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# Solutions for present and future emerging pollutants in land and water resources management

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# Internal Deliverable

# ID S6.1 Discussion paper "Pollution of tomorrow"

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## 1.1 Objectives of this deliverable

Work package S6 of the SOLUTIONS project aims to predict future emerging pollutants – based on scenarios for developments in society. After a first analysis of existing scenarios, a think tank is set up for a deeper, sector-specific analysis of future use and emissions of chemicals. A sequence of four workshops is planned to address specific drivers for releases of chemicals.

This discussion paper documents the work and the results of Task 1: Identification and first analysis of existing scenarios. First indications for future pollutants are described in an overview. This overview is used as a thought starter for the think tank.

## 1.2 Summary

Emerging pollutants (EPs) are monitored in surface waters since the nineties. With progress in analytical chemistry it is possible to analyse these substances in low concentrations. Which pollutants can be expected if future developments in society are taken into account? Such developments in society are described in a broad range of scenarios. Until now, implications of such developments for future pollutants have not been systematically discussed. This discussion paper addresses the question whether predictions of changes in society can be used as an information source for pollutants of tomorrow. In the first step, an overview about existing scenarios and their main findings on developments in society has been prepared. The second step assesses whether causal links can be seen between these societal and also technological development and future pollutants.

36 reports on developments in society (see Table 2 in chapter 6) have been analysed regarding potential implications on future emerging pollutants. The analysis leads to the conclusions, that it is possible – at least to a certain degree – to predict future EPs by such an analysis:

- The demographic change could impair EPs in a negative way. Due to the higher life expectancy in the next decades, the amount of pharmaceuticals circulating in sewage treatment plants and in the end in ecosystems will increase with high probability.
- The world population growth and ongoing urbanization will lead to an increase of the distribution of EPs in the environment.
- Legislation can induce the substitution of hazardous substances by others – sometimes with similar properties. The REACH candidate list shows which substances have been identified in Europe as substances of very high concern. It can be foreseen that for these substances substitutes

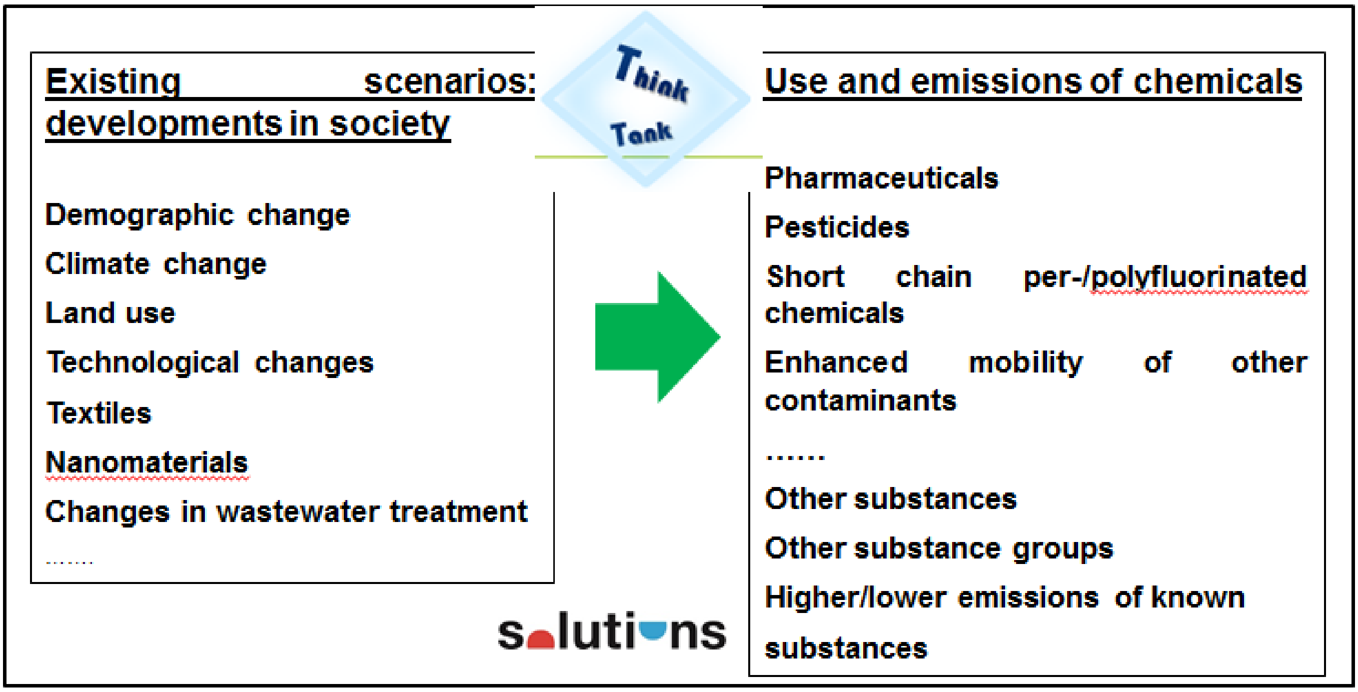
will be placed on the market. They can become future emerging pollutants.

The results indicate several connections between developments in technology and the increase of emerging pollutants, such as flame retardants, plasticiers and medium and short chain PFCs (per and polyfluorinated chemicals). New emerging pollutants can originate from well-known groups of chemicals. However, they can also come from unexpected new areas – such as Fracking or the development of key enabling technologies.

Based on the findings presented in this discussion paper, four workshops organised within the project SOLUTIONS will focus on specific developments in society and related future pollutants.

## 1.2 Graph

The following graph depicts the main approach used to identify future emerging pollutants.



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## 3. List of Abbreviations

| | |
|---|---|
| **EAWAG** | Swiss Federal Institute of Aquatic Science and Technology |
| **ECs** | Emerging Contaminants |
| **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 |
| **PVC** | Polyvinylchloride |
| **REACH** | Registration, Evaluation, Authorization and Restriction of Chemicals |
| **SETAC** | Society of Environmental Toxicology and Chemistry |
| **SVHC** | Substances of very high concern |
| **WATCH** | Water and Global Change |
| **WFD** | Water Framework Directive |
| **WWQA** | Assessment of World Water Quality to Meet the Global Water Quality Challenge |
| **WWTP** | Waste Water Treatment plants |

# 4. Pollution of tomorrow: Developments in society and future emerging pollutants

## 4.1 Introduction

Since the nineties anthropogenic substances called emerging pollutants are monitored in surface waters. With progress in analytical chemistry it is possible to analyse these substances in low concentrations. The NORMAN Network published a list with up to 700 previously analysed chemicals and will revisit it early this year. These chemicals should be limited or substituted in parallel to being discussed in political frameworks.

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 and published by the IPCC (IPCC 2013). Other studies set the focus on economic, technological and demographic developments. Predicted changes can have implications on the future contamination of the environment by emerging pollutants. The following sections give indications for developments in society which can be foreseen, and potential (causal) links between changes in society, use of chemicals/materials and emissions of pollutants. These indications are based on the analysis of a number of publicly available scenarios from different sectors. They address the following aspects:

- **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** (e.g. Costs on Inaction on the sound management of chemicals (UNEP); Trace Contaminants in Water Cycles (Acatech));
- **Developments due to climate change** (e.g. the IPPC Special Report Emission Scenarios from UNEP; the SCARCE project);
- **Developments due to demographic change** (e.g. OECD Environmental Outlook to 2050);
- **Developments due to technological and/or economic** changes (e.g. THOUGHTS Megatrends);
- **Predictions for food production and nutrients** (e.g. World Social Science Report from UNEP);

In addition, a number of related aspects have been included in the analysis, e.g. a retrospective analysis of technological changes (EEA, Late lessons from early warnings) and EU Environmental Policy Targets for 2010- 2050.

