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Susanne Moritz, Dirk Bunke, Werner Brack, David López Herráez, Leo Posthuma

Öko-Institut e.V. / Oeko-Institut e.V.

Geschäftsstelle Freiburg / Freiburg Head Office
Postfach / P.O. Box 17 71
79017 Freiburg. Deutschland / Germany
Tel.: +49 761 45295-0
Fax: +49 761 45295-288

Büro Darmstadt / Darmstadt Office
Rheinstraße 95
64295 Darmstadt. Deutschland / Germany
Tel.: +49 6151 8191-0
Fax: +49 6151 8191-133

Büro Berlin / Berlin Office
Schicklerstraße 5-7
10179 Berlin. Deutschland / Germany
Tel.: +49 30 405085-0
Fax: +49 30 405085-388

info@oeko.de
www.oeko.de

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Scenarios on developments in society and implications for emerging pollutants in the aquatic environment

Susanne Moritz[1], Dirk Bunke[1,] Werner Brack [2,3], David López Herráez[2], Leo Posthuma[4]

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[1]Öko- Institut e.V. Freiburg, D- 79100 Freiburg, Germany, Email: S.Moritz@oeko.de and D.Bunke@oeko.de

[2]Helmholtz Centre for Environmental Research – UFZ, Permoserstraße 15, 04318 Leipzig, Germany. Email: werner.brack@ufz.de and david.lopez-herraez@ufz.de

[3]RWTH University of Aachen, Department of Ecosystem Analysis, Institute for Environmental Research, ABBt – Aachen Biology and Biotechnology, Aachen, Germany

[4]RIVM – Dutch National Institute for Public Health and the Environment, Centre for Sustainability, Environment and Health, P.O. Box 1, 3720 BA Bilthoven, the Netherlands and Department of Environmental Science, Institute for Water and Wetland Research, Radboud University Nijmegen, Heyendaalseweg 135, 6525 AJ Nijmegen, The Netherlands; Email: leo.posthuma@rivm.nl.

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Abstract

Pollutant emissions in river basins change continuously. Management strategies should address such developments. Many scenarios are published which describe future changes in the environment and in society. Examples concern climate change, demographic change and urbanization. Based on these scenarios, specific trends can already be predicted (with uncertainties). Do these scenarios help to get a picture on future pollutants?

The study presented here is based on the hypothesis that existing scenarios on developments in society may provide useful indications for future pollutants. The analysis of more than 30 reports on future scenarios shows that some developments are directly connected to consumption and the emission of specific substances. Secondly, it became evident that the effects of other development scenarios, such as those associated with climate change, are more complex. A precise quantitative evaluation of the implications of some scenarios on future pollutants can be particularly difficult for such scenarios. An important field of changes is technological developments. Frequently observed changes in this respect are substitutions of problematic substances with substances of similar structure.

When the consequences of pollution outlined in future development scenarios are taken together, it will be possible to explore political, societal or technical mitigation efforts which can be undertaken now or in the near future to counteract the effects of the developments that are considered to be among the most hazardous for man and the environment. Thereby, a careful monitoring of developments in society can help to develop appropriate strategies which should include preemptive emission and impact reduction efforts.

Keywords: Emerging pollutants; surface water; developments; scenarios; prediction; substitution

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List of abbreviations

EPs	Emerging Pollutants
IPCC	Intergovernmental Panel on Climate Change
NORMAN	Network of reference laboratories, research centers and related organizations for monitoring of emerging environmental substances
OECD	Organization for economic cooperation and development
PFC	Per- and polyfluorinated hydrocarbons
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals (https://echa.europa.eu/regulations/reach)
UNESCO	United Nations Educational, Scientific and Cultural Organization

1. Background and objectives of the review

Pollutants in river basins may change with time. Over the last decades, increasing numbers of emerging pollutants have been found in European waterbodies [1] [2] [3] and also worldwide [4] [5], not only by means of innovative detection techniques, but also regarding the more complex composition of the combined exposures. The NORMAN Network group "enhances the exchange of information on emerging environmental substances, and encourages the validation and harmonisation of common measurement methods and monitoring tools so that the requirements of risk assessors and risk managers can be better met" [6]. In this review, the term "emerging pollutants" is used as defined by the NORMAN Network [6].

"Emerging pollutants" A substance currently not included in routine environmental monitoring programmes and which may be candidate for future legislation due to its adverse effects and / or persistency [4].

Around 970 Substances of emerging pollutants (EPs) have been detected by the NORMAN Network group in the last 10 years [6]. The most important classes and their subclasses are shown in the following Table 1. and illustrate the high amount of EPs. In this review, not all substances shown in Table 1 are considered.

Table 1 : Most important substances/classes and its subclasses/subcategory by NORMAN Network group

Classes	Subcategory
Pharmaceuticals	Analgesic Antibacterial Antidepressant Antidiabetic Antihypertensive Anti-inflammatory Beta-Blockers Lipid regulators Steroids and hormones X-ray contrast media
Industrial Chemicals	Perfluoroalkylated substances Fluorotelomer alcohols Plasticizers Flame retardants

Consumption Products	Detergents Food- additives Parabens (hydroxybenzoic acid esters) Insect repellents Sun-screen agents Carriers Fra- grances
Pesticides	Insecticides Herbicides Fungicides
Biocides	Antimicrobial agents
Nanomaterials	Carbon Nano Tubes Titania

It has been shown that EPs affect ecosystems and human health and reduce the quality of water bodies [1], [7], [8]. The most important sources of EPs including hospitals, animal husbandries, household discharges, companies manufacturing drugs, and wastewater and sewage treatment plants are shown in [1], [7]. Inputs of „disposal of municipal, industrial and agricultural wastes, excretion of pharmaceuticals and accidental spills" also play an important role [8]. A summary about emissions of emerging contaminants found in the urban water cycle is given by Pal et al. [9]. If this increased inputs continues – and this is expected from international chemical outlooks, e.g. the Global Chemical Outlook [10] – this means that management strategies to ensure a good water quality should try to address the risks of future pollutants beyond those of current concern. How can they be predicted? The approach presented here is based on the hypothesis that existing scenarios on developments in society can give useful indications for future pollutants, and – in turn – information that is useful for designing preemptive management strategies intended to protect environmental even for novel compounds that may be designed and emitted in the future.

