures states of the future is developed. In the second phase the scenarios are analyzed and the consequences for today's decisions are drawn. The development phase is cut into three sub-steps: scenario framing, scanning, and forecasting, and another three steps in the transfer phase: visioning, implementing and controlling. In this article we focus on the development phase.

Beside the study design, another differentiating factor is the scenario goal. *Börjeson et al.* [2006] differentiate between predictive and explorative scenarios. Predictive scenarios answer the question: What will happen? They focus on specific drivers and their impacts on the analyzed system. Further characteristics are a short time horizon, foreseeable challenges and a more quantitative study design. In contrast, explorative scenarios provide an answer to the question: What can happen? Thus the focus lies on strategic issues [*van der Heijden et al.*, 2002], the identification of the drivers or challenges and a long time horizon. They tend to apply a more qualitative oriented study design. In the water research context, scenarios are often used in a predictive way. [*Chenoweth and Wehrmeyer*, 2006; *Mahmoud et al.*, 2011; *Soboll et al.*, 2011; *Straatsma et al.*, 2009] In Europe, the water framework directive and its call for more participation pushes studies that analyze the possibilities of scenario planning as a tool for stakeholder participation. [*Caille et al.*, 2007; *Hatzilacou et al.*, 2007; *Jessel and Jacobs*, 2005; *Kok et al.*, 2011; *Valkering et al.*, 2010] (For an overview on scenario planning in the water and sanitation sector see Table 1 and Table 2).

A prominent use of scenarios is the use in global environmental outlooks. Besides the water related work of the *IPCC* [2008], water plays an important role, among others, in the Environmental Outlook of the *OECD* [2012], in the Global Environmental Outlook of the *United Nations Environmental Programme (UNEP)* [2012] as well as in the Millennium Ecosystem Assessment coordinated as well by the *UNEP* [2005].

Water plays the key role in the Global International Waters Assessment [*UNEP,* 2006] as well as in the scenario study of the World Business Council on Sustainable Development [*WBCSD*, 2006] "Business in the World of Water - Water Scenarios to 2025". Further global scenario studies with a focus on water can be found in the following Table 1.

Table 1. Global Water Scenario Studies

Reference	Title	Description
[*World Water Council*, 2000]	World Water Vision	analysis of the state of the global water resources
[*International Food Policy Research Institute*, 2002]	World water and food to 2025	water as a determining resource for food safety
[*UNEP*, 2006]	Global International Waters Assessment (GIWA)	systematic assessment of the environmental conditions and problems in transboundary waters
[*WBCSD*, 2006]	Business in the World of Water - water Scenarios to 2025	analysis and awareness raising of potential water risks for companies
[*International Water Management Institute*, 2007]	Water for Food, Water for Life	efficient water management in agriculture for a safe food supply
[*UNESCO*, 2012]	Global Environmental Outlook 5 – Chapter 4	Water-efficiency and sanitation are vital for global health

Very few studies have a comparable local focus and the same explorative scenario goal as the study presented in this article. One of the closest studies is the study of *Hiessel et al.* [2002]. They evaluate three different future urban water systems for Germany in which they integrate different technological, organizational and institutional innovations. They also describe three possible states of the infrastructure system, mostly varying the degree of separation of the various water and wastewater streams. But they do not assess which possible drivers or challenges might lead to this outcome. Nevertheless, the three system scenarios describe possible technological developments of the infrastructure system and one of their scenarios will be reflected in one of our scenarios. The scholars of the Eidgenössische Technische Hochschule Zürich [*Lienert et al.*, 2006; *Störmer et al.*, 2009] as well as *Dominguez et al.* [2009]

develop explorative scenarios for Switzerland. Nevertheless, so far no explorative scenario study exists for the German sanitation sector, which focuses on the identification of possible future challenges. Even though global and national trends from other scenario studies are partially applicable to Germany, the particularity of the German sanitation sector as described in *Kraemer and Hansen* [2004] requires the development of customized scenarios.

Therefore the two research questions we want to answer are:

1. What are possible future challenges that the sanitation sector in Germany has to face in the future?
2. What are possible future scenarios for the year 2050?

Besides the case-specific research interest, we develop and test a new Delphi-based scenario methodology based on a compilation of prior studies [*Nowack et al.*, 2011]. Moreover, we emphasize the possibilities of the Delphi technique within scenario development to identify weak signals [*Rossel*, 2009] as an important prerequisite to identify and prepare for discontinuities or shocks [*Saritas and Smith*, 2011; *van Notten et al.*, 2005]

The scenarios are developed primarily for decision-makers at the executive and management levels, but can be used as well on regional and national levels by politicians and governments for developing long range strategies to facilitate the incorporation of possible future challenges. Consequently, we decided for an explorative scenario study. The purpose of this scenario study is therefore to enhance organizational adaptation and learning by recognizing and interpreting external signals of a changing environment. [*Berkhout et al.*, 2006; *Chermack and Van Der Merwe*, 2003; *Galer and van der Heijden*, 2001; *Phelps et al.*, 2001] Therefore we included a wide arrange of sanitation professionals, administrative authorities, as well as academic experts into the Delphi studies and organized workshops to which we invited relevant stakeholders. The target time horizon is the year 2050, but this is rather a symbolic value as we intended to develop scenarios for a time period that allows not only incremental adjustments but also structural changes. [*Kindler*, 1979; *Miller and Friesen*, 1982; *Wright et al.*, 2008]

The remainder of this paper is organized as follows: after having deducted the research question, the research background and research methodology will be described. Subsequently, the findings with respect to the Delphi survey, the Fuzzy Cognitive Map analysis, the business-as-usual scenario and the final explorative scenarios are presented. Finally, we discuss the results and the methodology and conclude by giving recommendations on how decision-makers might use the results for future foresight studies.

Table 2. Overview of explorative scenario studies in the water and sanitation sector[3]

Study	Title	Purpose	Region	Time frame
[*Straton et al.*, 2010]	Exploring and Evaluating Scenarios for a River Catchment in Northern Australia Using Scenario Development, Multi-criteria Analysis and a Deliberative Process as a Tool for Water Planning	identification of future challenges and stakeholders interests	Australia	20 years
[*O'Connor et al.*, 2005]	The Avon River Basin in 2050: Scenario planning in the Western Australian Wheatbelt	strategic regional planning	Australia	2050
[*Christoph et al.*, 2008]	IMPETUS: Implementing HELP in the upper Ouémé basin	analysis of the impacts of different economic, demographic, and climate developments on water resources	Benin and Morocco	2050
[*Kok et al.*, 2011]	Combining participative backcasting and exploratory scenario development: Experiences from the SCENES project	identification of important trends, development of stakeholder-based scenarios, used as input for hydrological modeling	Europe	2050
[*Jessel and Jacobs*, 2005]	Land use scenario development and stakeholder involvement as tools for watershed management within the Havel River Basin	development of land use scenarios based on stakeholder interviews, used as input for hydrological modeling	Germany	2015
[*Hiessl et al.*, 2002]	Design and sustainability assessment of scenarios of urban water infrastructure systems	analysis of different technological, organizational and institutional innovations in three prepared scenarios	Germany	2050
[*Hatzilacou et al.*, 2007]	Scenario workshops: A useful method for participatory water resources planning?	discussion of prepared scenarios, identification of preferred future, derivation of action needs	Greece	2020
[*Valkering et al.*, 2010]	Scenario analysis of perspective change to support climate adaptation: lessons from a pilot study on Dutch river management	stakeholder participation	Netherlands	"toward the future"
[*De Jong et al.*, 1989]	Scenario planning for water resources: a Saudi Arabian case study	modeling based on business-as-usual and most probable policy scenarios	Saudi Arabia	2000
[*Caille et al.*, 2007]	Participatory scenario development for integrated assessment of nutrient flows in a Catalan river catchment	identification and analysis of external drivers that impinge on nutrient emissions	Spain	2030
[*Lienert et al.*, 2006]	Future Scenarios for a Sustainable Sector: A Case Study from Switzerland	expert-based scenario development for the Swiss (waste)water sector	Switzerland	20-30 years
[*Störmer et al.*, 2009]	The exploratory analysis of trade-offs in strategic planning: Lessons from Regional Infrastructure Foresight	strategic planning in the sanitation sector on management level	Switzerland	25 years
[*Means et al.*, 2005b] and [*Means et al.*, 2005a]	Scenario planning: A tool to manage future water utility uncertainty	strategic planning for water utilities	USA	2025