The publications used for this overview are listed in Table 2 (see chapter 6, Appendix). In some cases studies refer to several of the items mentioned above (see comment fields in Table 2). For each of the studies which have been analysed, key characteristics are documented in a report profile. Key characteristics are: Institution, aspects which are covered, time period, main developments which are predicted, drivers for change, number and type of scenarios, (causal) link to pollutants. Table 1 show the main topics of 34 scenarios which have been analysed.

*Table 1: Topics of scenarios and numbers of repeats addresses them. Total numbers of reports analysed: 34 (not included: further, more general studies mentioned in section 9 of table 2)*

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

The analysis 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 in food production and increase in the amount of pesticides used).

Based on the analysis of the scenarios, an overview has been made on most important developments in society which are predicted in a broad range of scenarios. Indications for connections between these developments and pollutants of tomorrow are described. The developments refer to the following changes:

- **Climate change (see section 4.2);**
- **Demographic change in Europe (see section 4.3);**
- **World population growth (see section 4.4);**
- **Technological changes (see section 4.5).**

## 4.2 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 *(IPCC 2013)*. A significant number of scientists agreed, that temperature has risen exceptionally during the past 15-20 years, in air *(Tett et al., 1999)* and also in water *(Barnett et al., 2005)*. Probably there will be consequences for the hydrological system *(Zhang et al., 2007)* and also for the climatic system. Figure 1 shows the observed global change in surface temperature from 1901 – 2012.

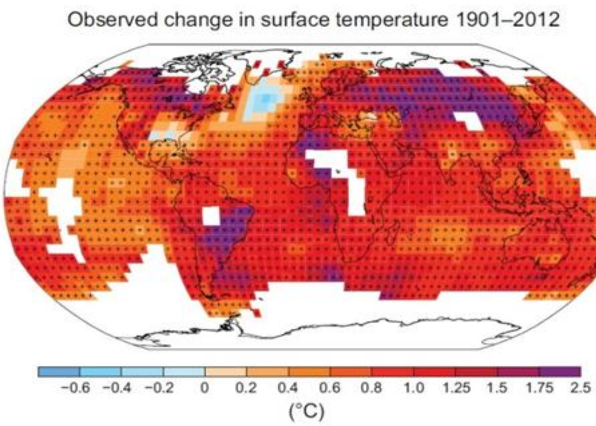



*Figure 1: IPCC: Change in surface temperature due to climate change (Stocker & Qin, 2013)*

Figure 2 shows predictions for the change in global average surface temperature between 1970 and 2100. These predictions are part of the fourth Millenium Ecosystem Assessments (MA). (For further details on the MA, see *Alcamo and Vuuren 2005*).

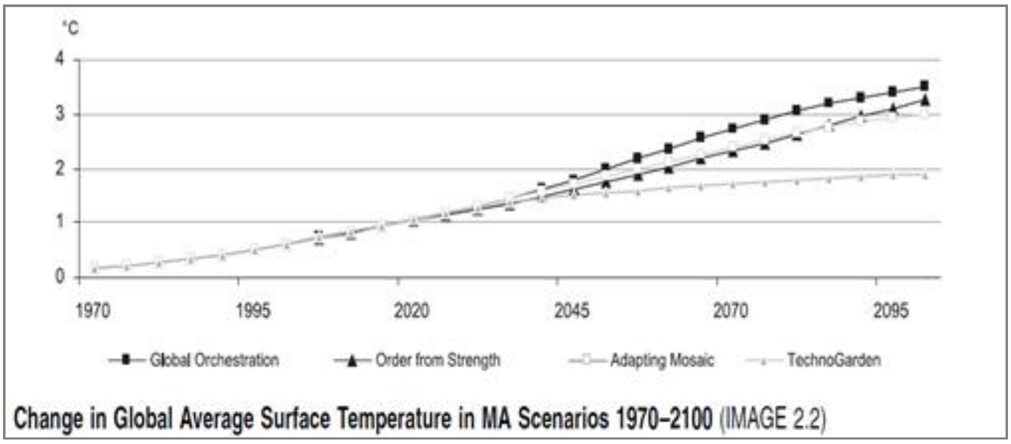



*Figure 2: Predictions of change in global average surface temperature. Predicitions are made for four different scenarios. (Alcamo & Vuuren 2005)*

„*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*" *(Noyes et al., 2009).* Additionally some regions, like North and South America, Northern Europe, and northern and central Asia are projected that precipitation will increase. Africa and Asia and also the Mediterranean, are expected to have more and more substantial droughts *(Noyes et al., 2009).* Also extreme weather events will rise within droughts and floods with torrential rainfalls, periods with high temperature and storm events *(McMichael, Woodruff, & Hales, 2006) (Böhme, Krüger, Ockenfeld, & Geller, 2002)* Figure 3 shows the number of people affected by extreme weather events. Figure 4 shows the impacts of climate change on ecosystems and also the direct impacts on biota. These impacts affect the transport, the transfer between compartments of the ecosystems and also the transformation of contaminants. The most important topics will be insight in droughts, floods and water scarcity affect the behaviour of contaminants in water.

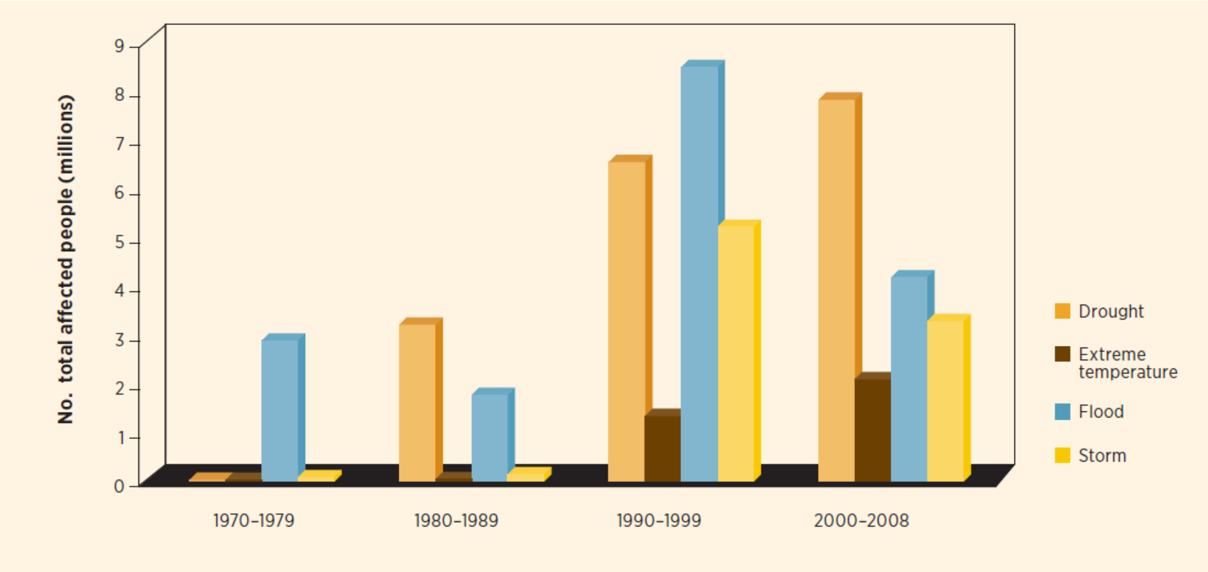



*Figure 3 Number of people affected by extreme weather events in the UNECE region between 1970-2008 (UNESCO, 2012)*

These developments can be seen in the Mediterranean basin. *Barceló and Sabater 2010* claimed that the Mediterranean „*is one of the world's regions most vulnerable to global changes". Giorgi and Lionello 2008* predict that this region is one of the most important regions where oncoming problems in water availability could be seen. IPCC forecasts that this region will have increasing temperature in summer, more droughts and also stronger rainfall. *Calbó 2010* also predicts that the average river discharge will decrease. Water temperature and the frequency of large floods will increase in future *(Calbó 2010)*. In 1999 *Gasith and Resh* found out that typical characteristics of rivers under Mediterranean climate have/ will have low water flow in summer, but large floods in autumn and winter. Therefore we think that this scenario could be taken for other worldwide hydrological scenarios. Droughts and floods, water scarcity, changing in water temperature and also storm intensity will have consequences on the occurrence of EPs.