Recent developments in society and technology are described in a wide range of different scenarios. Scenarios on climate change are well known and published by the Intergovernmental panel on climate change (IPCC) [11]. IPCC is the international body for assessing the science related to climate change. UNESCO (United Nations Educational, Scientific and Cultural Organization) — WWAP (World Water Scenario Project) [12] refers to future trends in water consumption and water resources. Other scenarios address demographic changes in Europe and world population growth, as well as economic and technological changes. We reviewed the options to translate future societal scenarios into chemical emission scenario expectations, thereby including aspects of emissions, exposure levels, and expected impacts on human health and the environment, starting from a solution-focused paradigm of risk assessment. That is, we evaluate the scenarios with a view to the derivation of mitigation measures that can contribute to the protection of the environment by limiting current and future emissions, exposures and risks, even for chemicals not yet designed, used or produced.

- Firstly, the evaluation provides an overview on developments which are expected in society over the coming two or three decades.
- Secondly, it analyses to what extend these predictions can be used as an information source to qualify and/or quantify the ‘pollutants of tomorrow’
- Thirdly, it takes a solution-focused approach with regard to the results, so as to be able to discuss general mitigation options.

Existing scenarios for developments of society are identified and analysed. An evaluation is furthermore carried out as to whether there is a causal link between societal developments and emissions of new or already known substances to the environment. For specific areas, expected developments are discussed in more detail with the aim to support the development of appropriate management options for risk management.

More details are given in the Masterthesis “Emerging Pollutants in surface water; Developments in society and pollution of tomorrow” of Susanne Moritz.

2. Approach

Which pollutants can be expected if future developments in society and climate are taken into account? Such developments are described in a broad range of scenarios. The scenarios on climate change are well known, published by the IPCC [11]. Other studies focus on economic, technological and demographic developments. These changes in society can cause releases of new or already known substances to the environment.

In the following sections, a review of developments in society which can be foreseen will be undertaken. In addition, potential causal links between changes in society, use of chemicals/materials and emissions of pollutants will be described. This analysis refers to 34 publicly available studies with a large number of scenarios from different sectors. The scenarios can be classified as follows:

- **Scenarios for middle- and long-term developments in society, caused by multiple drivers** (e.g. the UNEP GEO 5 – Global Environmental Outlook; the UN Millenium Ecosystem Assessment (MA); the European Environment – State and Outlook 2010; the Planetary Boundary Approach);
- **Predictions for water use and water cycle** (e.g. The World Water Vision of Earthscan; Water in a changing world (The United Nations World Water Development Report); Water resources across Europe (European Environmental Agency);
- **Predictions for industrial chemicals and hazardous waste** (Costs on Inaction on the sound management of chemicals (UNEP); Trace Contaminants in Water Cycles (Acatech));
- **Developments due to climate change** (the IPPC Special Report Emission Scenarios from UNEP; the SCARCE project);
- **Developments due to demographic change** (OECD Environmental Outlook to 2050);
- **Developments due to technological and/or economic** changes (THOUGHTS Megatrends);
- **Predictions for food production and nutrients** (World Social Science Report from UNEP);

The publications used for this analysis are listed in Table 3 see Appendix. An overview is given in Table 2. It shows the main topics of different thematically analysed scenarios.

Table 2 Topics of scnearios and numbers of repeats addresses them. Total numbers of reports analysed: 34

Topics	Amount
Scenarios for middle and longterm developments in society by multiple drivers	6
Developments in water use/ cycle	7
Developments in use and impacts of chemicals	5
Specific driver: climate change	4
Specific driver: demographic change	2
Specific driver: technological and economical change	2
Specific driver: nutrients	3
Further aspects	5

Table 3 shows that the number of studies addressing potential developments in society is quite large. However, only in a few cases implications of the predicted developments on emerging pollutants are mentioned explicitly. More frequently general predictions can be found, e.g. regarding future water consumption, food production and consumption behaviour. In some cases it is possible to use these general predictions to draw conclusions on potential future developments of contaminants (e.g. increase of older people and increase in the amount of pharmaceutical use).

Up to now, the implications of the increasing distributions of EPs is just poorly discussed.

In the following sections, most important developments in climate, society and technology are described which are predicted in a broad range of scenarios. Indications for connections between these developments and pollutants of tomorrow are discussed. The developments refer to the following changes:

- **Climate change (see section 3.1);**
- **Demographic change in Europe (see section 3.2);**
- **World population growth (see section 3.3);**
- **Technological changes (see section 3.4).**

3. Results

3.1. Climate Change

Climate change is one of the most intensively discussed future developments. Main references are the emission scenarios published by the Intergovernmental Panel on Climate Change *(IPCC)*, IPCC Working Group III [11]*)*. A significant number of scientists agreed, that temperature has risen exceptionally during the past 15-20 years, in air [13] and also in water [14].