3 The overview is result of a literature search using the scopus database. The search resulted in 75 hits from which pure modelling and predictive scenario studies were excluded. The scopus search string was: (TITLE-ABS-KEY(wastewater AND "scenario planning") OR TITLE-ABS-KEY(sanitation AND "scenario planning") OR TITLE-ABS-KEY(sewer AND "scenario planning") OR TITLE-ABS-KEY(wastewater AND "scenario development") OR TITLE-ABS-KEY(sanitation AND "scenario development") OR TITLE-ABS-KEY(sewer AND "scenario development") OR TITLE-ABS-KEY(wwtp AND "scenario development") OR TITLE-ABS-KEY(wwtp AND "scenario planning") OR TITLE-ABS-KEY(water AND "scenario development") OR TITLE-ABS-KEY(water AND "scenario planning")).

2. Method

To gather the necessary input from a broad array of experts for the scenarios we chose the Delphi technique and integrated sanitation professionals, researchers and specialists from the authorities.

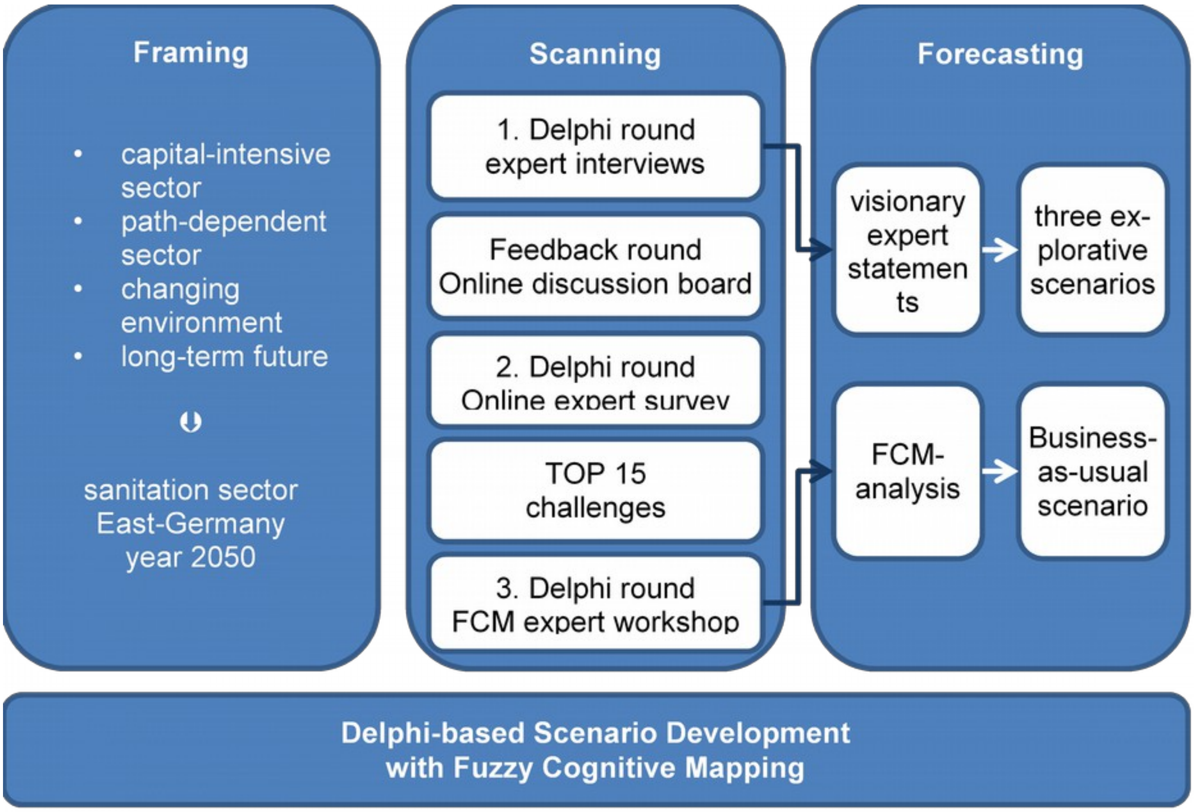


Figure 2. Research Design

2.1 Delphi technique

The Delphi technique itself is defined as "a method for structuring a group communication process so that the process is effective in allowing a group of individuals as a whole, to deal with a complex problem." [*Linstone and Turoff*, 1975] The key elements of the method [*Landeta*, 2006; *Linstone and Turoff*, 1975; *Rowe and Wright*, 1999; *Nowack et al.*, 2011] are anonymity to avoid a "Bandwagon effect" [*Leibenstein*, *1950*], iteration to compile the viewpoints [*Hill and Fowles*, *1975; Linstone*, *1975; Turoff*, *1975; Tapio*, *2002; Kuusi and Meye,r* 2002; *Rikkonen and Tapio,* 2009], controlled feedback in terms of quotes, summaries, median and mean statistics and participating experts via procedures such as Real Time Delphi [*Steinert*, *2009; Gordon and Pease*, *2006*] which allows immediate feedback and almost infinite iteration. If the Delphi technique is integrated in a scenario study, it can support the scenarist mainly by three functions [*Nowack et al.*, 2011]: idea generation making use of experts for the scanning phase, consolidation by evaluating or ranking the drivers during forecasting, and judgment for deriving consequences in the visioning phase. For this case study we integrated the Delphi technique in the scanning as well as in the forecasting step.