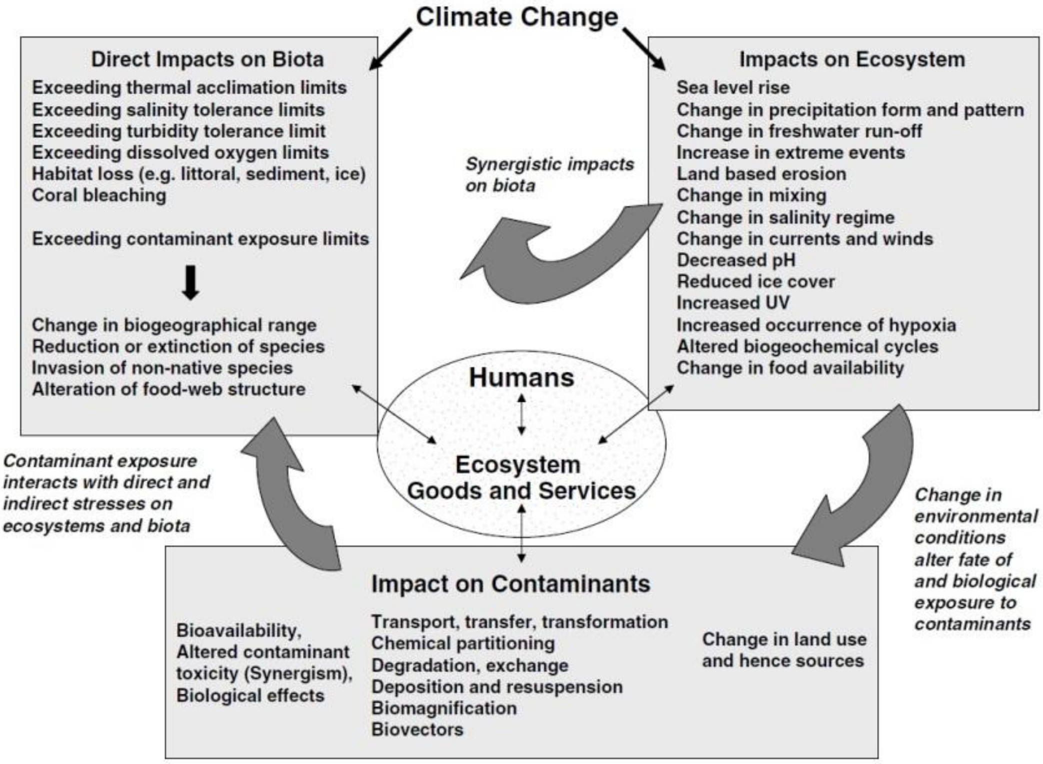



*Figure 4: Overview of climate change impacts on ecosystem and biota (Schiedek, Sundelin, Readman, & Macdonald, 2007)*

*Noyes et al., 2009* predict that „*Climate change will have a powerful effect on the environmental fate and behavior of chemical toxicant*". As it can be seen in Figure 4 there are a lot of biotic and abiotic factors influencing the behavior of chemicals. Further abiotic and biotic factors are physical, chemical, and biological drivers of reaction and exchange between the atmosphere, water, soil/sediment, and also biota. Examples are air-surface exchange, wet/dry deposition, and reaction rates as photolysis, biodegradation or oxidation in air *(Noyes et al., 2009). Schmitt- Jansen et al., 2007, Buser H. et al., 1998 and Schneider, 2004,* predict that solar irradiations have impacts to some pharmaceuticals as Diclofenac, Ibuprofen or the X-Ray contrast medium Iopromid. Example phototransformation of the anti- inflammatory drug Diclofenac: *Schneider, 2004* found out, that the phototransformation substances of Diclofenac, 8-Chlorcarbazol-or-8 Hydroxycarbazol Derivate or Diphenylamin-derivate, are more stable than Diclofenac *(Agüera et al., 2005)*. The most negative aspect is that phototransformation products mostly are more toxic than Diclofenac itself for e.g. *Scenedesmus vacuolatus.* (*Schmitt- Jansen et al., 2007).* In addition, *Schmitt- Jansen et al., 2007,* found out, that there are several photolysis products produced under UV-light.

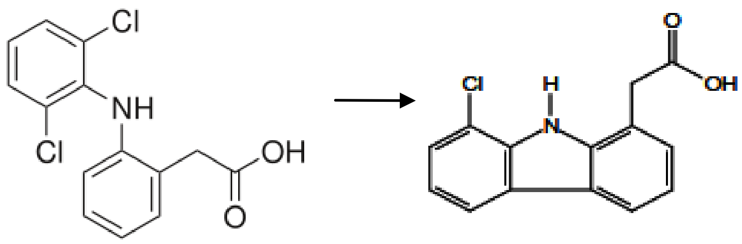



*Figure 5: Phototransformation of Diclofenac to Chlorocarbazole acetic acid*

The number of pollutants is large, since the chemical reaction of chemicals can be manifold and extensive. However there is a link between droughts, water scarcity and its linkage to pollutants in water. In the following the main consequences of climate change relating to emerging pollutants will be described. Figure 5 shows the chemical process of the phototransformation of diclofenac.

**<u>Consequences of water scarcity and droughts</u>**

The European Commission distinguish between water scarcity and droughts. Due to climate change upcoming weather extremes will increase.

***„<u>Water scarcity</u> occurs where there are insufficient water resources to satisfy long-term average requirements. It refers to long-term water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural system. “***

***„<u>Droughts</u> can be considered as a temporary decrease of the average water availability due to e.g. rainfall deficiency. Droughts can occur anywhere in Europe, in both high and low rainfall areas and in any seasons. The impact of droughts can be exacerbated when they occur in a region with low water resources or where water resources are not being properly managed resulting in imbalances between water demands and the supply capacity of the natural system.”***

Water scarcity will increase and also expected droughts. This development could have negative impacts to the flow river regime *(Barceló & Sabater, 2010)* and also for the chemical quality of water systems *(Navarro-Ortega, Sabater, & Barceló, 2012). Muñoz et al., 2009* discovered that water has a high concentration of nutrients, pesticides, surfactants, pharmaceuticals, and estrogenic compounds if there is available scarcity. *„During droughts, dilution capacity decreases, increasing the risk of pollutants in the environment, which might affect the functioning of the river ecosystem” (Navarro-Ortega, Acuña, et al., 2012) (Navarro-Ortega, Sabater, et al., 2012)* found out that because of pollutant inflows the nutrient and pollutant concentrations will rise under lower water river flows. At present this is urgent in arid or semiarid regions as the Mediterranean basin. But in future it could be an intense problem for other regions of the world. So the only river flow would arise through treated sewage effluents like nowadays in the tested area of the SCARCE project *(SCARCE CONSOLIDER)*. In addition, due to water scarcity and droughts, in arid regions the contaminants could be concentrated in river waters. Increasing of this problem it will get a risk for the environment *(Navarro-Ortega, Tauler, Lacorte, & Barceló, 2010)*. Water is still used for drinking purposes and agriculture. But if water scarcity will increase, wastewaters must being reused for these applications. This development could increase and chemical compounds might be transported from waste water treatment plants to river waters. There they affect the chemical and biological quality of these waters *(Navarro-Ortega, Sabater, et al., 2012) (Barceló & Sabater, 2010)*. This would have a negative impact for the hydrological cycle. It is expected that this will lead to more dissemination of pollution, because the required purification of emerging pollutants in waste water before reuse often does not take place.

