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

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Pollution of tomorrow: Options to act on Future Risks.

Recommendations for a successful management of emerging pollutants

Final report of Work Package (WP) 6

WP 6: S6 – Trends and Scenarios: Think Tank "Pollution of tomorrow and options to act"

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PU	Public	**X**
PP	Restricted to other programme participants (including EC)	
RE	Restricted to a group specified by the consortium (including EC)	
CO	Confidential, only for members of the consortium (including EC)	

1. Background information

1.1. Summary

This report is the official deliverable and the final report of work package 6 of the SOLUTIONS project. It has the objective to give recommendations on how to include future emerging pollutants in the management of river basins. In addition, it describes and documents the work of the Think Tank "Pollution of Tomorrow" – on which the recommendations are based.

Recommendations for the management of future emerging pollutants

With regard to the successful management of future emerging pollutants, 21 recommendations can be given. They are based on the analysis of future trends in society. They can be summarized as follows:

- Expect a future increase in pressure and change of pollutant patterns.
- Expect more demand for integrated (waste) water management.
- Include scenarios on future regional developments in river basin management plans.
- Monitor the total burden: chemicals and effects.
- Implement risk reduction and abatement measures which address multiple exposures in a solution-focused approach.
- Reduce complexity of the exposure situation.
- Track consumption of chemicals of high concern.
- Look into the future to predict future emerging pollutants at an early stage.
- Prevent from the beginning by technology assessments and benign-by-design strategies.
- Model future chemical burdens using Trend Indications (TI).
- Apply grouping approaches to avoid regrettable substitutions.
- Support information campaigns about chemicals of high concern and support behavioural changes.

These recommendations are described in detail in section 3.3 of this report.

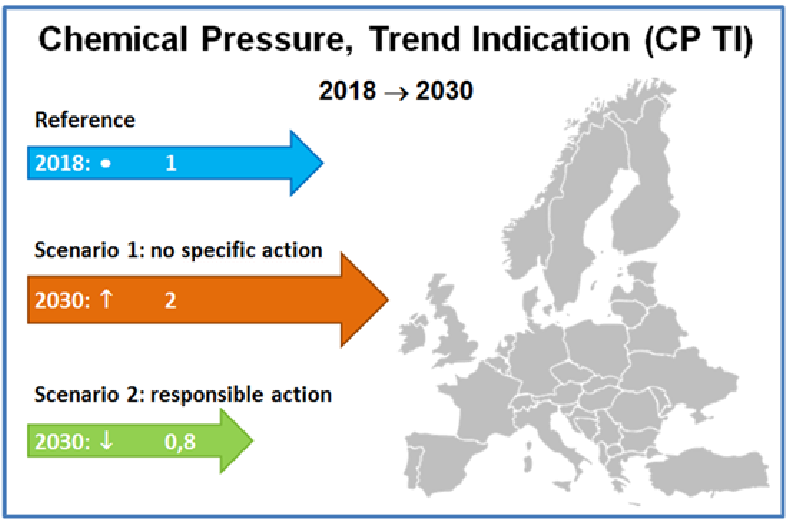
Our analysis on developments in society revealed that many changes regarding future emerging pollutants can be expected to occur. At least parts of them can be predicted. This enables a rational decision about political, societal or technical mitigation efforts to reduce the chemical pressure on river systems.

A careful monitoring of developments in society is needed to develop appropriate mitigation strategies. This will require more than end-of-pipe technologies. It is more important to make greater efforts to implement reduction and prevention measures. Horizontal instruments are needed which include approaches for the design and production of more sustainable chemicals and products. A broad variety of abatement technologies is still available (van Wezel et al. 2017). To achieve an effective and successful management of river basins, mitigation options for chemicals of emerging concern have to be applied in a prioritized and solutions-focused approach. An extended conceptual framework for the solutions-focused management of chemical pollution in European waters has been developed and applied within the

SOLUTIONS project (Munthe et al. 2017). The decision support system RiBaTox helps decision makers to find the appropriate instruments to select and implement these efforts (RiBaTox, Version 2018). It includes recommendations how to predict future chemical burdens by modelling of emission profiles and chemical footprints (Posthuma et al. 2017; Zijp et al. 2014).