2.1.1 First Delphi Round: Expert Interviews

The main purpose in the beginning was to identify possible future challenges and rely on the experts to generate ideas on how the future may unfold. The Delphi process started with 21 semi-structured expert interviews. We invited the authors of pertinent publications, cooperating industry partners (mostly operators of wastewater utilities), important stakeholders as representatives of the administrative bodies on state level as well as of the Federal Government and from non-governmental organizations. Nearly half of the interviews were conducted face-to-face, whereas the other half was conducted as telephone interviews. During the semi-structured interviews we used an interview guideline that was developed based upon the PESTEL framework and the stakeholder model [*Fassin*, 2009; *Freeman*, 2010] in combination with Porter's Five Forces [*Porter*, 1985, 2008]. We asked the experts in open-ended questions to designate possible future political, economic, societal, technological and ecological challenges that might affect the sanitation sector in the year 2050 in Germany. The experts were also asked to nominate possible demands on and of the employees, the owner, the public or the creditors that might play a role in the future and to assess how the five forces that shape competition (suppliers, clients, substitutes, new market entrants, and the competition within the sector) might evolve in the future. We also encouraged the experts to think about possible weak signals. The interviews took in average 49.9 minutes; some of them even took more than one and a half hours. The 21 interviews resulted in 17 hours and 28 minutes of recorded interviews. These records were transcribed into 254 pages of text, or 112,706 words. The interview and transcription phases were supported by a team of young scientists. After a training period they conducted a few interviews on their own and were responsible for the entire transcription. The transcription was then used for a summarizing content analysis supported by the content-analysis software MAXQDA. Applicable text passages were marked and assigned to the categories of the interview guideline. The following quote illustrated how the inputs from the interviews were processed:

> *"We have the unsolved problem of prions. These proteins cause the mad cow disease, and scrapie as well as the Creutzfeldt-Jakob disease. They are accumulating in the sewage sludge. This is not problematic if the sludge is burned, but it is problematic if the sludge is used for agricultural purposes. […] This is a highly problematic topic and you should discuss if you want to include it in your study because it might start a heated debate"*

This statement was coded as "accumulation of new so far unknown substances" (POL1) as one possible challenge in the scenario study. In the following runs, redundancies were removed and some of the categories were combined. We concluded that the stakeholder categories were mostly covered by the PESTE categories and therefore this set of categories was removed. In the end we could identify 46 possible future challenges that we assigned to 10 major categories. See also Error: Reference source not found.

2.1.2 Feedback Round: Online Discussion

The results of the first Delphi round were fed into an online discussion board. Two external experts were asked to review the board and to comment on the results in order to start the conversation. Each participating expert was assigned an anonymous access to the board and was invited to review and comment on the results. The anonymity of the answers as well as of the experts was maintained during the whole Delphi procedure. A short online video explained the basic functions of the discussion board to facilitate the use. The experts were also asked to co-nominate [*Loveridge*, 1999; *Nedeva et al.*, 1996] further experts. In total, 11 of the 28 experts that had access to the anonymous discussion board visited the board. In general, no new challenges were added, but the probability of occurrence of some items was discussed.

2.1.3 Second Delphi round: Online Expert Survey

The reviewed results of the first Delphi round were then fed into an online survey. In this step, we used the consolidation function of the Delphi technique in order to identify the most relevant future challenges. We invited all experts that had participated so far, as well as some additional sanitation professionals. We asked the experts to answer ten questions with 46 items. The experts were asked to evaluate the relevance of the future challenges in the year 2050 on a Likert-type scale from 1 (very low relevance) to 5 (very high relevance). For a high response rate the questionnaire was kept as simple as possible and integrated a lottery as an incentive to participate. The survey took about ten minutes time to be completed. 27 from 39 invited experts responded to the questionnaire. The feedback to this second Delphi, the statistical group response, and the top ranked challenges were presented at the beginning of the expert workshop in the next Delphi round.

2.1.4 Third Delphi Round: FCM Expert Workshop

Based on the top 15 future challenges, identified in the second Delphi round, a Fuzzy Cognitive Map was developed and consequently analyzed based on graph theory [*Kosko*, 1986; *Papageorgiou et al.*, 2003], specifically social network analysis [*Grienitz et al.*, 2010; *Özesmi and Özesmi*, 2004]. Fuzzy Cognitive Maps (FCM) are causal cognitive maps that capture the mental models, they were used for the first time in context with scenario planning by *Jetter and Schweinfort* [2011], *Kok* [2011] and *van Vliet* [2010].

We invited all experts to a workshop of which 19 experts participated, among them were eight operators, one representative of the federal state ministry on environment, and three external scientists and the moderating team. Anonymity was assured until the workshop in order to allow the experts also to mention non-mainstream topics. Only during the workshop the participants were introduced to each other, the statements that were given in the preceding steps are still not attributable to any expert. After an introduction to the topic and an explanation of the methodology, we asked the participants of the expert workshop to illustrate how the top 15 future challenges are affecting the sustainability of the sanitation sector. In order to facilitate the discussion we started with three target variables in the FCM, economic sustainability (cost-covering wastewater fees), ecological-technical sustainability (good status of the receiving water bodies) and social sustainability (social acceptance and satisfaction with the service). [*European Parliament and European Council*, 2000; *German Advisory Council on Global Change*, 1997] In order to facilitate the communication the group was split into two sub-groups. In a first step the two groups drew the Fuzzy Cognitive Map without conducting the weighting of the relationships. Then the two moderators compared the two Fuzzy Cognitive Maps and observed a very high degree of concordance. Very few arrows varied, which was a result of different interpretations of some terms. The moderator team could quickly combine the two maps into one map. Finally, in a last step the entire workshop group evaluated the strengths of the relationships.

2.2 Scenario building

The results of the second Delphi round, the online survey, are summarized in a Business-as-Usual scenario. The challenges identified in the first Delphi round and evaluated in the second round are analyzed using Fuzzy Cognitive Maps. This work builds upon the precedent of the methodological work of *Jetter and Schweinfort* [2011], *Kok* [2009], and *van Vliet* [2010]. Fuzzy Cognitive Maps capture the mental models of experts by drawing loop and weighted arrows [Jetter and Schweinfort, 2011]. The Fuzzy Cognitive Map can be transformed to a square adjacency matrix. We used the coding steps + = 0.25, ++ = 0.5 and +++ = 0.75 for positive relationships between the variables and vice versa for negative relationships. There are three types of variables: transmitter, receiver, and ordinary variables. The distinguishing features between these are the indegree and the outdegree. The outdegree (od) is defined as the sum of the absolute values of a row of a variable. The outdegree stands for the active influencing impact of a variable, whereas the indegree (id) is a measure on how much it is driven by other variables. Transmitter variables have a positive outdegree and zero indegree. Receiver variables are characterized by a zero outdegree and a positive indegree. Ordinary variables have a positive in- and outdegree. [Özesmi and Özesmi, 2004] The overall influence of a variable in a matrix can be measured by calculating its centrality. The centrality (ci) is the sum of the outdegree and indegree of a variable.This can be an important indication for a key driver of the analyzed system. [Grienitz and Schmidt, 2010] Finally the system can be simulated: As described in Özesmi and Özesmi [2004], an initial state vector is multiplied by the adjacency matrix. This auto-associative neural network method is used to calculate the steady state and repeated until the new state vector is stable. [Reimann, 1998] In the following, additional policy simulations can be run and compared with the steady state outcome.

We use Fuzzy Cognitive Maps primarily to illustrate the complexity and the dynamics of the sanitation system. Often the Cross-Impact Analysis is chosen for the same purpose. [*Bañuls and Turoff*, 2011; *Gordon and Pease*, 2006; *Phelps et al.*, 2001; *Tversky and Kahneman*, 1974] But the high degree of complexity makes this technique less attractive for a participatory scenario study and handicaps starting a learning process. As illustrated in the precedent combinations of Fuzzy Cognitive Maps and scenarios, Fuzzy Cognitive Maps are especially well suited for a participatory approach. The Fuzzy Cognitive Maps developed in the expert workshop are basis for further analysis based on the graph theory [*Kosko*, 1986; *Papageorgiou et al.*, 2003]. We used the software FCMappers, which implements the methodology proposed in *Özesmi and Özesmi* [2004].