„Climate change is an increasingly urgent problem with potentially far reaching consequences for life on earth and also reports unequivocal global warming with evidence of increases in global mean air and ocean temperatures, widespread snow and ice melt, and rising global sea level" [15]. Droughts, floods and water scarcity are the most important impacts which affect the behavior of pollutants in water. Changes in precipitation directly affect water dilution volumes, and thus concentration variability in space and time – whilst the net result of chemical load and water volume determines the concentrations that are eventually the key predictors of risks and impacts. These developments can be seen in the Mediterranean basin, one of the world's regions most vulnerable to global change [16]. Predictions show that in this region upcoming problems in water availability can be clearly seen [17], [18]. IPCC forecasts that this region will have increasing temperature in summer, more droughts and also stronger rainfall. In addition, the average river flow will decrease [19]. In these respects, freshwater ecosystems like the ones of the Mediterranean basin are particularly vulnerable to global change [20], [21], [22]. Water temperature and the frequency of large floods will increase in future [19].

Droughts and floods, water scarcity, changes in water temperature and also storm intensity will have consequences on the occurrence and concentrations of EPs. Climate change also affects the transport of contaminants, their transfer between compartments of the ecosystems and also their transformation. In addition, climate change has consequences for the incidences of diseases and the related use of drugs. These impacts of climate change on EPs are described in more detail in the following sections.

Water scarcity and droughts: consequences of climate change

Due to climate change, water scarcity as well as droughts will increase. This development could have negative impacts on the flow river regime [16] and also on the chemical quality of water systems [22], [19].

Even without changes in pollutant masses emitted, water scarcity leads to a higher concentration of nutrients, pesticides, surfactants, pharmaceuticals, and estrogenic compounds [23], [24]. The dilution capacity during droughts decreases. Therefore, the risks associated with pollutants in the environment increase. This might affect the functioning of the river ecosystem [3]. At present, this is an urgent problem in arid or semi- arid regions as the Mediterranean basin. Due to climate change, this problem could extend to other regions of the world, too. In arid regions, contaminants in river waters could be encountered in even higher concentrations than today [25].

The main uses of water by man are the production of drinking water and agricultural use. If water scar- city will increase, wastewaters must be reused for these applications. Pollutants from wastewater might be emitted to river waters, because the required purification of emerging pollutants in waste water before reuse is insufficiently effective, or often does not take place at all [26], [27], [16].

Torrential rainfalls and floods: consequences of climate change

Extreme weather events like rainfalls will affect river flows, thus producing an increasing shear stress [28]. Sediments can be mobilized and deposited in lakes and reservoirs. Problems with pollutants in flood plains are expected in the event of flooding of sewage plants, extruded agriculture land or waste dumps behind dams in which EPs are stored [29], [30]. Hence, immobilized pesticides or other EPs can enter surface waters at torrential rainfalls and floods. For example, concentrations of the insecticides carbayl and imidacloprid increased with increasing storm intensity [15], [31]. Changes in the hydrological regime can mobilize stored contaminants [29]. Furthermore, contaminated water can deposit pollutants to agriculture land. Productive livestock or agriculture plants could absorb these contaminants [32].

Elevated water temperatures: consequences of climate change

Under climate change, the water temperature at low river flow conditions will probably increase [16], [1 9] . This may lead to a synergistic effect of two stressor types: increasing amounts of emerging pollutants due to reuse of wastewater (see above) and also rising water temperatures. Wildlife will suffer from this second stress factor in combination with multiple other stress factors.

Climate change is expected to have further manifold implications on terrestrial and aquatic ecosystems. A constant increase of surface water temperature can alter or influence the environmental fate of chemicals, e.g. bioaccumulation, degradability and mobility [29]. Due to these changes, the exposure of biota to these contaminants can change [29]. Elevated water temperatures may alter the biotransformation of contaminants to more bioactive metabolites, and impair homeostasis. In addition, increasing temperatures are able to increase the toxicity of contaminants[15], [33], [34] , [35]. Higher water temperature has long been known for modifying the chemistry of a number of pollutants, resulting in significant alterations in their toxicities, e.g. for fish [29].

Higher water temperature is a further stressor for aquatic animals, but at the same time will influence the uptake rate of pollutants by higher ventilation and the metabolic rate e.g. in fish [29]. Another example for a synergistic effect has been reported for the Baltic amphipod *Monopreia affinis*. Combined exposure to increased water temperature and the *fungicide fenarimol* resulted in an increased numbers of females with dead eggs [29].

Further overviews about the interactions between various classes of chemicals and different environmental factors as temperature in aquatic organisms are given in Schiedek et al. 2007 and Heugens et al. 2001 [29], [36].

Environmental behaviour and fate of chemicals: consequences of climate change

Climate change can have a large effect on the environmental fate and behaviour of chemicals [15]. Several biotic and abiotic factors influencing the behaviour and the fate of chemicals [29] show a temperature dependency. Examples are air-surface exchange, wet/dry deposition, and reaction rates as photolysis, biodegradation or oxidation in air [15]. Solar irradiations are expected to increase in intensity. This results in an intense photodegradation of chemicals such as pharmaceuticals (e.g. diclofenac and ibuprofen) or the X-Ray contrast medium iopromid [37], [38] , [39]. An example is the phototransformation of the anti- inflammatory drug diclofenac. Its phototransformation products have been shown to be more stable as well as more toxic than parent diclofenac [40] [38], [39]. Similarly, the photoproducts of anti-inflammatory drugs showed an increase in toxicity [37], [41] , [42] , [43]. As it can be seen in Figure 1, there are a lot of biotic and abiotic factors influencing the behaviour of chemicals. Figure 1 shows the increasing number of these change impacts.