1.2. [publishable] Graph

See below, Fig.1:



Further explanations to the information given in the summary:

1. **Future emerging pollutants and their management: The objectives of work package 6**

Until 2030, many developments having implications on water quality will take place in Europe and all over the world. They range from changes in our environment (e.g. increase in surface temperature) up to an increased level of specific substances or substance groups, such as sweeteners in convenience food, and to changes in legislation in different areas of the world. A successful management of river basins has to address future changes in emerging pollutants. But how can future developments affect emerging pollutants and how can this be predicted?

The aim of work package (WP) 6 of the SOLUTIONS project has been to predict future emerging pollutants (EPs) – based on scenarios for developments in society. It has furthermore the objective to discuss and assess future developments in society – regarding their potential impacts on pollutants of tomorrow. Results of this analysis and the related discussions are used

- to identify potential trends in pollutants;
- to predict consequences for risks to the aquatic environment;
- to propose specific substances/substance groups for environmental modelling and monitoring;
- to develop management options for future emerging pollutants.

2. Developments in society and implications for future emerging pollutants

Pollutant emissions in river basins change continuously. Future developments in society and in the environment can influence the pattern of pollutants in river basins. Examples for important developments are climate change, demographic change, urbanisation, technological innovations, developments in legislations and changes in consumption behaviour. Most of these developments implicitly have consequences on material flows and emissions in society. Management strategies for river basins should address such developments and their implications on emerging pollutants. But how can we predict future emerging pollutants caused by developments in society?

Numerous scenarios trying to describe future changes have been published. In most cases, implications on emerging pollutions in river basins are not taken into account in these scenarios. Nevertheless, in many cases published scenarios can be linked to knowledge regarding materials and chemicals, e.g. chemicals which are connected with specific types of land use. Based on these "extended" scenarios, a number of specific trends for emerging pollutants can already be predicted (with uncertainties). This approach helps us to gain a better picture on future pollutants. In addition, it allows an adjustment of risk management options to future developments.

3. Analysis of existing scenarios on developments in society

The study presented here is based on the hypothesis that existing scenarios on developments in society may provide useful indications for future emerging 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.

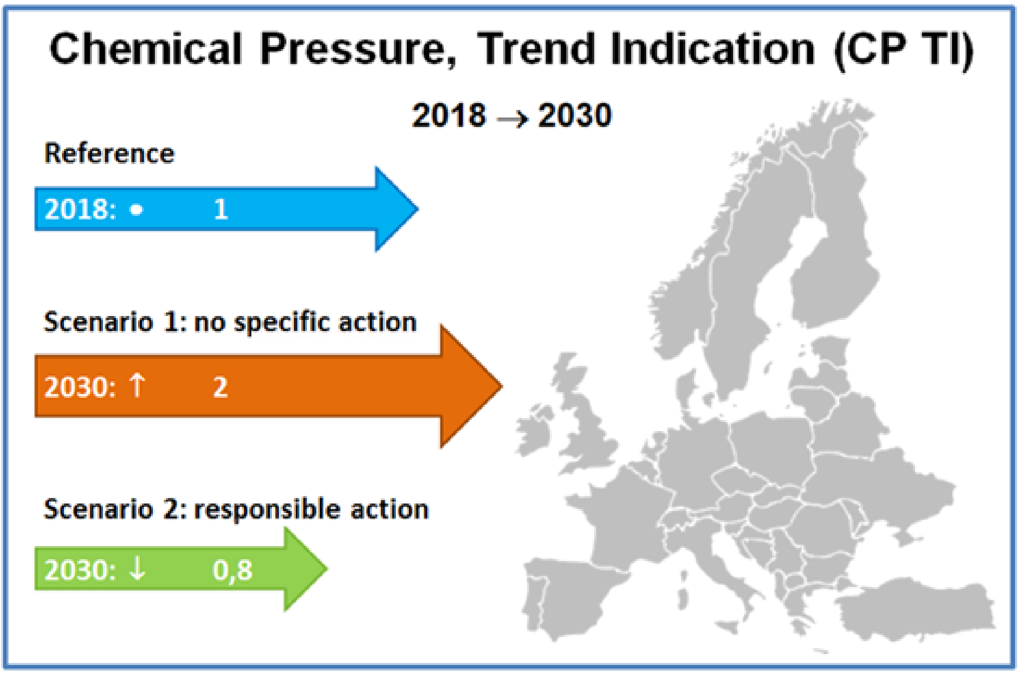
4. Trend Indications for modelling of future chemical pressures