In order to overcome traditional mind models and to stimulate creative thinking about alternative futures we completed the Business-as-Usual scenario based on the Fuzzy Cognitive Map with three visionary explorative scenarios. They are not based on the average group response but on the most visionary ideas of some of the experts in the interviews. The three explorative scenarios highlight different aspects of a possible future sanitation sector.

Whereas the "Watershed-First" scenario focuses on an alternative regulatory regime, the "Recycling-First" scenario illustrates a different technological development, as does the "Mega-City" scenario.

3. Results

3.1 First and Second Delphi Round

This chapter will provide an answer to research question 1 "What are possible future challenges that the sanitation sector in Germany has to face in the future?". Error: Reference source not found summarizes the results of the first and second Delphi round. The future challenges together with the corresponding categories represent the summarized results of the first Delphi round. Each variable (Var) is assigned to a category and a superordinated PESTEL category. The mean and the standard deviation (SD) in Error: Reference source not found are the results of the second Delphi round. The top 15 challenges with the highest relevance are marked by an asterisk and also illustrated in figure 5Error: Reference source not found in the Appendix. In average the experts evaluated "sewer remediation needs" (1.) as the most relevant challenge, followed by "drug residues" (2.) and "short public budgets" (3.).
Furthermore, the results show that among the top 15 challenges the consensus in terms of a relatively low standard deviation is high. The standard deviation among the top 15 challenges varies between 0.64 and 1.01, whereas it varies between 0.82 and 1.23 among the remaining variables. The consensus is especially high for "4th treatment stage" (15.) and the first ranked "sewer remediation needs". A very high degree of consensus between the experts exists also about the relevance of "drug residues" (2.), "phosphorus recycling" (9.) the "precautionary principle" (6.) and "heavy rainfalls" (4.). The opinion of the experts varies the most concerning the importance of "nanoparticles" (30.) and "reduction of subsidies" (17.).

Table 3. Results of the first and second Delphi round

Category		Var	Name	Description	Mean	SD
Political	New Standards	STA1	Precautionary principle	Avoidance of new pollutants at the source. i.e. approval of medicine only if the medicine is degradable in water	**4.04***	0.73
		STA2	Watershed-regulation	Enlargement of the area of responsibility to watershed level	3.17	1.05
		STA3	Regulation of agriculture	Regulation of agricultural pollutions. i.e. excessive discharge of nutrients	**3.88***	0.88
		STA4	Receiving water-dependent standards	Purification standards vary depending on the status of the receiving waters	3.50	0.98
		STA5	Classical standards	Increase of classical purification standards	**3.84***	0.85
Economic	Sector-specific Development	SEC1	Public relations	Enhancing of the public relation in an open and activating way	3.20	1.15
		SEC2	Formal privatization	Continuation of the trend towards formal organizational privatization. i.e. private partners are called in up to a co-ownership of 49 per cent	2.96	0.82
		SEC3	Cooperation intensity	Inner-city. inter-communal and inter-sectoral cooperation of the wastewater utility	3.56	0.96
		SEC4	Indirect competition	Competition takes only place between specific subservices e.g. sewer cleaning	3.25	1.15
		SEC5	Direct competition	Central sanitation services are in direct competition with decentral solutions. starting at large properties	3.30	0.97
	Finance	FIN1	Allowing of provisions	Legal allowing of provisions (saving funds) for future investment needs e.g. remediation of the sewer system	3.33	1.09
		FIN2	Coordinated charging	Charging in cooperation with water utilities for an optimal water demand management	3.13	0.97
		FIN2	Fix cost-depending charging	Charging of a basic rate in the amount of the fix costs	3.52	1.12
		FIN4	Pollution-depending charging	Charging of wastewater rates that are depending on the degree of the pollution and installation of a corresponding measuring system	3.22	1.09
		FIN5	Short public budgets	Short financial resources of public budgets limit the local government's room for maneuver	**4.12***	1.01
		FIN6	Reduction of subsidies	Considerable reduction of subsidies as important source of investments	3.71	1.23
		FIN7	Revision of rates	Revision of wastewater rates by an independent third party	3.00	0.98
		FIN8	Sustainability checks	Introduction of sustainability or demography checks for investments e.g. as part of appropriations	3.33	0.82
Social	Demo-graphy	DEM1	Population decrease	Decrease of the population due to demographic and structural changes	**4.04***	0.89
		DEM2	Rise in average age	Rise in the average age of the population due to declining birth rates and rising life expectancy	3.28	1.10
		DEM3	Skills shortage	Due to demographic change qualified employees are increasingly difficult to find	3.20	1.04
	Water Demand	WAD1	Decreasing water demand (dom.)	Decreasing domestic water demand	**3.85***	0.92
		WAD2	Decreasing water demand (ind.)	Decreasing industrial water demand	**3.85***	0.92

Technological	Sewer System	**TCS1**	**Storage capacities**	**Real time controlling and management of the storage capacities of the sewer system for a better management of heavy rainfalls**	**3.63**	**0.92**
		TCS2	Trenchless restructuring	Use of trenchless restructing methods for the remediation of the sewer system	3.40	0.91
		TCS3	Stormwater infiltration	Decentral collection. storage and infiltration of stormwater	**4.00***	0.85
		TCS4	Sewer remediation needs	Remediation needs of sewer system	**4.46***	0.71
		TCS5	Separate sewers	Continuation of the separation of the drain and sewer system	**4.08***	0.93
		TCS6	Infrastructure tunnels	Installation of combined infrastructure tunnels (walkable) for better maintenance possibilities. possibility to pull in additional infrastructure pipes (e.g. telecommunication) by winches	2.63	0.92
	Wastewater treatment plant	TCW1	4th treatment stage	Fourth advanced treatment stage to remove new pollutants. e.g. membrane technology	**3.83***	0.64
		TCW2	Disinfection	Disinfection of wastewater before it leaves the wwtp	3.23	0.92
		TCW3	Renewable energies	Use of renewable energy sources at the wwtp. e.g. solar power. fermentation gas etc.	3.80	0.87
		TCW4	Hydropower plants	Installation of wastewater hydropower plants on the wwtp as a standard	3.13	1.03
		TCW5	Sludge hygienisation	Hygienisation of sewage sludge for a better recycling	3.52	0.85
		TCW6	Phosphor recycling	Recycling of phosphor at the wwtp	**3.96***	0.68
		TCW7	Heat recovery	Use of heat from wastewater	3.38	0.85
	Decentr ality	DEC1	Household level reuse	Reuse of water and recycling of nutrients (phosphorus) on household level. cascade use of water	3.08	1.10
		DEC2	Decentral sanitaion	Profuse installation of decentral sanitation systems. in urban as well as in rural areas	3.42	0.99
Environmental	**Climate Change**	CLI1	Heavy rainfalls	Increased frequency of heavy rainfall	**4.12***	0.82
		CLI2	Heat periods	Increased frequency of drought and heat periods	**3.88***	0.95
		CLI3	Weather phenomena	Increasing vulnerability to unusual weather phenomena	3.27	1.08
	Pollutants	POL1	Unknown substances	Accumulation of new so far unknown substances	3.55	1.06
		POL2	Nanoparticles	Accumulation of nanoparticles in sewage	3.32	1.17
		POL3	Heavy metals	Accumulation of heavy metals in sewage	3.04	0.98
		POL4	Bacteria and viruses	Accumulation of bacteria and viruses in sewage	3.56	1.00
		POL5	Drug residues	Accumulation of drug residues and hormones sewage	**4.12***	0.67

3.2 Third Delphi Round

The top 15 ranked challenges were analyzed by developing a Fuzzy Cognitive Map during the expert workshop. An illustration of the resulting Fuzzy Cognitive Map is given in figure 3.