Not only water scarcity and droughts will affect water quality. Also storm intensity will increase because of climate change. Because of storm intensity and torrential rainfalls, floods can get common in river systems as droughts.

**<u>Consequences of torrential rainfalls and floods</u>**

Extreme weather events like rainfalls will affect river flows as well. *Whitehead et al., 2009* identified, that rivers will react with an increase change of the stream power. Sediments can be deposited to lakes and have a big impact to freshwater habitants like lakes or streams. Beside to that, the scientists found out, that it is possible that rainfall changes will affect the mobility and the dilution of contaminants in rivers. The dilution characteristic is the other way around as described for Consequences of droughts. Dangerous floodplains are expected within possible flooding of sewage plants or extruded agriculture land. Pesticides or other contaminants could be mobilized and washed away to surface water. As an example *Chiovarou and Siewicki 2007* measured the two insecticides Carbayl and Imidacloprid. Chemical contaminations of aquatic systems during storms have been of different intensity. It has been found that the concentrations of both insecticides increase with increasing storm intensity *(Noyes et al., 2009)*.

But flooding implicates also another risk. Contaminated water can deposit pollutants to agriculture land. Therefore it is necessary to consider both sides. Productive livestock or agriculture plants could absorb these contaminants *(Böhme et al., 2002)*. That would be one way for EPs to enter in food chain by depositing on sediments.

In summary it can be concluded, that floods and droughts would have negative impacts. In an Interview, *Tümpling 2014 (Zentrum für Umweltforschung)* predicts, that the amount of precipitation will almost stay constant for Germany. But the length of dry spells and also intense rains will increase. For this reason the increase of low water line and also flooding in many regions is predicted, leading to an increase of the amount of water required for agriculture lands during dry spells. Water must be withdrawn out of the rivers which have a low water line. At the same time the quantity of waste water entering river systems will not decrease, because the frequency using the shower, toilet, washing will stay constant. One possible risk is that the amount of waste water during low water line will increase. As a consequence, the concentrations of EPs increase as described before. *Navarro- Ortega et al., 2010* predict that *„urban, industrial and agricultural activities release a cocktail of compounds of toxicological relevance, such as pesticides (Fernández et al., 1999), surfactants (Ying et al., 2002) and hydrocarbons” (Tolosa et al., 1996)* and others. *Tümpling* added that it can become more difficult to meet the objectives of the Water Framework Directive.

**<u>Consequences of elevated water temperatures</u>**

*Barcelo et al., 2010* predict that it is possible that under climate change temperature in low river flow conditions will increase. This can lead to a synergetic effect: increasing amounts of emerging pollutants and also rising water temperatures. Wildlife will suffer from this second stress facto, together with multiple other stress factors, life in water will suffer from a so called “cocktail effect” in future.

Climate change can 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. Due to these changes, the exposure of biota to these contaminants can change. Elevated water temperatures may alter the biotransformation of contaminants to more bioactive metabolites and impair homeostasis and also the toxicity of contaminants may be enhanced with increasing temperatures *(Boone and Bridges, 1999; Capkin et al., 2006; Gaunt and Barker, 2000; Silbergeld, 1973) (Noyes et al., 2009)*. *Schiedek et al., 2007* described that higher water *„temperature has long been known to modify the chemistry of a number of pollutants resulting in significant alterations in their toxicities e.g. for fish”.*

Higher water temperature is a further stressor for water living animals. Consequently this will influence the uptake rate of pollutants by higher ventilation and the metabolic rate e.g. in fish *(Kennedy and Walsh, 1997)*. Another example for a synergetic effect is described for the Baltic *„amphitod Monopreia affinis react with temperature and the fungicide fenarimol with in increased numbers of females with dead eggs”*

*(Schiedek et al., 2007).*

A further overview about the interactions between various classes of chemicals and different environmental factors as temperature in aquatic organisms can be looked up in (*Heugens et al., 2001) (Schiedek et al., 2007).*

## 4.3 Demographic Change in Europe

According to predictions for the next 40 years, total population in Europe will stay constant. For Germany, a reduction of population is predicted (from 82 million in 2005 to 72 million inhabitants in 2050). Figure 6 shows the demographic development in Germany *(Prognos & Öko-Institut, 2009), (DESTATIS, 2011).* Also *(bpb 2011)* predict the same scenario for whole Europe.

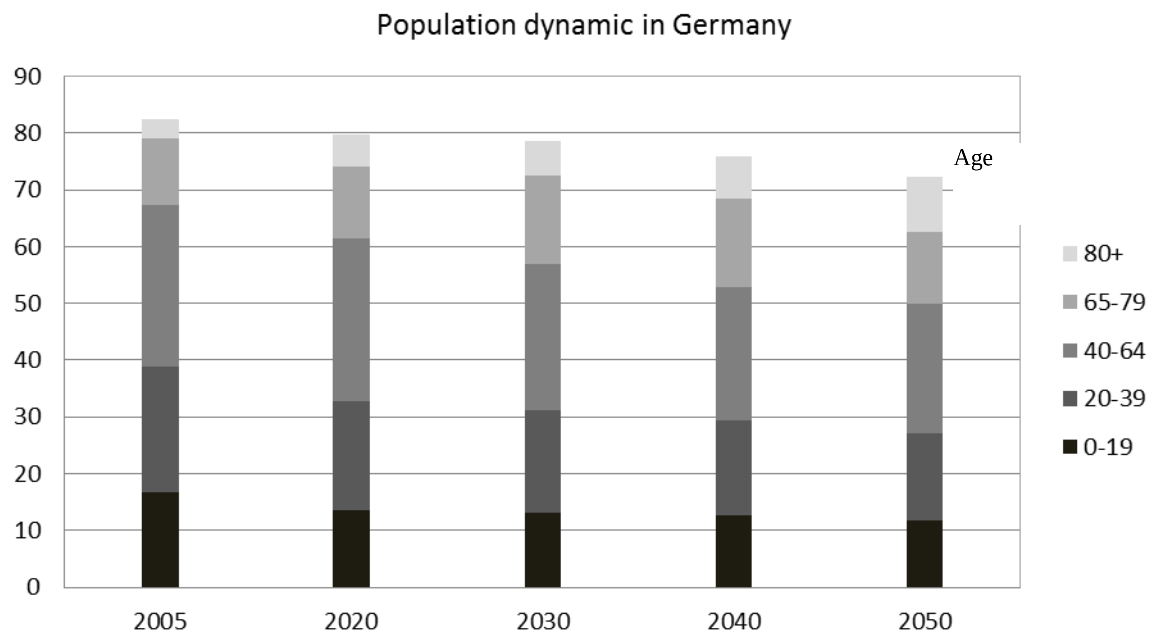



*Figure 6: Total Population and its Demographic change in Germany until the year 2050 in millions (Prognos & Öko- Institut, 2009)*

Figure 6 shows the decrease of the total population, an increase of people between 65 years and older, and a nearly unchanging trend of youths and children in the age from 0-19. The numbers in the age group between 20- 39 years and 40- 64 years diminish continuously. The group of 65-79 years old people will grow until the year 2040 and then decrease slowly while the 80 years old generation will grow. *(Berkermann et al., 2007)* prognosticate that the growth of people older than 65 will have an increase by 38% until 2030 while the people under 20 years old will have a decrease by 17 % until 2030 *(Sigman,* *Henk, Natahlie, Nils Axel, & Xavier, 2012)*. As a consequence diseases which are typical for elderly people as heart- circulation disease, cancer or diabetes will increase *(Schwabe & Paffrath, 2013)*. This development will induce many changes in the health system. *Berkermann et al., 2007*, predict that there will be an increasing demand for pharmaceuticals with increasing mean age.