By 2030, implications of several developments in society on the water quality of river basins will become visible. Some of these developments can be described in quantitative terms, e.g. the population growth in Europe, or the demographic change in Europe by 2020, 2030 or 2050. It is regarded as certain that some other developments will occur too, e.g. increased frequency of heavy rainfall events with an increase in emissions from chemicals used in building facades and an increase of particle emissions from traffic. For these trends, however, any quantitative assessment which could be used for emission modeling is difficult to make. At least it can be described in a qualitative way whether a decrease or an increase of emissions can be expected.

The development of emissions will be quite different for specific substances and substance groups. There are clear indications that individual substances will be introduced in the market. Some which are already in use will increase by orders of one or two magnitudes (e.g. dimethylfumarat, a pharmaceutical against multiple sclerosis, shows an increase by a factor of five). Consumption of pharmaceuticals used by elderly people will increase due to demographic change, e.g. beta blockers. In addition, several substances are expected to disappear from the market (though they may remain in stocks which have been built up in the past).

For a number of developments, which are relevant for water quality, trends are difficult to describe. Examples are the increased application of wastewater treatment technologies, the enhanced use of more sustainable chemicals, the change of use patterns by consumers as well as the occurrence of substances resulting from incomplete mineralization of chemicals in effluent treatment and processes in the environment (transformation products).

As far as possible, these developments are described in quantitative terms in this report. These data are called Trend Indications ("TI"). They are derived for individual substances and for groups of substances (e.g. 1.5 fold increase of leaching of biocides from building facades).



Scenarios for future developments (scenario 1, scenario 2) are compared with the reference situation in 2018.
Note: Numbers in the arrows are indicative for increase of chemical pressure (factor 2) and decrease of chemical pressure (factor 0.8). The real values of these numbers depend on the conditions chosen for the scenarios.

Fig. 1: Trend Indications ("TI") show in which way future developments change the chemical pressure

The trend indications developed can be used to describe different scenarios for the future development of chemical pressure in a quantitative manner. Scenarios and the related trend indications allow the inclusion of future trends in the modelling for individual sites of river basins, as well as for the calculation of chemical footprints.