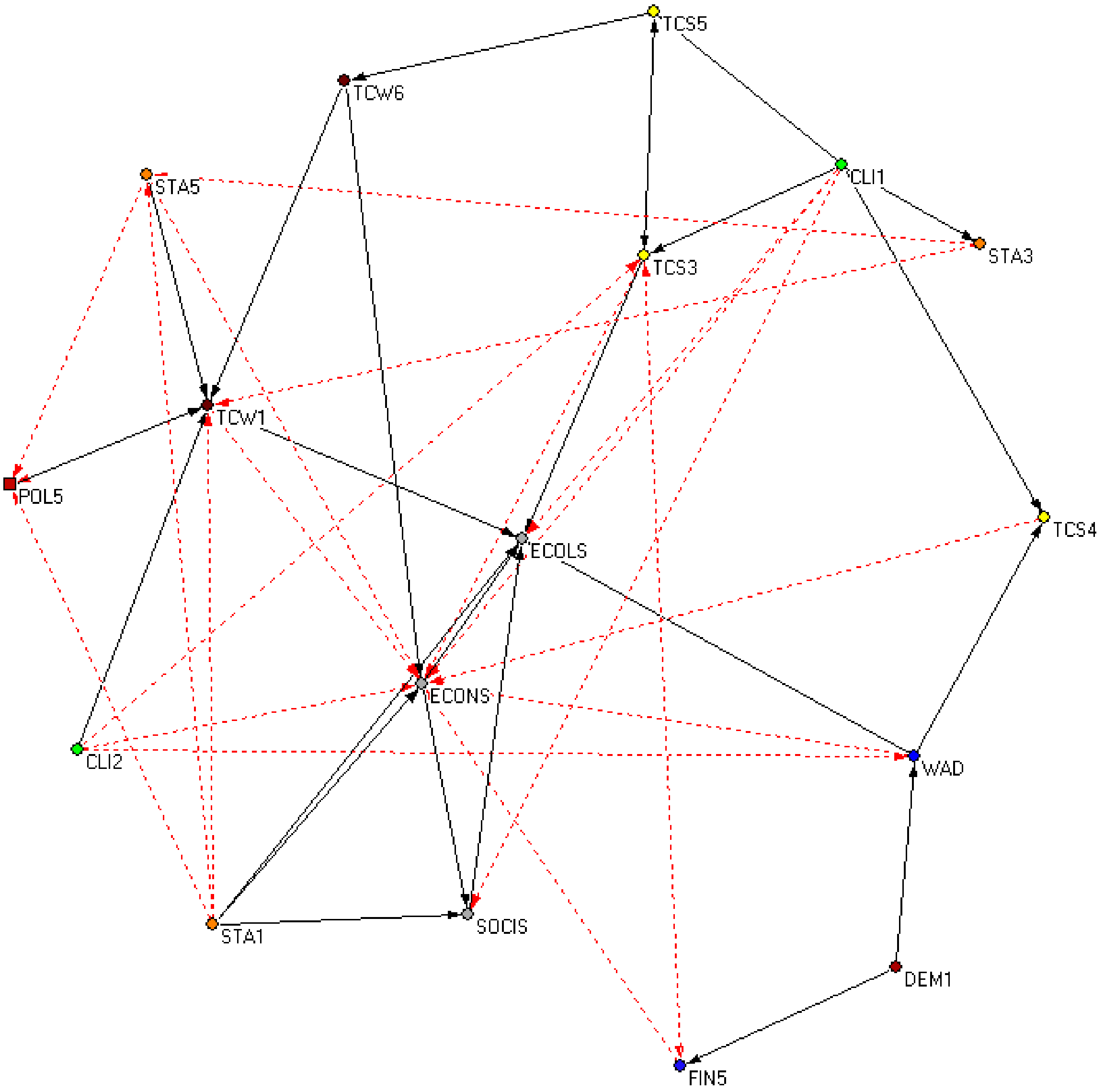


Figure 3. Fuzzy Cognitive Map developed in the expert workshop

The Fuzzy Cognitive Map is characterized by a total of 17 variables[4], 45 connections, 4 transmitters, 1 receiver, and 12 ordinary variables and by a density of 0.1557. The transmitter variables are "heat periods", "heavy rainfalls", "population decrease", and "precautionary principle", thus they influence other variables but are not affected by others. Except for "population decrease", these four variables are also characterized by the highest outdegree, i.e. they have the highest impact on other variables.

4 The two water demand variables WAD1 and WAD2 were integrated in one variable WAD during the FCM workshop.

Table 4. Adjacency Matrix and their graph theoretical indicators

TCS3				0.25			-0.25	-0.25		0.50								1.25
CLI2	-0.25		-0.50					-0.25						0.25				1.25
WAD					0.25			-0.25		0.25								0.75
TCS5	0.75																0.25	1.00
TCS4								-0.75										0.75
CLI1	0.50			0.50	0.25			-0.50	-0.25	-0.50			0.25					2.75
FIN5	-0.25							-0.25										0.50
ECONS									0.75	0.75								1.50
SOCIS										0.25								0.25
ECOLS																		0.00
DEM1			0.25				0.25											0.50
STA1								0.25	0.25	0.25				-0.25	-0.75	-0.25		2.00
STA3														-0.25		-0.25		0.50
TCW1								-0.25		0.50					-0.75			1.50
POL5														0.50				0.50
STA5								-0.25						0.25	-0.75			1.25
TCW6								0.25						0.25				0.50
Indegree	1.75	0.00	0.75	0.75	0.50	0.00	0.50	3.25	1.25	3.00	0.00	0.00	0.25	1.75	2.25	0.50	0.25	
Centrality	3.00	1.25	1.50	1.75	1.25	2.75	1.00	4.75	1.50	3.00	0.50	2.00	0.75	3.25	2.75	1.75	0.75	
Iterations until stability	18	1	2	18	3	1	18	19	19	18	1	1	2	19	19	3	18	

The analysis of the Fuzzy Cognitive Map shows that the target variable “ecological sustainability” is only driven by other factors and is not a driver of other variables, and is thus a receiver variable. It also belongs to the variables with the highest indegree, as well as the “economical sustainability, “drug residues” and “4th treatment stage”. “Economic sustainability”, “ecological sustainability, and “drug residues” are also among the variables with the highest centrality.

If the steady state is simulated, the last variables reach a stable state after 19 iterations, whereby the changes of the variable after the third round are only of marginal nature. Among the variables that need 19 iterations until they reach a stable state are the target variables “ecological, economic and social sustainability” as well as “storm water infiltration”, “separate sewers”, “4th treatment stage”, and “drug residues”. “Short public budgets” and “phosphorus recycling” stabilize after 18 iterations. This shows that the analyzed system itself is stable and does not lead to a vicious-circle of reinforcing effects.

Based on the Fuzzy Cognitive Map, the modeled system is simulated. Table 5 illustrates the steady state as well as the final stable state of the simulation and the difference (Δ) of the latter two. In all simulations the system also reaches a stable state after a maximum of 19 iterations.