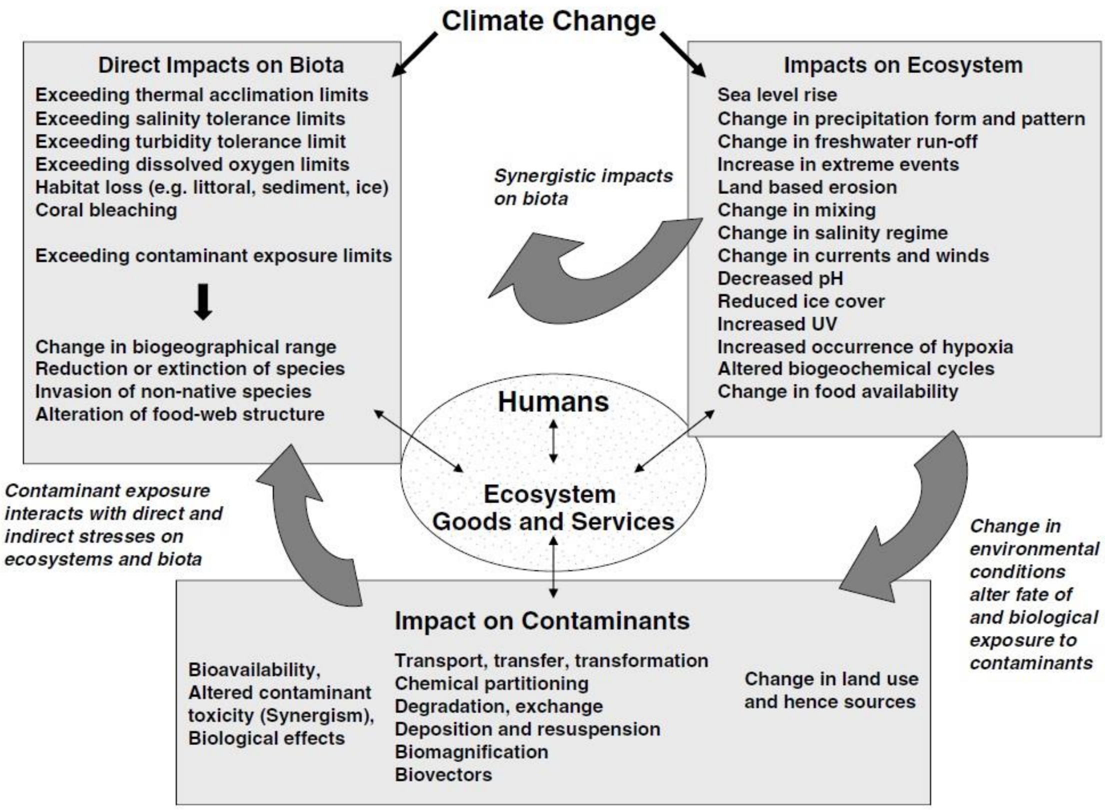

Figure 1 **Overview of climate change impacts on the ecosystem and biota [29]**

Incidence of diseases and drug consumption: consequences of climate change

It can be assumed that climate-related environmental alterations are associated with an increase in chronic diseases already common in the Northern Hemisphere – such as cardiovascular, respiratory and mental health problems. It is reasonable to assume that this will lead to a greater need for chemical medications, such as vasodilators, anticoagulants, anti-inflammatories, antidepressants and analgesics, which then will potentially be emitted to the environment [44].

Changes in climate are likely to cause an increase in pathogens and invertebrate vectors (such as mosquitos) for infectious diseases. With the emergence of new disease threats, an increased use of pharmaceuticals seems inevitable. It is likely that medical drugs not yet commonly used at present, such as anti-protozoals, will be prescribed in future for cases of malaria, amoebiasis and other diseases [44].

These trends “need to be viewed in the context of other major environmental changes (e.g., industrial chemical pollution, biodiversity loss, reduced water and food security) as well as marked shifts in human demographics, including aging of the population“ [44] which is also mentioned in this review.

3.2. Demographic Change in Europe

Demographic changes may be important for future chemical emissions. Figure 2 shows the expected distribution of demographic change for Europe in 2080 compared with 2015. According to demographic predictions for the next 40 years, the total population in Europe will remain relatively stable [45]. In parallel, the growth of the share of people older than 65 in the whole population is likely to grow by 38% until 2030, while the proportion of people under 20 years will decrease by 17 % until 2030 [46] [47].