This could have been several implications for future emerging pollutants mainly pharmaceuticals. To have a high expectation of life, elderly people will need more pharmaceuticals *(Sueddeutsche, 2010)*. It is foreseeable that the consumption of pharmaceuticals will increase mostly in hospitals *(Pinnekamp, 2013)* and elderly homes, but also in privately owned-homes. Pharmaceuticals like Lipidregulators (e.g. Bezafibrates) or antiinflammatory (e.g. diclofenac) are mainly used by elderly people *(Schwabe & Paffrath, 2013)*. Other widely-used groups will be diabetic medicaments *(Berkermann et al., 2007)* and antibiotics, also mainly used from elderly people. X-ray contrast medium and Antineoplastics used in chemotherapy are further examples for groups of pharmaceuticals mostly consumed in hospitals but also in practical surgeries *(Heberer, 2002)*. It is reasonable to assume that the consumption of these pharmaceuticals will further increase. *SauberPlus* and *Berkermann et al., 2007* both predict that demographic change and pharmaceuticals consumption is linked together. Because of their structure, several of these substances are difficult to remove from waste water. They can enter aquatic and terrestrial ecosystems *(Heberer, 2002)* and even in small concentrations drinking water *(Kümmerer et al., 2008)*.

## 4.4 World population growth and urbanization

In 2050 world population is projected to grow to 8.9 billion *(UN, 2004)*. The world population is mainly growing in developing countries such as Africa, South America and Asia. Figure 7 shows the expected areas of population growth and decline between 2000- 2080. The trend of a declining population in Europe is noticeable (mentioned in chapter 4.3 (Demographic change)). Due to population growth it is conspicuous 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% are living in cities and in 2030 around two- thirds of the global population are predicted to live in cities *(United Nations, 2009)*. UNESCO forecasts that 60 % will live in cities in 2030 *(UNESCO, 2003)*.

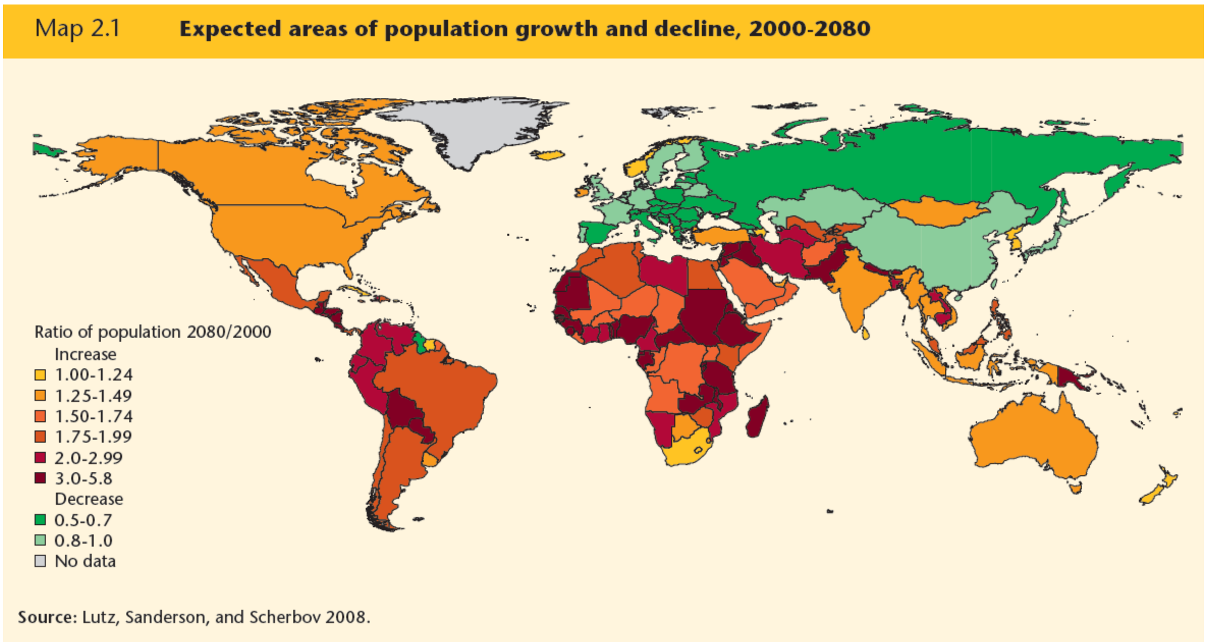



*Figure 7: Population in major areas, estimates and medium scenarios: 2000-2080 (UNESCO & Earthscan, 2009)*

This phenomenon is called urbanization and will entail many problems for the environment. In the following the linkage and impacts of urbanization on EPs will be described.

Problems as waste water, -waste management and also traffic regulation in cities will gain in importance. Urban development means also an increase of ground sealing which have negative impacts for environment. It is *„accompanied by the transformation of natural land surfaces into impervious surfaces, such as streets, parking lots, roofs and other types of structures that block the percolation of rainwater and snowmelt into soil" (UNESCO & Earthscan, 2009).* UNESCO and Earthscan 2009 predict that these constructions can have dangerous impacts as an *„intense flow of water over the land, carrying polluting materials into receiving water systems, degrading water quality and causing local pollution problems".* Ground sealing can increase the frequency and intensity of floods. Floods can transport pesticides, surfactants, pharmaceuticals and other emerging pollutants to river systems *(Fernández et al., 1999, Ying et al., 2002, Tolosa et al., 1996)* (see also chapter 4.2).

Urbanization requires a well managing of waste water. Waste water can create pressure on local freshwater *(UNESCO & Earthscan, 2009).* Purification systems are very important to get a good water quality. Increase of population results in an increase in waste water volume. Integrated management of the water system for households and industry is needed. A good waste water treatment, decrease of pollution, conduction of rainfall and prevention against floods are necessary for a well-planned management in cities *(UNESCO, 2003).*

Another important topic in big cities is waste management *(UNEP, 2012).* Waste and waste dumps are already gearing up towards becoming major problems. It cannot be assumed that suitable waste management will be in place on a global scale. In this situation, disposal flows with emerging pollutants such as plasticizer or deposits from pharmaceuticals can directly enter ecosystems and surface water *(UNESCO & Earthscan, 2009).*

Furthermore it is necessary to manage food production for covering nutrition of a growing world population. By increasing sustainable agriculture *(EEA, 2005)* with a reduced use of pesticides and its management. The major source of aliment provision comes from agriculture within farming, cattle breeding, aquaculture and forestry *(UNESCO, 2003).* Therefore water management adjusts one of the biggest challenges for this development. As mentioned before it would be important to pay attention for the water quality. By reusing sewage water a future circulation of agrochemicals and other emerging pollutants is expected in regions with water scarcity (see chapter 4.2).