Table 5. Simulations of the FCM

	steady state	Climate change	Δ	Demo-graphic change	Δ	*End-of pipe policy*	Δ	*Pre-cautio-nary policy*	Δ	*Old relics*	Δ
stormwater infiltration	0.6109	0.6507	0.0398	0.6090	-0.0019	*0.6109*	*0*	*0.6109*	*0*	0.5801	*-0.0308*
heat periods	0.5000	1	0.3891	*0.5000*	*-0.1109*	*0.5000*	*-0.1109*	*0.5000*	*-0.1109*	*0.5000*	*-0.1109*
decreasing water demand	0.4688	0.4073	-0.2036	1	0.3891	*0.4688*	*-0.1421*	*0.4688*	*-0.1421*	*0.4688*	*-0.1421*
seperate sewers	0.5993	0.6599	0.0490	0.5992	-0.0117	*0.5993*	*-0.0116*	*0.5993*	*-0.0116*	0.5975	*-0.0134*
sewer remediation needs	0.5603	0.5871	-0.0238	0.5927	-0.0182	*0.5603*	*-0.0506*	*0.5603*	*-0.0506*	1	*0.3891*
heavy rainfalls	0.5000	1	0.3891	*0.5000*	*-0.1109*	*0.5000*	*-0.1109*	*0.5000*	*-0.1109*	*0.5000*	*-0.1109*
short public budgets	0.4931	0.4906	-0.1203	0.5244	-0.0865	*0.4931*	*-0.1178*	*0.4931*	*-0.1178*	1	*0.3891*
ECONS	0.2355	0.1719	-0.4390	0.2035	-0.4074	0.1932	-0.4177	0.2649	-0.346	0.1643	-0.4466
SOCIS	0.5440	0.5010	-0.1099	0.5381	-0.0728	0.5362	-0.0747	0.5802	-0.0307	0.5308	-0.0801
ECOLS	0.7088	0.6456	0.0347	0.7390	0.1281	0.7459	0.135	0.7331	0.1222	0.6936	0.0827
population decrease	0.5000	*0.5000*	*-0.1109*	1	0.3891	*0.5000*	*-0.1109*	*0.5000*	*-0.1109*	*0.5000*	*-0.1109*
precautionary principle	0.5000	*0.5000*	*-0.1109*	*0.5000*	*-0.1109*	*0.5000*	*-0.1109*	1	0.3891	*0.5000*	-0.1109
regulation of agriculture	0.5312	0.5622	-0.0487	*0.5312*	*-0.0797*	*0.5312*	*-0.0797*	1	0.3891	*0.5312*	-0.0797
4th treatment stage	0.5581	0.5865	-0.0244	0.6481	0.0372	1	0.3891	0.4882	-0.1227	0.5581	-0.0528
drug residues	0.2459	0.2423	-0.3686	1	0.3891	0.1330	-0.4779	0.1979	-0.4130	0.2459	-0.3650
classical standards	0.4359	0.4340	-0.1769	*0.4359*	*-0.1750*	1	0.3891	0.3775	-0.2334	*0.4359*	-0.1750
phosphorus recycling	0.5374	0.5411	-0.0698	0.5374	-0.0735	*0.5374*	*-0.0735*	*0.5374*	*-0.0735*	0.5373	*-0.0736*

3.2.1 Climate Change

In the first simulation run, "climate change", the variables "heavy rainfalls" and "heat periods" are activated. The comparison of the steady state and the final state of the climate change simulation shows the high impact of climate change on the sanitation system. Almost all variables except "population decrease" and "precautionary principle" have changed in the simulation. This is also due to the high outdegree of the two variables, and especially of the "heavy rainfall" variable. More frequent heavy rainfalls lead to an increasing need for a decentralized stormwater capture and storage (TCS3) and a further separation of the drain and sewer system (TCS5) which facilitates the recycling of phosphorus at the wastewater treatment plant (WWTP). The need to regulate agricultural pollutions increases because of the vulnerability of farmland to heavy rainfall. Following the evaluation of the participating experts, heat periods increase the need to increase the cleaning capacity (TCW1) which is lowering the need to increase classical cleaning standards and consequently lowering the accumulation of drug residues in the sewage. In the end the system is characterized by an increasing pressure on the local public budgets, and a decrease of the target variables ecological, economic, and social sustainability.

3.2.2 Demographic Change

In the second simulation, "demographic change", the variables "decreasing water demand", "population decrease", and "drug residues" are activated. These three variables cover three important aspects discussed in Germany in relation to demographic change. Besides population decrease, the German society is also affected by an ageing population, which is suspected to reinforce the accumulation of drug residues in the sewage. Recent research has shown that the increase of drug residues that can be found in German rivers [*Heberer*, 2002a, 2002b] is less the result of demographic change, but of a steady increase of the volume of pharmaceuticals prescribed. [*Morgan*, 2006; *Royal Commission on Environmental Pollution*, 2011]. “Water demand” is expected to fall because of the lower number of inhabitants, but also due to a lower water demand per capita. The simulation shows that the increase of “drug residues” increases the need for a “4th treatment stage”. The decreasing “water demand” and population (DEM1) mainly limit further investments, such as “stormwater infiltration” and “separate sewers”. The “sewer remediation needs” in contrary are expected to increase. Variables concerning the purification standards (STA1, STA3, STA5) are not affected by demographic change in this simulation. Finally, the economic burden leads to a lower economic sustainability and less customer satisfaction (SOCIS).

3.2.3 Precautionary Principle vs. End-of-Pipe

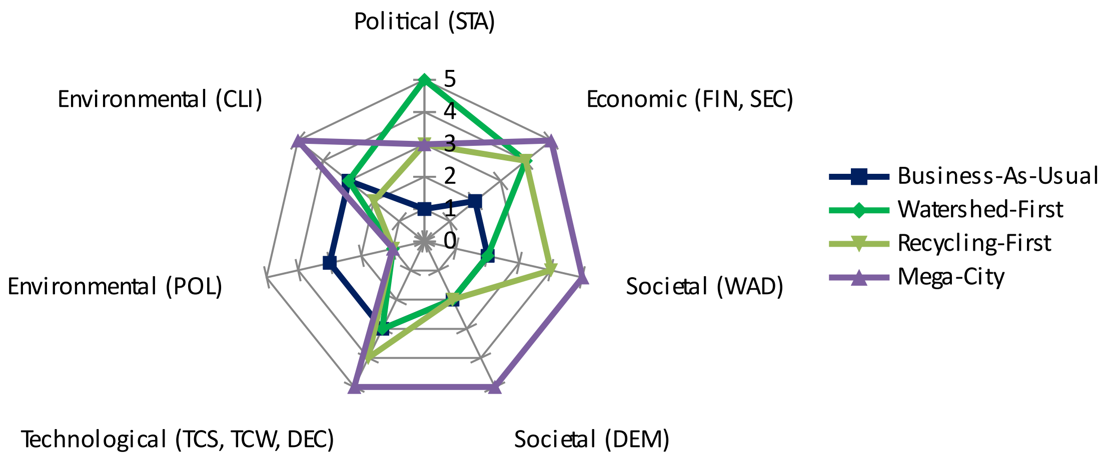
In the third simulation two different policy philosophies are analyzed, the precautionary approach is compared with a classical end-of-pipe approach. In the first simulation the variables “precautionary principle” and “regulation of agriculture” are activated, whereas in the end-of-pipe simulation “4th treatment stage” and “classical standards” are activated. Both simulations show that “drug residues” are reduced, but in the precautionary principle simulation this achievement goes hand in hand with an increase of all three aspects of sustainability whereas the end of pipe approach can increase the ecological sustainability only at the expense of a lower economic and social sustainability.