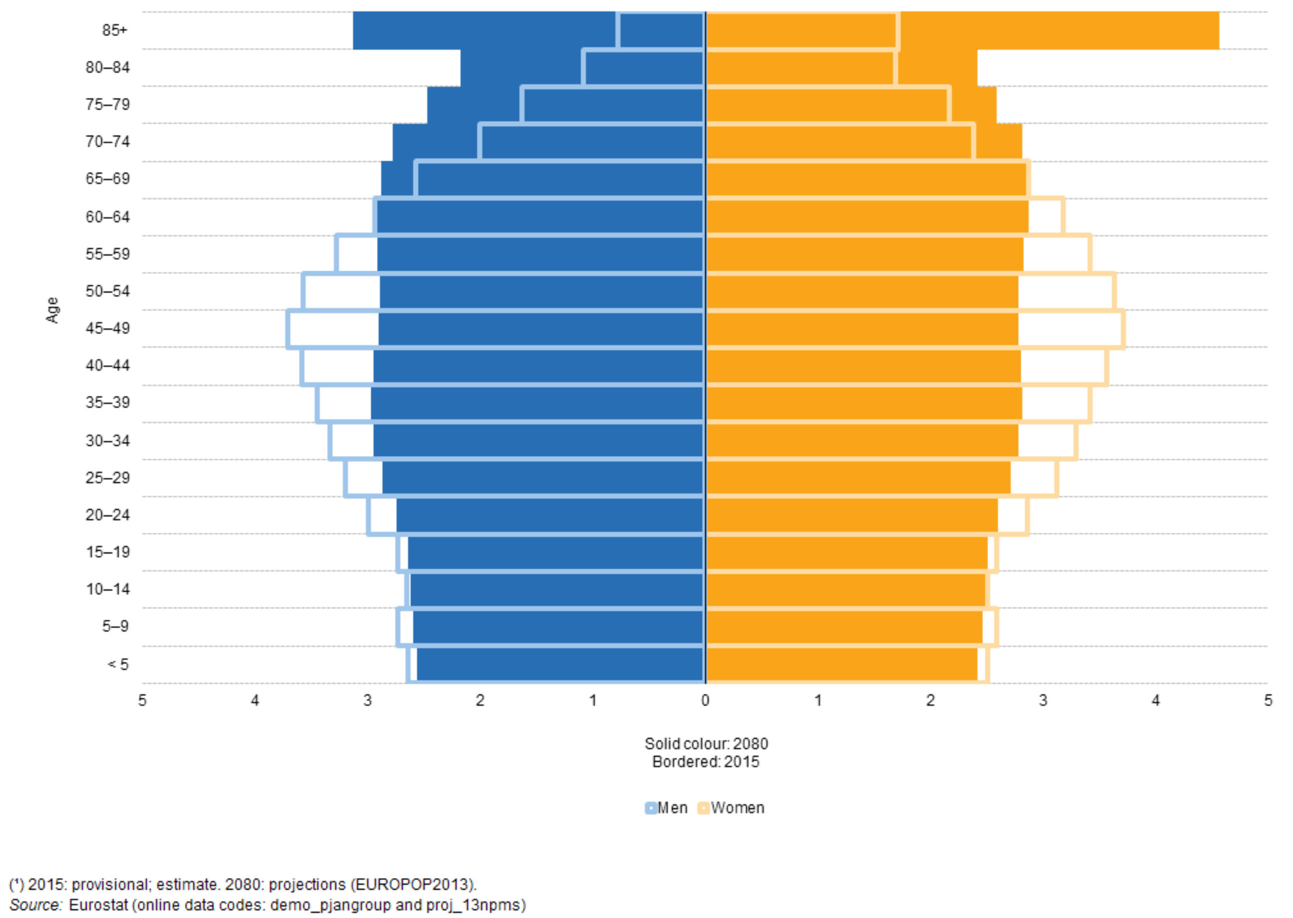

Figure 2 Demographic change for EU 28 member states. Expected distribution of inhabitants in age groups for 2080, compared to 2015. [48]

As a consequence, disease incidences will increase for those diseases that are typical for elderly people. Examples are cardiovascular diseases, cancer or diabetes, which are all likely to become more frequent [45] [49] According to the German Arzneiverordnungsreport [49] (drug regulation report), there will also be an increasing demand for pharmaceuticals that are used in association with increasing mean age [49] as also shown in Figure 2 [50].

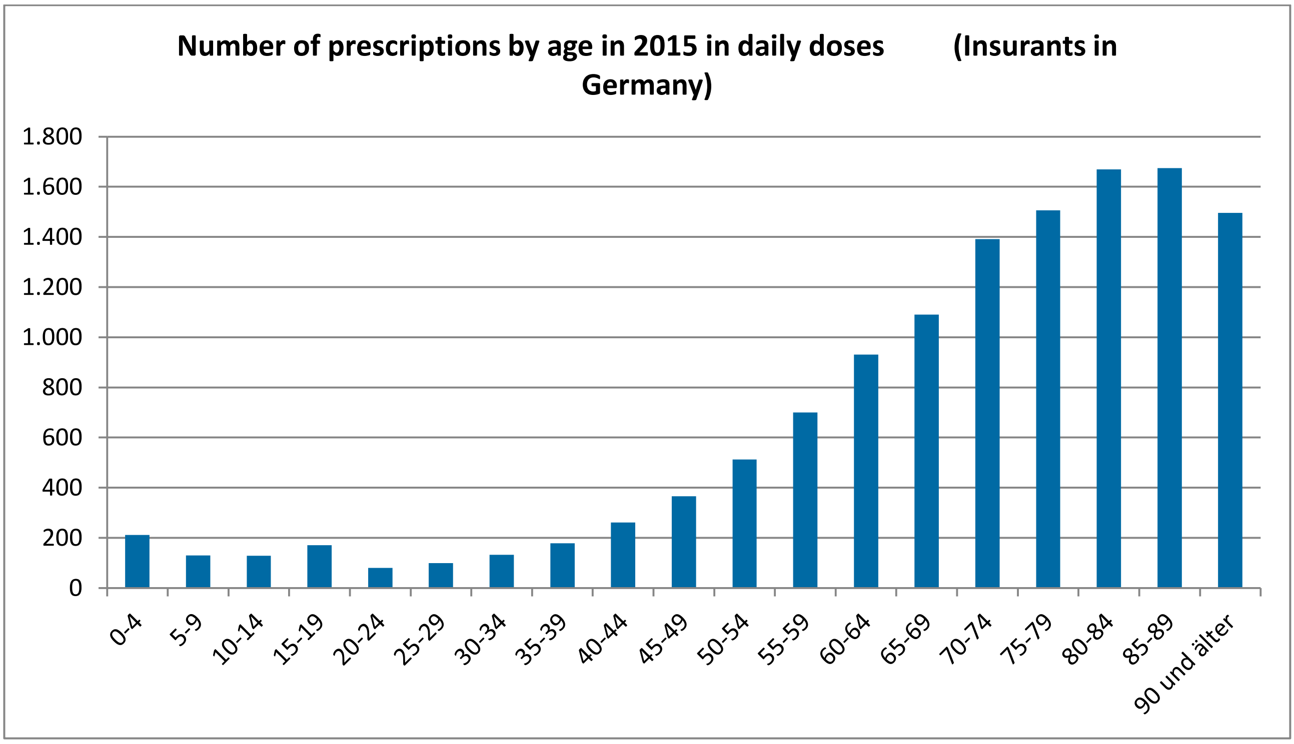

Figure 3 Age group-specific use of pharmaceuticals. The figure shows how many prescriptions of drugs are made for age groups from below five years up to above 100 years. Numbers are given in defined daily doses ("DDD"s) per year. The numbers refer to insurants in Germany [50].