Another point is that Megacities are likely to cause major changes in the lifestyles of the inhabitants. *„The age of the population will influence the consumption, „production patterns" and behaviour (UNESCO & Earthscan, 2009).* E.g., plastic packaging is putting forward a source of EPs. Also higher consumptions of human care products, pharmaceuticals and probably of food additives are foreseen in cities due to urbanization *(UNESCO & Earthscan, 2009 Part 1, Chapter 2).*

## 4.5 Technological changes

Technological developments take place in a large number of sectors continuously. New products or new functions of existing products are generated. In many cases, these changes become possible due to the use of specific substances. Permanent water resistance of outdoor textiles is an example for such functionality. It has been realized with the use of per- and polyfluorinated chemicals (PFCs) *(Greenpeace e.V. 2012).* Such new developments can cause new contaminations of surface water, if these substances are released during production, service life, recycling, reuse or disposal of the products. Therefore future technological changes can lead to new and also more emerging pollutants.

Technological developments can take place in all branches. They are difficult to predict. In the following sections some examples are given for pollutants which are emerging due to changes in technology. Two cases can be distinguished:

- Substitution of problematic substances due to regulation
- Technological developments with new uses of chemicals and materials

### 4.5.1 Substitution of problematic substances due to regulation

An important driver for future emerging pollutants is the substitution of problematic substances by substances with similar emission behaviour. Phthalate used as plasticizers are a well-known example. Plasticisers are used for many daily life products e.g. plasticized PVC, packaging and sport articles *(BMUB, 2009)*.

Recent monitoring studies show an increase in concentrations of phthalates (diisononyl phthalate (DINP) and diisodecyl phthalate DIDP)), used as substitutes for phthalates which have been restricted by law (LfU, 2012 and UBA, 2007). The regulation of phthalates under REACH has been shown in Table 4. Substitutes for DEHP are DEHT (Figure 8), DINCH (Figure 9) , DOZ or TEHTM *(Brutus, Calero, Corden, Esparrago, & Mackay, 2013)*. But also these substances have to be assessed carefully. It has been found that these substances have data gaps for neurotoxicity, endocrine activity or cancer *(Becke r, 2013)*. *Brutus et al., 2013* report that there are even naturally substitutes as bio plastics derived from renewable biomass sources (e.g. vegetable oils).

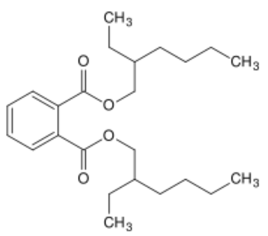



*Figure 8 Structure formula of Bis (2-etyhlhexyl)phthalate (DEHP)*

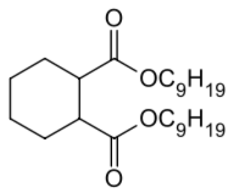



*Figure 9 Structure formula of 1,2-Cyclohexane dicarboxylic acid diisononyl ester (DINCH/Hexamoll)*

Similarly, long-chain per- and polyfluorinated hydrocarbons (PFCs) (see Figure 10) are replaced by short-chain 2- 4 PCFs (*(Greenpeace e.V. 2012)* and *(UBA, 2009)*) – which are already detected in the environment in increasing concentrations *(Benskin et al., 2012)*. Some of these substances are bio accumulative, some are persistent, and some are toxic for humans and/or biota *(Farre et al., 2008)*.

These "new" phthalates and short chain PFCs are not yet all regulated under a legal framework such as REACH. Therefore producers can place these critical substances on the market.

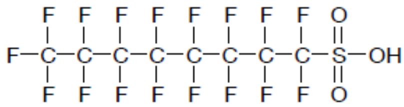
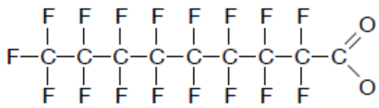
| Group[12] | Example for a compound | Chemical Structure |
|---|---|---|
| Perfluorinated sulfonic acids | PFOS |  |
| Perfluorinated carboxylic acids | PFOA |  |

*Figure 10: Chemical structures of PFOS and PFOA (Greenpeace e.V. (2012). Chemistry for any weather.Greenpeace tests outdoor clothes for perfluorinated toxins report.)*

The third group of substitutes belongs to the group of flame retardants. Hexabromobenzene (HBB) (Figure 11) and bis (2, 4, 6-tribromphenoxy) ethene (BTBPE) are newly emerging pollutants - and substitutes for polybrominated biphenyls. These substitutes were recently found in surface waters as well as in wild animals *(Moskeland, 2010)*. The flame retardant Hexabromocyclododecane is another example of a substance for which substitutes can be expected in near future. As a persistent, bio accumulative and toxic substance, future use of HBCDD will be forbidden in the European Union after August 2015. The substance is listed in REACH Annex XIV. After this so- called "sunset date" a specific authorization is required for the use of HBCDD. For more details see the following subsection *(ECHA, webpage)*.

*Figure 11: Structural formula of the flame retardant Hexabromobenzene*

## 4.5.2 Technological developments with new uses of chemicals

### Substances for insulation

Some substances used for insulation materials are already emerging pollutants according to the

NORMAN list. Examples are HBCDD Hexabromocyclododecane (Figure 12) and biocides such as Terbutryn used as a Herbicide and 2-Octyl-2H-isothiazol-3-on, named in a Swiss study from Eawag *(Walser, Burkhard, Zuleg, & Boller, 2008)*. These substances can be found in surface waters. Terbutryn can be released by rain water from insulation mats. It contaminates ground-, surface-, and drinking water. At present there is no purification method for these substances in waste water treatment plants. They are emitted to the receiving water bodies after the sewage treatment plants *(UBA, 2008)*. Currently and until 2015 large amounts of HBCDD are allowed to be used in insulation materials for buildings *(UBA, 2008)*.
These substances can become important future emerging pollutants, if buildings are replaced or renovated. This is likely to happen within the next 30-50 years. In a best case scenario, all the walls will be disposed as toxic waste. But if not, HBCDD and also Terbutryn from historical uses will contaminate ecosystems, groundwater and surface water for a long time even if the future use if forbidden due to REACH.

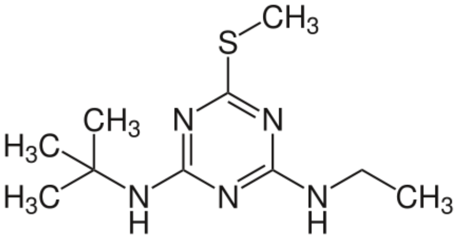


*Figure 12: Structural formula of Terbutryn, a biocide used for insulation.*

**Substances used in convenience products**

Another area with new technological developments are convenience products focused on lifestyle: convenience food or convenience in human care products *(Ziegler, Reitbauer, & Rizzo, 2007)*. For these convenience products, substances as Sucralose (Figure 13) or Triacetin (Figure 14) are used as food additives and as aroma. This could increase the consumption of products containing these substances. As per the report of SevenOneMedia from 2007, convenience products will be increase in future. Convenience products will be definitely more applied in entertainment electronics, manufactured products and also in human care products. These developments will have an impact for new technologies and also chemical developments and application. These products are focused on the changing lifestyle of human. The general public are in a way of changing, more convenience and less time will dominate most lives. Because of better mobility, more part-time jobs and concurrent activities in either family managing or job managing induces to less time for e.g. cooking, cleaning, social contacts or personal hygiene away on business. Examples of developments of the food industry will be the use of more preservatives, additives for a longer stability and the zero sugar trend. Sucralose or Triacetin are used as food additives in sweet products. They can be found as new emerging pollutants. Sucralose is a polar, chlorinated sugar containing five hydroxyl groups, synthetically produced from saccharose by the selective replacement of three hydroxyl groups with chlorine atoms. Sucralose is extremely persistent, with a half-life in water of up to several years, depending on pH and temperature *(Loos et al. Sucralose screening in European surface waters using a solid-phase extraction-liquid chromatography–triple quadruple mass spectrometry method. 2008)*. Triacetin is used as an aroma in chewing gums and as a food additive.