Table of contents

1. Background information 3

1.1. Summary 3

1.2. [publishable] Graph 4

2. Pollution of Tomorrow: Options to act on Future Risks 14

2.1. Background and scope of this report 14

2.2. Content and structure of this report 15

3. Recommendations for the management of future emerging pollutants in river basins. 16

3.1. Developments in society which affect future emerging pollutants 16

3.2. Key findings from the analysis of developments in society 20

3.3. Recommendations: How to manage future emerging pollutants in river basins? 23

4. Pollution of tomorrow: Developments in society and future emerging pollutants 32

4.1. Introduction 32

4.2. Climate Change 37

4.2.1. Consequences of water scarcity and droughts 40

4.2.2. Consequences of torrential rainfalls and floods 41

4.2.3. Consequences of elevated water temperatures 42

4.3. Demographic Change in Europe 42

4.4. World population growth and urbanisation 44

4.5. Technological changes 45

4.5.1. Substitution of problematic substances due to regulation 46

4.5.2. Technological developments with new uses of chemicals 47

4.6. Conclusions 51

5. Developments in specific sectors and implications for future emerging pollutants 53

5.1. Sector 1: “Health Care“ 53

5.1.1. Background and objectives of the sector specific analysis 53

5.1.2. Important topics in the sector “Health Care” 54

5.1.3. Future developments in the sector “Health Care” 54

5.1.4. Key findings for the sector “Health Care” 57

5.2. Sector 2: “Food” 58

5.2.1. Background and objectives of the sector specific analysis 58

5.2.2. Important topics in the sector “Food” 58

5.2.3. Future developments in the sector “Food” 59

5.2.4. Key findings for the sector “Food” 61

5.3. Sector 3: “Cities” 61

5.3.1.	Background and objectives of the sector-specific analysis	61
5.3.2.	Important topics in the sector “Cities”	62
5.3.3.	Future developments in the sector “Cities”	62
5.3.4.	Key findings for the sector “Cities”	66
5.4.	**Sector 4: “Technologies”**	**67**
5.4.1.	Background and objectives of the sector-specific analysis	67
5.4.2.	Important topics in the sector “Technologies”	68
5.4.3.	Future developments in the sector “Technologies”	68
5.4.4.	Key findings for the sector “Technologies”	72
5.5.	**Conclusions from the sector-specific analysis**	**73**
6.	**Trend Indications to model future emerging pollutants**	**74**
6.1.	**Quantitative descriptions of future developments**	**74**
6.2.	**Developments in society, which can be described in quantitative terms**	**75**
6.2.1.	D1: Population growth in Europe	76
6.2.2.	D2: Demographic change in Europe	77
6.2.3.	D3: Age-dependent increase in prescription of drugs	80
6.2.4.	D4: Urbanisation: increase in share of population living in large cities	82
6.3.	**Trends in society which can be described more qualitatively**	**82**
6.3.1.	D5: Climate change, water scarcity and re-use of untreated waste water	82
6.3.2.	D6: Climate change and stormwater run-off	83
6.3.3.	D7: Climate change, heavy rainfalls and leaching of chemicals from building facades	83
6.3.4.	D8: Climate change, incidence of (new) diseases and use of (new) drugs	83
6.3.5.	D9: Convenience food: sweeteners and other food additives	84
6.4.	**Development which are difficult to foreseen**	**84**
6.4.1.	D10: Pesticides: changes due to climate change and land use change	84
6.4.2.	D11: New substances from new technologies and innovative materials	85
6.4.3.	D12: Abatement technologies: use and development	85
6.4.4.	D13: Substitution by less problematic substances	85
6.4.5.	D14: National reduction plans and voluntary stewardships	86
6.4.6.	D15: Design of less problematic substances (“benign by design”)	86
6.5.	**Trends for individual substances and substance groups**	**86**
6.5.1.	D16: Substances expected to decrease in volume	87
6.5.2.	D17: Substances expected to increase in volume	88
6.5.3.	D18: Data-rich substances expected to change in volume	89
6.6.	**Endpoints for effect based monitoring**	**89**
6.7.	**Summary and outlook**	**90**
7.	**Annexes**	**92**
7.1.	**Annex 1: Substances in run off from urban areas**	**92**
7.2.	**Annex 2: Trends in drug consumption worldwide (figures in million US $) (BPC 2016)**	**100**
7.3.	**Annex 3: Antibiotics for animal farming, amounts used**	**102**
7.4.	**Annex 4: Participants of the workshops**	**103**
7.4.1.	Participants of Workshop 1: Health Care	103

7.4.2. Participants of Workshop 2: Food 103
7.4.3. Participants of Workshop 3: Cities 104
7.4.4. Participants of Workshop 4: Technologies 104

8. Literature 105

List of tables

Tab. 1: Documents on developments in society and scenarios analysed (for details see chapter) 17

Tab. 2: Increase in population in Europe. Number of inhabitants in the EU 28 Member States. Population in 2030 and 2050, compared to the reference year 2015. 76

Tab. 3: Demographic change in Europe: number of inhabitants between 15 and 65 years old, and above 65, in the year 2030, compared to the reference year 2015 80

Tab. 4: Development of use of human pharmaceuticals, taking into account the increased population, demographic change and increased prescriptions. Prescribed defined daily dosages per male inhabitant per years. Numbers for 2015 and 2030 81

Tab. 5: Substances in run off from urban areas, emitted from buildings 92

Tab. 6: 50 most important human pharmaceuticals. Amounts sold globally. Figures in million US $, for the years 2014, 2020 and 2030. Source: BPC as cited in Statista (2016) 100