The foreseeable effect of these developments e is an increase in the consumption of pharmaceuticals mostly in hospitals [51] and elderly homes, but also in privately owned homes. Pharmaceuticals which have a detrimental effect on aquatic biota [8] [36] like lipid regulators (e.g. bezafibrates), anti-inflammatory drugs (e.g. diclofenac), antidiabetics and antibiotics are mainly used by elderly people [52] [51], [49]. X-ray contrast medium and antineoplastics used in association with chemotherapy are further examples for groups of pharmaceuticals mostly consumed in hospitals but also in doctors' surgeries [53]. It is reasonable to assume that the consumption of these pharmaceuticals will further increase. Demographic change and the consumption of pharmaceuticals are interrelated [49]. Pharmaceuticals enter aquatic and terrestrial ecosystems [53], and have even been detected in drinking water in small concentrations [54].

3.3. World population growth and urbanization

The world population is projected to grow to 9,7 billion in 2050 [55] [56]. This growth will mainly take place in developing countries such as Africa, South America and Asia. In the scenario of population growth, a trend that has been observed is that the number of inhabitants in big cities will increase rapidly. In 1975, only 38% of the world population lived in cities. Presently, around 50% of the people are living in cities while around two- thirds of the global population is predicted to live in cities in the year 2030 [45] [57] [58]. This can result in increased concentrations of EPs in surface waters.

As a result of urbanization, the management of water, waste and waste water as well as traffic regulation in cities will gain in importance. Urban development means also an increase of ground-sealing (e.g., pavement, roads, and industrial areas) with negative impacts for the environment [59]. Natural land surfaces are transformed into impervious surfaces such as streets, parking lots, and roofs. Percolation of rainwater and snow melt into soil is blocked [45], [60]. Ground sealing can increase the frequency and intensity of floods. Floods can transport pesticides, surfactants, pharmaceuticals and other emerging pollutants to river systems, resulting in local pollution problems [60].

Urbanization requires a proper management of waste water to avoid the contamination of local freshwater resources [60]. The population increase in cities results in an increase in the volume of waste water. Purification systems become an even more essential requirement to ensure good water quality. Growing cities require the drainage of rainfall and flood prevention, an effective waste water treatment, pollution mitigation, and in many cases an integrated management of the water system for households and industry [58].

Another important topic in big cities with effects on emerging pollutants is waste management [61], [62]. Waste and waste dumps are a breeding ground for contaminants. On a global scale, a suitable system for waste management is not in place. Waste streams containing emerging pollutants such as plasticizers or deposits from pharmaceuticals can directly enter ecosystems and surface water [60].

3.4. Technological changes

Technological developments are continuously taking place in a large number of sectors. New products or new functions of existing products or substances are generated. In many cases, these innovations are based on the use of specific substances. Permanent water resistance of outdoor textiles is an example for such functionality improvements which has been achieved by the use of per- and polyfluorinated chemicals (PFCs) [63]. New developments of that kind can cause the emergence of new contaminations of surface water, if these substances are released during production, service life, recycling, reuse or disposal of the products. For PFOA, PFOS and several other PFCs, adverse properties (toxicity, ecotoxicity, persistence, bioaccumulation) have been confirmed [64], [65] [66], [67] [68].

Technological changes are difficult to predict and are found in all branches. In the following sections some examples for emerging pollutants resulting from such changes are given. For these changes, two drivers can be distinguished: Regulation of problematic substances and technological developments with new uses of chemicals and materials.

Substitution of problematic substances due to regulation

The use of substances with very problematic properties can be prohibited by regulatory measures. Examples are restrictions for specific uses of substances under chemical legislation or the process of authorization under REACH [69]. REACH is the chemical legislation in the European Union. Experience of the last decades has shown that very often regulated substances are substituted by substances which belong to the same structural group. Often, these substitutes show a similar behaviour in the environment. Recent examples for EP which have been “triggered” by regulatory measures are phthalates and per- and polyfluorinated compounds. A third example is brominated flame retardants.

Recent monitoring studies show an increase in concentrations of phthalates (diisononyl phthalate (DINP) and diisodecyl phthalate DIDP)) used as substitutes for low molecular weight phthalates which have been restricted by law in the EU (REACH) [24], [70]. Phthalates can be easily released out of the product because they are not chemically bound. They are semi-volatile organic compounds. They can evaporate, be washed or abraded out of products [70], [71]. For several phthalates, severe adverse effects on humans and animals have been confirmed [72], [73], [74]. Phthalates are frequently found as EPs in surface water [75].

Similarly, restrictions on long-chain (C8) per- and polyfluorinated hydrocarbons (PFCs) lead to the re- placement of these substances by short-chain 2- 4 PCFs [70], [76] – which have already been detected in the environment in increasing concentrations [77]].

Some of these “new” phthalates and short-chain PFCs have not yet been regulated under a legal framework such as REACH. Producers may thus place these critical substances on the market.

Specific brominated flame retardants are the third example of substitutes triggered by regulatory measures. Hexabromobenzene (HBB) and bis-(2, 4, 6-tribromphenoxy)ethene (BTBPE) are new emerging pollutants – and substitutes for polybrominated biphenyls which have been prohibited by chemical legislation. The main emissions from these flame retardants result from the production of plastic materials from point sources. There are also diffuse sources caused by the migration from articles and elution of flame retardants out of the products while they are produced, used or depolluted. The persistent and bioaccumulative substances can be found in sediments, dust, in wild animals and human beings [78], [79]. They can also be detected in surface water. In a review paper, increased concentrations of brominated flame retardants in environmental waters have been documented [80].

The flame retardant hexabromocyclododecane is another example of a substance for which sub- sti- tutes in water are to be expected in the near future. HBCD has been identified under REACH as a substance of very high concern. Since August 2015, the future use of this substance is prohibited, if no authorization has been granted for specific uses.