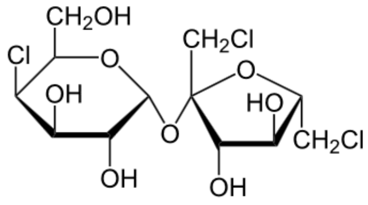



*Figure 13: Structural formula of sucralose*

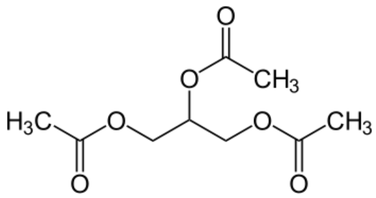



*Figure 14: Structural formula of Triacetin*

Two other factors supporting the application of sucralose and other sweetener are probably demographic change and also urbanization. As described in chapter 4.3 people getting older and suffering more under diseases as diabetic. Popular diabetic products are made with sucralose or other sweetener instead of sugar. This could increase the consumption of sucralose in future.

In addition, technological developments in packaging for human care products can lead to new EPs. It is assumed that industry aims to make packaging more efficient (and maybe more biodegradable). Packaging of biodegradable substances could be more produced for a better environment *(UBA & Ifeu, 2012)*. The use of future specific substances can be expected to fulfil these functional requirements. In addition it would be an advantage to produce more biodegradable or recycled materials to reduce the inputs of contaminants.  Another trend of the society is and will be that Triclosan, *„professionally used as a biocide, but also in household products and cosmetics such as toothpastes, or in textiles* will be grow in application and will increase in surface water *(Ruedel, 2012)*.

## 4.6 Nanomaterials

The sector of nanotechnology is and will be a rapidly growing market. Nanomaterials are used in many sectors to produce human care products, medicine-, food- and packaging materials, UV-preservatives, building and construction- and other products. Figure 15 illustrates the broad use of some nanomaterials-/ particles for different product sectors.

It is expected that production and use of nanomaterials will grow further. Examples for nanomaterials with a high production volume are *(Moeller et al., 2013):*

- Carbon- Nano- Tubes (CNTs)
- Carbon black
- Titania (titanium dioxide)
- Ferrous oxide
- Silver
- Silica
- Zincoxide

These materials are in application for *„commercial purposes such as fillers, catalysts, semiconductors, cosmetics*, textiles, *microelectronics, pharmaceuticals, drug carriers, energy storage and anti- friction coatings"*. As mentioned in the *EAWAG News 2009* there are more than 800 products *(Behra, 2009)* in the nanotechnology sector applied for pharma- and medicine technology, energy- and environmental technology, information- and communication technology, manufacturing systems engineering and the textile industry as well as for the building sector *(Moeller et al., 2013). Moeller et al.2013* mentioned that with these substances nearly every class of material could be improved and affected. The size of a Nanomaterial ranges typically between 1 and 100 nm. They can „*be composed of many different base materials (carbon, silicon and metals, such as gold, cadmium and selenium) and they have different shapes" (Marinella Farré et al., 2009).* Due to their small size, nanomaterials show an extremely high surface to volume ratio explaining their high reactivity. The different applications and uses require a careful assessment of potential exposures and risks for humans and the environment. Depending on its substance, form, size and surface, a nanoparticle can have completely different physical, chemical or biological interactions with the environment, e.g. in soils, water bodies and human or with other substances, compared to the bulk material *(Krug, 2005)*. Therefore they might have negative impacts to ecosystems *(Krug, 2005)*. In the following some examples of important nanomaterials are given:

Figure 15 from *Keller& Lazareva 2013* shows the estimated annual mass flow of some well- known engineered nanomaterials and their further lifecycle. The impacts of nanomaterials to the environment are a current important research topic.

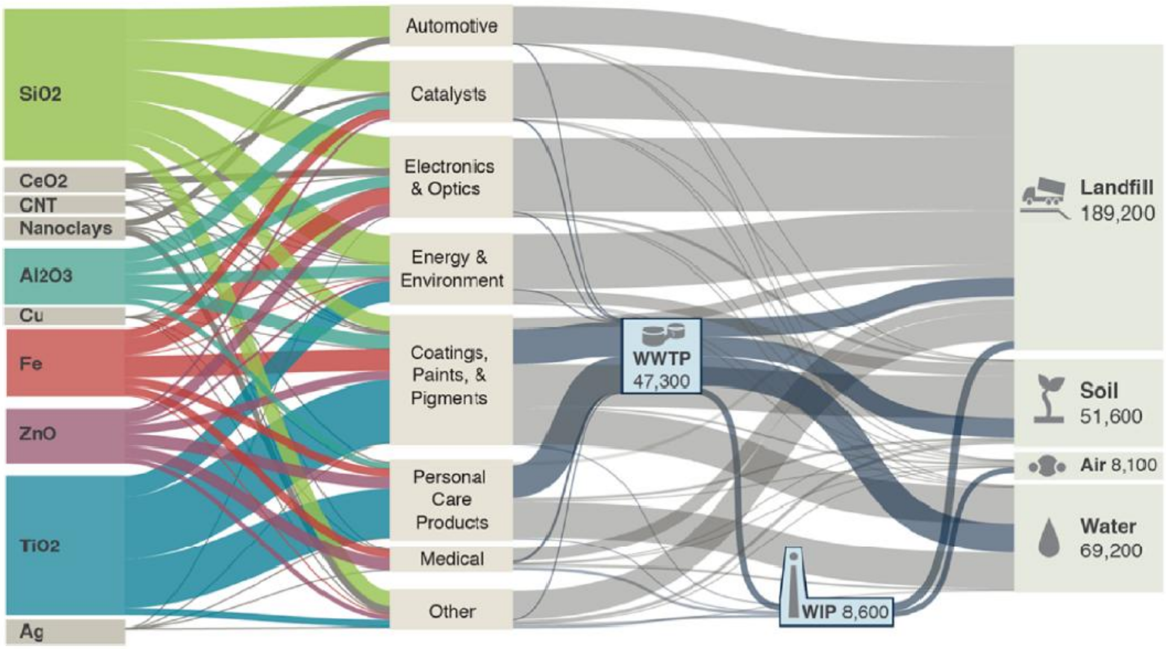



*Figure 15: Estimated global mass flow of engineered nanomaterials (in metric tons per year) from production to disposal or release, considering high production and release estimates as of 2010. Source: (Keller & Lazareva, 2013)*

Even if the major part of materials is deposited in landfills, a remarkable part of the total production is emitted to soil, air and water.

Due to the increasing use of Nanomaterials-/particles in different sectors, it can be expected that specific Nanomaterials-/ particles will be found as new emerging pollutants in surface water. Nanoparticles are spread *„ either to a wastewater stream and treatment or to a municipal solid waste handling "* or in *„ many other countries of the world wastewater is released with no treatment to canals and water bodies" (Keller & Lazareva, 2013)* . *Kaegi et al., 2008* also found out, that Nanoparticles as Titania can be washed out from house walls and enter surface waters in detectable concentrations. This was approved by *Mueller and Nowack 2008* within a simulation. With increasing relevance of nanomaterials the described impacts will gain importance in the future. *Greßler and Nentwich, 2012* assert, that *„In the environment, nanomaterials can undergo a* range of chemical processes *that depend on many factors (e.g. pH value, salinity, concentration differences, the presence of organic or inorganic material). The characteristics and properties of a nanomaterial also play a major role".* Therefore, it is not easily to forecast the fate and behaviour of the different nanoparticles in the environment. Because of the variety of nanomaterials, they differ in their ecotoxicological properties.