3.2.4 Old Relics

The fourth simulation, “old relics”, discusses the consequences of an insufficient maintenance of the sewer system and inappropriate budgeting and debt management (TCW4=FIN5=1). These bad management practices that might have been committed in the past are impairing those of the future generations. The simulation shows that investments in the infrastructure (TCS3 and TCS5) decrease. The lower financial capacities also reduce the possibility to invest for example in phosphorus recycling and installing a “4th treatment stage” which leads, as a consequence, to a slight increase of drug residues. All three aspects of sustainability decrease in this simulation. The “old relics” simulation shows that bad management practices limit adaptation options in the future.

3.3 Scenario building

In this chapter we will give an answer on research question 2 “What are possible future scenarios for the year 2050?”. Therefore, four scenarios are described. Based on the precedent analysis, we identified the most relevant future challenges and analyzed their interdependency. The first scenario, “Business-as-Usual”, incorporates the results of the FCM and the simulations. But in order to integrate the visionary statements expressed in the interviews, we complemented the Business-as-Usual scenario with three more visionary scenarios: “Watershed-First”, “Recycling-First”, and “Mega-City”. The scenario “Watershed-First” describes a future in which an alternative regulatory approach is applied. This scenario can be congruent with the existing central sanitation system, but it is also imaginable in combination with the following two scenarios. The “Recycling-First” and the “Mega-City” scenarios describe a future sanitation system that is fundamentally different to the existing central system and makes it mostly obsolete. The following figure 4 illustrates the degree of change for each PESTEL category in the four different scenarios.



Fi

gure 4. The four different scenarios and the differentiating PESTE categories

3.3.1 Business-as-Usual

In the "Business-as-Usual" scenario the existing system is principally maintained but challenged by external turbulences. The wastewater streams are collected via a central sewer system. Due to increased frequency of heavy rainfall caused by climate change (CLI1), the sewer system is separated into a drain and a sewer system. As much as possible, stormwater is collected, stored and infiltrated in decentralized manner. New pollutants such as drug residues (POL1) will be removed by using a fourth treatment stage (TCW1). The wastewater treatment plant is developed as the central place for recycling, for example, of biomass and phosphorus (TCW6). Local farmers deliver biomass to the wastewater treatment plant. Phosphorus is recycled and used for fertilizer production. Increasing energy prices push forward the use of renewable energy (TCW3,4,7) on the wastewater treatment plant. The huge remediation needs (TCS4) are tackled by mainly trenchless restructuring methods (TCS2). This financial burden is financed by a reduction of subsidies for new constructions and a strict alignment on remediation (FIN6). The financial impacts of demographic change (DEM1) are counteracted by an adjustment of the wastewater rates, in the form of a basic rate in the amount of the fixed costs (FIN2). The water demand (WAD) is stabilized at 80 liters per capita and day. In a few peripheral settlements decentralized and small wastewater treatment plants are installed, which are controlled via remote supervision under the management of the local sanitation utility. The predominant regulatory approach is the classical specification of standards (STA5). For a few specified pharmaceutical products the precautionary principle is applied (STA1), i.e. they are only licensed as a medical drug if they are degradable in water. In general, the sanitation utilities rise to the future challenges by a high degree of cooperation (SEC3). The high number of wastewater utilities is reduced by fusions and mergers of wastewater authorities. Purely public authorities integrate private knowledge by formal privatization (SEC2). Competition takes place only in a very limited indirect way (SEC4) between partial services, such as sewer cleaning.

3.3.2 Watershed-First

The "Watershed-First" scenario describes a possible future that emphasizes an ecological alignment of the regulatory regime and is principally consistent with the existing system but not necessarily. This scenario was based on the following expert statement:

> *"Until now the operator of the wastewater treatment plant has to fulfill specific quality standards at the final effluent discharge point. But a combined approach based on the emissions as well as on the immissions-principle would be more efficient, economically as well as ecologically. In the future, the operator has still to fulfill specific quality standards but this time on the watershed-level and he can decide whether he prefers to improve the technology on the wastewater treatment plant or an investment in stream morphology or other measures." (summarized, translated, analogous quote, similar statements in interview No. 9, 15 and 21)*

The main idea of this scenario is that "water agencies" (to be established) manage the entire watershed (STA2), i.e. water as well as wastewater services are combined in one integrated agency (FIN2). It is in the responsibility of the water agency to achieve specified management goals (e.g. water quality goals). The water agencies need to apply with their management plans during a bidding procedure that is repeated every ten years. In this scenario the water agency is in direct competition (SEC5) during the bidding procedure. In the management plans the agency can freely decide whether they invest in wastewater treatment technologies (TCW1) or pursue alternative approaches such as payments for environmental services to motivate farmers to reduce pollution from diffuse sources (STA3). Pollution-depending charging (FIN4) might be implemented in some hot spots where a high degree of pollution (POL2,3,4,5) and sensitive receiving waters come into conflict. It is also in the responsibility of the water agency to decide whether settlements are connected to a central sewer system or to small and decentral systems (DEC2).

3.3.3 Recycling-First[5]

The primary concern of the recycling-first scenario is the highest possible degree of recycling of nutrients at a household level as described in *Hiessl et al.* [2002] and *Traeckner* [2013]. This can be achieved by rainwater harvesting, grey water recycling and the separation of wastewater streams. Greywater is used for gardening and washing. Yellowwater is used for

5 This scenario is also described by *Hiessl et al.* [2002] in a comparable way.

the production of fertilizers and separated in urine diversion toilets (DEC1). Brownwater and organic waste is used for energy production. The used technology is mainly based on on-site treatment technologies, e.g. membrane technology (DEC2). Water demand (WAD) decreases significantly (<60 liters per capita and day).

> *"We have already today technologies that allow us to reduce the water consumption drastically, for example: vacuum toilets, the 15 liter shower or the 2.5 liter dish-washer. The question here is much more, if the technology is accepted by the end-user. In the short run this technology is mostly interesting for rural areas, development areas and major green real estate projects." (summarized, translated and analogous quote, similar statements in interviews No. 3, 9 and 12)*

The regulatory idea behind this scenario is mainly the polluter-pays-principle, whereas rising energy and commodity prices make it more and more financially attractive to recycle the wastewater streams. Thus, the most important driver for this scenario is, besides the financial burden of "Old Relics" (FIN5) and the financial consequences of demographic change (DEM1), an increasing scarcity of resources and energy, pushing energy and commodity prices such as phosphorus (DEC1). The central system is obsolete in the outskirts and low populated areas but maintained in densely populated settlements leading to direct competition between central and decentralized systems (SEC5) in the overlapping area.

3.3.4 Mega-City

The "Mega-City" scenario describes a further development of the "Recycling-First" scenario. Due to an extreme urbanization and, in these areas, high population growth (DEM1), the water demand (WAD) cannot be satisfied by the usual sources. Therefore a fixed yearly water allocation is apportioned to each inhabitant. As this allocation covers only the necessary amount of drinking water, water needs to be recycled as in the "Recycling-First" scenario, but in this scenario also in areas of high population density. Rain water harvesting, closed water cycles, and cascade-use of water are implemented on building level. Wastewater is purified and used several times (DEC2). Large buildings are constructed in such a way that they can supply themselves with water, energy [*Varis et al.*, 2006] and food [*Despommier*, 2008, 2011]. Water and energy prices increase drastically (FIN), making the on-site infrastructure financially attractive. This scenario is first realized in megacities of the fast growing and developing countries and in the following also implemented in countries with a highly sophisticated sanitation system, such as Germany.