Technological developments with new uses of chemicals

Approximately 70% of all product innovations in Europe are based on new material developments [81]. Materials innovations comprise new substances, substance and material modifications (e.g. surface functionalization), new material combinations (e.g. multi-material systems, composites) and a new application context of established substances. Substitution can have different reasons: re- placement of rare or cost-intensive raw materials, replacement of hazardous and toxic substances, use of materials allowing a better product performance.

The VDI Technology Center has identified more than a hundred innovative technologies and materi- als, of which it has selected 20 for analysis [81]. They belong to the following six groups: new pro- duction technologies (such as 3D printing), electronics (such as OLEDs and printable electronics), construction and lightweight engineering, energy and environmental engineering (as organic photo- voltaics), textile technologies and functional materials and coatings (as polymeric foals) [81]. Many of the 470 substances compiled for these new technologies were polymers. (Polymers are ex- empted from the registration of REACH. However, the related monomers have to be regis- tered). Convenience products are another product group with many innovations in the last years – resulting in EPs.

Convenience food and convenience in human care products are two groups of convenience life- style products [82]. The consumption of these products steadily increased during the last decade [83]. They often contain substances as sucralose or aspartame which are used as food additives [82], [83], [84]. Ecotoxicology tests shows that “physiology and locomotion behaviour were affected by exposure to sucralose tested in *Daphnia magna*” [85].

As described in chapter 5, the proportion of older people will rise, which leads to higher rates of diseases such as diabetes. Popular diabetic products are produced on the basis of sucralose or oth- er sweeteners instead of sugar [86]. This could increase the consumption of sucralose in future. Sucralose as well as triacetin have already been found as contaminants in surface waters [83] [87]. It is reasonable to assume that their concentrations will increase, if consumption rates will continue to rise.

4. Conclusion and Outlook

Future developments in society can result in the emission of new substances to the environment. In this review, an investigation on many reports on trends in society has been carried out in terms of their potential implications on future emerging pollutants.

Scenarios on the future development of society can provide valuable indications on changes in future pollutants in river basins. Some developments are directly connected to consumption and emission of specific substances, e.g. demographic change in Europe. Due to the higher life expectancy in the next decades, the amount of pharmaceuticals circulating in sewage treatment plants and the related concentrations in the environment will most likely increase.

For specific product groups related to societal behaviours, evidence of increased emissions has been found. Examples are chemicals used for convenience products.

Other developments such as climate change are more complex. It is much more difficult to predict quantitatively their implications on future pollutants. The IPPC expects a rise in temperature as well as the increase of extreme weather events. As a result, the behaviour of chemicals in water will change. Mobilization of chemicals from sediments might be facilitated by erosion, flood events or rising sea levels.

Another important group of changes are technological developments. Substitutions of problematic substances by substances of similar structure are frequently observed. “New” phthalates as well as per- and polyfluorinated hydrocarbons (PFCs) have been detected in surface waters in increasing quantities under the regulatory control of a restricted number of substances of these classes.

Some of the developments described here could be mitigated by political, societal or technical efforts. A careful monitoring of developments in society can help to develop appropriate strategies which should include pre-emptive emission and impact reduction efforts.

Future technological progress may help to identify suitable alternatives for currently used EPs as phthalates, PFCs, flame retardants or nanomaterials. These new substances, however, might also have negative impacts on the ecosystem. If risks are checked in advance and minimized them from the very beginning, a powerful sales argument for novel technologies could be built up. In the framework of a Dutch project called Nanonext, a specific method for Risk Analysis and Technology Assessment – termed RATA – has been developed. It includes a specific tool set to check new business ideas for risks from the very beginning [88].

The on-going horizon scanning activity of the EU shows the importance of monitoring future development in society [89]. This can help to predict and to manage future emerging pollutants [89].

Based on the analysis of scenarios presented here, we identified the following areas in which major changes within the next two decades can be expected: public health, food, urbanization and technologies.

Specific trends can be integrated in exposure and risk modelling. Examples are predictions on demographic change and changes in the consumption pattern of pharmaceuticals during life time. Other trends can have implications for effect monitoring. The expected increase of emissions of pharmaceuticals could stimulate the monitoring of drug-specific endpoints, e.g. behavioral changes in fish. A deeper analysis of the findings of the sector-specific workshops organized so far will be done in the project SOLUTIONS. Finally this aims to develop prioritization and risk reduction approaches for individual chemicals and mixtures and for assessment of abatement and policy options. In order to reduce complexity emission profiles and chemical finger printing can become important tools. Political, societal and technical efforts will be required to mitigate the impact of complex mixtures of chemicals in future. This needs more than end-of-pipe technologies. It calls increasingly for input reduction and prevention measures. In a solution-focused approach, horizontal instruments are needed which include approaches for the design and production of more sustainable chemicals and products.

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6. Appendix

Table 3 Documents on developments in society and scenarios analysed (for chapter 3)

Title		Institution/ Author	Year of publication	Reference (for details: see report)	Main topics
1) Scenarios for middle- and longterm developments in society, caused by multiple drivers					
1.1	GEO 5 for Business- Impacts of a changing environment on the corporate sector	UNEP- United Nation Envi-ronment Pro-gramme Dave Grossmann	2013	www.unep.org	Environmental change- because of two main drivers population growth and economic development
1.2	GEO 5-Global Environmental Outlook	UNEP	2012		Climate change Population growth Urbanization Water scarcity -And its impacts
1.3	UN Millenium Ecosystem Assessment (MA)	Alcamo et al.			The four MA Scenarios and their direct and indirect drivers
1.4	Measuring Progress- Envi-ronmental Goals and Gaps	UNEP	2012		Climate change Chemicals Waste, Water
1.5	The European Environment-State and Outlook 2010	European Environment Agency Jock Martin and Thomas Henrichs and many more	2010	Eea.europe.eu/enquiries	Climate change Na-ture& biodiversity Natural resources and waste Environment, health and quality of life These are directly/ indirectly linked
1.6	Planetary Bounderies: Exploring the Safe Operating Space for Humanity	Rockström et al	2009		Seven planetary bounderies: climate change, ocean acidifi-cation, stratospheric ozone, biogeochemi-cal N and P cycle, global fresh water use, land system change, biological diversity lost
2) Developments in water use and water cycles					