The main facts about environmental fate will be presented for a few nanoparticles. *Jones 2002 and Lyklmea 2005* predict, that *„dispersed nanomaterials within water will behave according to the well-described and understood phenomena which govern colloid-science"*. In addition it is reasonable to assume that they will alter the behaviour of other organic compounds in aquatic ecosystems. It is important to mention that for example Carbon Nanotubes can absorb to some other organic compounds as *(Farré et al., 2009):*

- Bisphenol A
- Phthalate esters
- Dioxin
- Nonylphenol
- DDT and its metabolites

The sorption is currently well explored by *Peng et al., 2003, Gerde et al., 2001*.

In addition, *Neukum, Braun, & Azzam, 2012* claim, that a mobile nanoparticle could act as carrier materials for other emerging substances. They predict that this so called "Co- Transport" may cause higher concentrations of pollutants in groundwater. This fact has been little studied till now and reclaims further investigations.

## 4.7 Conclusions

In this report, 36 reports on developments in society (see Table 2 in chapter 6) have been analysed regarding potential implications on future emerging pollutants. The analysis presented in the previous sections leads to the conclusion, that it is possible – at least to a certain degree – to predict future EPs by such an analysis.

- The demographic change could impair EPs in a negative way. Due to the higher life expectancy in the next decades, the amount of pharmaceuticals circulating in sewage treatment plants and in the end in ecosystems will increase with high probability. The most important pharmaceuticals for older peoples should be checked regularly for potential future emerging pollutants.
- The world population growth and ongoing urbanization will lead to an increase of the distribution of EPs in the environment. Examples of relevant groups of substances are pharmaceuticals, phthalate or plastic substances.
- Climate change can influence the dissemination of EPs worldwide. It is difficult to analyse the

behaviour of EPs in by influencing of climate change. But, since frequency and intensity of flood events, droughts or water scarcity will increase in future; these events can affect e.g. the dissemination of EPs in environment.

- Legislation can induce the substitution of hazardous substances by others – sometimes with similar properties. The REACH candidate list shows which substances have been identified in Europe as substances of very high concern. It can be foreseen that for these substances substitutes will be placed on the market. They can become future emerging pollutants.
- Future technological progress may enable to find suitable alternatives for currently used EPs as per-and polyfluorinated chemicals, flame retardants or nanomaterials. However, also these new substances might have negative impact on the ecosystem.
- Changes in lifestyle are accompagnied with increased consumption of convenience products – such as specific types of food or human care products. It can be assumed that substances as sucralose or triclosan will be used in larger amounts – with the risk of higher releases to the environment.

For some scenarios analysed so far it is difficult to make robust predictions on future pollutants. New emerging pollutants can originate from well-known groups of chemicals. However, they can also come from unexpected new areas – such as Fracking or the development of key enabling technologies.

Based on the findings presented in this discussion paper, four workshops organised within the project SOLUTIONS will focus on specific developments in society and related future pollutants.

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# 6 Appendix

*Table 2 Documents on developments in society and scenarios analysed (for chapter 4)*

| 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 Environment Programme<br>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<br>Population growth<br>Urbanization<br>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- Environmental Goals and Gaps | UNEP | 2012 | | Climate change<br>Chemicals<br>Waste, Water |
| 1.5 | The European Environment- State and Outlook 2010 | European Environment Agency<br>Jock Martin and Thomas Henrichs and many more | 2010 | Eea.europe.eu/enquiries | Climate change<br>Nature& biodiversity<br>Natural resources and waste<br>Environment, health and quality of life<br>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 acidification, stratospheric ozone, biogeochemical N and P cycle, global fresh water use, land system change, biological diversity lost |
| **2) Developments in water use and water cycles** | | | | | |
| 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<br>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<br>Changes of water cycle |

| Title | | Institution/ Author | Year of publication | Reference (for details: see report) | Main topics |
|---|---|---|---|---|---|
| 2.4 | GLOWA- Globaler Wandel des Wasserkreislaufes<br>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<br>Safety in Denmark | Government of Denmark | 2010-2013<br>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<br>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 |
| 3.5 | Organische Spurenstoffe im Wasserkreislauf Acatech Materialien Nr 12, Georessource Wasser-Herausforderung Globaler Wandel | Axel Bergmann | 2011 | www.acatech.de | Schadstoffe im Wasserkreislauf |
| 3.6 | SusChem- European Technology Platform for sustainable chemistry | Cefic- The European Chemical Industry Council | 2012 | http://www.suschem.org/ | SusChem addresses challenges specific to the European chemical and industrial biotechnology industry for the benefit of society as a whole. |

| Title | | Institution/ Author | Year of publication | Reference (for details: see report) | Main topics |
|---|---|---|---|---|---|
| 3.7 | Global Chemical Outlook | UNEP | 2012 | http://www.unep.org/pdf/GCO_Synthesis%20Report_CBDTIE_UNEP_September5_2012.pdf | Recycling management, Green chemistry<br><br>Global production, trade, use and disposal of chemicals and their health and environmental effects |
| **4) Specific driver: climate change** | | | | | |
| 4.1 | IPCC Special Report Emissions Scenarios, Summary for Policymakers Intergovernmental panel on climate change | IPCC Working group III<br>UNEP<br>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<br><br>Dr. Alícia Navarro-Ortega (projectmanager) alicia.navarro@idaea.csic.es | 2009-2014 | www.scarceconsolider.es | Change of water quality/quantity |
| 4.3 | WATCH- Water and global change | Richard Harding<br>Tanya Warnaars | 2011 | | introduction to the achievements of the WATCH Project<br>Water cycle and its changes |
| 4.4 | Modell Deutschland: Klimaschutz bis 2050 | Prognos<br>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** | | | | | |
| 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 |

| Title | | Institution/ Author | Year of publication | Reference (for details: see report) | Main topics |
|---|---|---|---|---|---|
| 6.2 | THOUGHTS Megatrends | Roland Berger School of Strategy and Education<br>Burkhard Schwenker Tobias Raffel | | | Different perception- see chances in economic/technology sector because of the scenarios |
| 6.3 | European Innovation Partnership on Smart Cities and Communities | | | http://ec.europa.eu /eip/smartcities/ | brings together cities, industry and citizens to improve urban life through more sustainable integrated solutions. |
| **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<br>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.c o.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<br>(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/enq uiries | 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 |
| 9.5 | Science and Decision: Advancing Risk Assessment | National academy of science | 2009 | | Advanced risk assessment / Silver Book of NAS |
| 9.6 | Control of hazardous substances in the Baltic Sea region- COHIBA | Finnish and Swedish Environment Institute and Research Institut2 | 2012 | www.cohiba-project.net/public ations<br>www.environmen t.fi/syke/cohiba | Control and manage hazardous substances in the baltic sea region |
| 9.7 | World business council | | | www.wbcsd.org | Business solution for a |

| Title | | Institution/ Author | Year of publication | Reference (for details: see report) | Main topics |
|---|---|---|---|---|---|
| | | | | | sustainable world<br>How does look like a sustainable world, how we can reach it, what can contribute the economy to reach the aim of a more sustainable world? |