> *"Especially in the fast growing urban centers in the developing and transition countries new decentralized technologies and closed-loop water system will be employed. First, Germany's industry will only deliver necessary technology but it is possible that in the far future these technologies will also be put into practice one day in Germany." (summarized, translated and analogous quote, interviews similar statements in interview No. 9 and 12)*

4. Discussion

Reflecting the methodology, four aspects concerning the expert interviews, the expert workshop, the degree of expert participation and the scenario development shall be reflected. In our case the expert interviews turned out to be especially fruitful. Contentious uncertainties could be removed during the interviews, negative impacts of group communication processes could be avoided, and weak signals such as POL1 could be identified. The anonymity of the interview and of Delphi technique played a crucial role here.

The expert workshop, in which the Fuzzy Cognitive Map was drawn, was also highly productive. Alternatively to identifying the top 15 challenges, a backcasting approach might allow the sanitation professionals to overcome the capability gap by asking them how a sustainable sanitation sector in the year 2050 might look like, and what is necessary to reach this goal. This might support the sanitation professionals to overcome their usual mind-models and to enhance creativity.

We combined a workshop, interviews, an online survey and an online discussion board to assure a high degree of participation, to facilitate a conversation and to allow experts to generate ideas in view of the responses of the other experts. Each part has had its own strengths and weaknesses. During the workshop the motivation of the participants was very high, but was mostly attractive for experts or sanitation professionals from the region. Here the integration of the workshop within a major conference is worth considering. This way the motivation of experts from other regions to attend to the workshop might be higher. The high response rate of the online survey also has proven its attractiveness for the experts and is definitely recommendable. Worth considering is also the use of existing social networks for a Delphi study. The use of already existing professional social networks assures a high degree of internet affinity and possibly also a high degree of participation in online surveys.

The Business-as-Usual scenario was complemented by three explorative scenarios which were built up on three visionary expert statements. The election of the expert statements was conducted as objectively as possible, but finally based on a subjective decision. Future research could ask the question how Fuzzy Cognitive Maps can contribute to develop explorative scenarios, that are characterized by a long range time horizon and challenges that are beyond the Business-as-Usual scenario.

Finally, the new Delphi-based scenario methodology that was tested and presented here facilitates to develop more objective and more creative scenarios.

5. Conclusions

The goal of this research article was to identify possible future challenges, to which the sanitation sector in Germany has to be prepared and to illustrate possible future states for the year 2050.

The results illustrate comprehensively possible future challenges, which might affect the sanitation sector in the future. We also provided an evaluation of the relevance of the specific challenges. The catalogue of identified challenges can be used by operators of sanitation utilities and decision-makers in the sector as a checklist within their strategic planning activities and for an intensive risk analysis, evaluating their utility specific vulnerability. For the research community the catalogue offers a perfect starting point for future research programs, which might investigate in more detail, for example, how the sanitation sector should deal with drug residues.

The Business-as-Usual scenario was completed by three explorative scenarios reflecting three possible future states of the sanitation sector in Germany in the year 2050. All three explorative scenarios are a valuable starting point for strategic planning activities for the authorities as well as for operators of the wastewater utilities. We recommend using the scenarios in strategic planning workshops as a starting point in order to assure an efficient scenario transfer and, consequently, to derive the necessary decisions that are adequate to the long life span of the infrastructure.

In view of the manifold challenges, decision-makers in capital intensive and path-dependent sectors need to close the capability gap and to increase its adaptive capacity. As shown in this article, Delphi-based scenario planning offers a valuable instrument to close this gap and thereby increase the adaptive capacity of the responsible organizations. Concerning the PESTE-analysis it might be helpful to differentiate in future studies between the political and legal environment and conduct a PESTEL-analysis.

Appendix

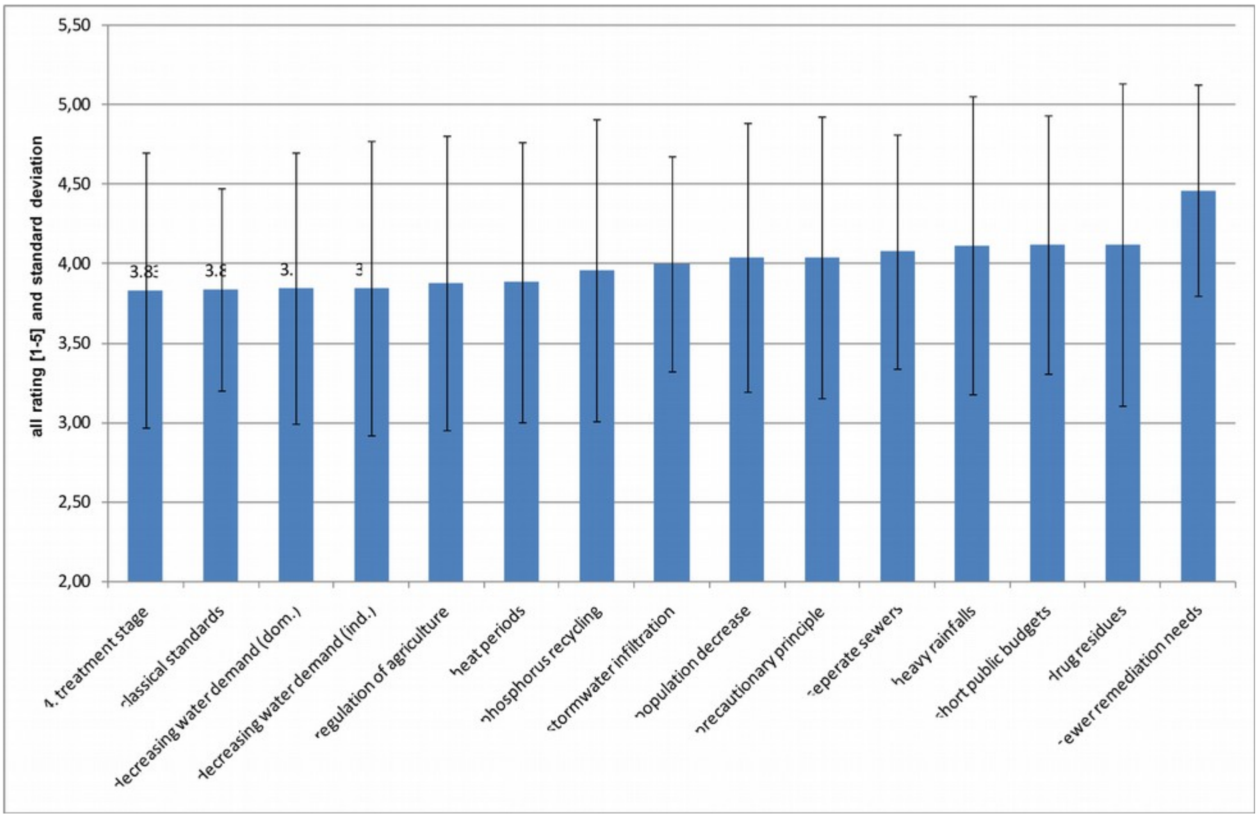


Figure 5. Top 15 future challenges

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