Title		Institution/ Author	Year of publication	Reference (for details: see report)	Main topics
2.1	World Water Vision- Making Water everybody's business	earthinfo@earthscan.co.uk	2000	www.earthscan.co.uk	Future scenarios for water, water business
2.2	Charting our water future Economic framework to inform decision-making	The 2030 water resources group	2009	2030WaterResourcesGroup@mckinsey.com	To get ideas for scenarios
2.3	Water in a changing world The United Nations World Water Development Report 3	UNESCO and others	2009		Drivers of water Changes of water cycle
2.4	GLOWA- Globaler Wandel des Wasserkreislaufes IHP/HWRP Berichte Heft 7	Bundesministerium für Bildung und Forschung	2008		Influence of demographic and technological change for water use, climate change
2.5	Future long term changes in global water resources driven by socioeconomic and climate changes	Alcamo et al	2007		
2.6	Wasser für Menschen/Wasser für Leben	World Water assessment programme			
2.7	Water resources across Europe	European Environment Agency	2009		About water use in future and drivers
3) Developments in use and impact of chemicals					
3.1	Chemicals Action Plan Safety in Denmark	Government of Denmark	2010-2013 Published in 2010	www.mst.dk	Get ideas to use chemicals from other countries
3.2	Costs on Inaction on the sound managements of chemicals	UNEP	2013		Impacts of chemicals for health, environmental and development effects
3.3	Harmful substances and hazardous waste	United Nation Environment Programme Dr David Piper		http://www.unep.org/hazardoussubstances/	
3.4	Ökotoxikologische Bewertung von anthropogenen Stoffen Acatech Materialien NR 10- Georessource Wasser- Herausforderung Globaler Wandel	Thomas Knacker Anja Coors	2011	www.acatech.de	Schadstoffe im Wasserkreislauf und Auswirkungen auf Ökosystem

Title		Institution/ Author	Year of publication	Reference (for details: see report)	Main topics
3.5	Organische Spurenstoffe im Wasserkreislauf Acatech Materialien Nr 12, Georessource Wasser- Herausforderung Globaler Wandel	Axel Bergmann	2011	www.acatech.de	Schadstoffe im Wasserkreisluaf
4) Specific driver: climate change					
4.1	IPCC Special Report Emissions Scenarios, Summary for Policymakers Intergovernmental panel on climate change	IPCC Working group III UNEP WMO- World Meterological Organization	2000		Climate change
4.2	SCARCE- Assessing and predicting effects on water quality and quantity in Iberian Rivers caused by global change	Prof. Damià Barceló (project coordinator) edamia.barcelo@idaea.csic.es Dr. Alícia Navarro-Ortega (project-manager) alicia.navarro@idaea.csic.es	2009-2014	www.scarceconsolider.es	Change of water quality/quantity
4.3	WATCH- Water and global change	Richard Harding Tanya Warnaars	2011		introduction to the achievements of the WATCH Project Water cycle and its changes
4.4	Modell Deutschland: Klimaschutz bis 2050	Prognos Ökoinstitut eV	2009		
5) Specific driver: demographic change					
5.1	Die demografische Zukunft Europas- wie sich Regionen verändern	Berlin Institut für Bevölkerung und Entwicklung	2008		demographic change in Europe
5.2	OECD Environmental Outlook to 2050- The Consequences of Inaction	Kumi.Kitamori@oecd.org	March 2012	www.oecd.org/environment/outlookto2050	Demographic change and its impact
6) Specific driver: technological/ economical changes					

Title	Institution/ Author	Year of publication	Reference (for details: see report)	Main topics

6.1	Trend Report Convenience- Machen Sie es sich bequem	SevenOne media	2007		Changing living standard, food, trade, human care products, e- commerce, consumer electronics
6.2	THOUGHTS Megatrends	Roland Berger School of Strategy and Education Burkhard Schwenker Tobias Raffel			Different perception- see chances in economic/technology sector because of the scenarios
7) Sector-specific topic: Development in food production					
7.1	Fisheries and aquaculture in Europe	European Commission	2012		aquaculture
7.2	The Food Gap- The Impacts of Climate Change on Food Production 2020	Liliana Hisas Executive Director, FEU-US			About the impacts of climate change on food production in 2020
8) Sector-specific topic: Nutrients					
8.1	Global river nutrient report: a scenario analysis of past and future trends	Seitzinger et al	2009		Including MA scenarios
8.2	World Social Science Report- Changing Global Environment	UNESCO	2013		
8.3	World Water Vision- Making Water everybody's business	earthinfo@earthscan.co.uk	2000	www.earthscan.co.uk	Future scenarios for water, water
9) Further aspects					
9.1	Late lessons from early warning: the precautionary principle 1896-2000 (a retrospection of scenarios)	European Environment Agency	2001	www.eea.eu.int	retrospection
9.2	Towards a green economy in Europe- EU environmental policy targets and objectives 2010-2050	European Environment Agency	2013	Eea.europe.eu/enquiries	About achieving a green economy in Europe with laws and implementations
9.3	World Social Science Report- Changing Global Environment	UNESCO	2013		
9.4	zPunkt Megatrends	zPunkt GmbH		www.z-punkt.de	Abstract of different megatrends