Tab. 7: Antibiotics used in Germany for animal farming. Consumption (in tons) from 2011 to 2015. Difference between 2011 and 2015 and decrease in %. Source: BVL (2016) 102

List of figures

Fig. 1: Trend Indications ("TI") show in which way future developments change the chemical pressure 6

Fig. 2: Implications of future developments on emerging pollutants 21

Fig. 3: Analysis of developments in society and implications for the use and emissions of chemicals 32

Fig. 4: IPCC: Change in surface temperature due to climate change. Source: IPCC (2013) 37

Fig. 5: Predictions of change in global average surface temperature. Predicitions are made for four different scenarios. Source: Alcamo et al. (2005) 37

Fig. 6: Number of people affected by extreme weather events in the UNECE region between 1970-2008 Source: UNESCO (2012) 38

Fig. 7: Overview of climate change impacts on ecosystem and biota. Source: Schiedek et al. (2007) 39

Fig. 8: Phototransformation of Diclofenac to chlorocarbazole acetic acid 39

Fig. 9: Total Population and its Demographic change in Germany until the year 2050 in millions. Source: own graph based on Kirchner and Matthes (2009) 43

Fig. 10: Population in major areas, estimates and medium scenarios: 2000-2080. Source: Lutz et al. (2008) as cited in UNESCO & Earthscan (2009) 44

Fig. 11: Structure formula of bis(2-etyhlhexyl)phthalate (DEHP) 46

Fig. 12: Structure formula of 1,2-cyclohexane dicarboxylic acid diisononyl ester (DINCH/hexamoll) 46

Fig. 13: Chemical structures of PFOS and PFOA. Source: Greenpeace (2012) 47

Fig. 14: Structural formula of the flame retardant hexabromobenzene 47

Fig. 15: Structural formula of terbutryn, a biocide used for insulation 48

Fig. 16: Structural formula of sucralose 48

Fig. 17: Structural formula of triacetin 48

Fig. 18: 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 and Lazareva (2014) 50

Fig. 19: Annual prescribing rates by therapeutic group in males from England and Wales in the year 1998. Image: Royal Commission on Environmental Pollution report on "Demographic Change and the Environment" February 2011; information used under UK Open Government Licence v3.0. 56

Fig. 20: Mobile phone subscribers per 100 inhabitants distinguishing developed and developing countries. Figures for 2005-2014 taken from International Telecommunication Union – ITU. Source: Wikimedia Commons. 69

Fig. 21: Trace elements needed for a smartphone. Source: Compound Interest (2014) 70

Fig. 22: Population growth in Europe, EU 28 member states. Source: Figures from EUROSTAT (2016) 76

Fig. 23: Demographic change for EU 28 member states. Expected distribution of inhabitants in age groups for 2080, compared to 2015. Source: EUROSTAT (2016) 78

Fig. 24: Demographic change, Europe. Distribution of inhabitants in age groups from 2015 to 2030. Source: United Nations (2015) 79

Fig. 25: 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 male inhabitants in Germany. Source: Wissenschaftliches Institut der AOK as cited by Statista (2016) 81

Fig. 26: Structure of triotropium bromide, a pharmaceutical against pulmonary diseases. Amount of use is expected decrease more than 2 fold from 2014 to 2030. 88

Fig. 27: Structure of afixaban, an anti coagulant which amounts of use are expected to increase more than 2 fold from 2014 to 2030. 88

Fig. 28: Development of the amounts used for pharmaceuticals which are of global importance. Numbers are given for the years 2014, 2020 and 2030, in billion $. Source: Statista (2016) 89

Fig. 29: Trend Indications (“TI”) as a way to show potential future developments of chemical pressure 91

List of abbreviations

ChemSEC	International Chemical Secretariat
D1.2.	Number of development which is described (D1 – D18)
DDD	Defined Daily Doses
DEHP	Diethylhexylphthalate
DINCH	1,2-Cyclohexane dicarboxylic acid diisononyl ester
EP	Emerging pollutant
EU	European Union
IPCC	Intergovernmental panel on climate change
MoA	Mode of Action
PFOS	Perfluoroctane sulfonic acid
PMOCs	Persistent and Mobile Organic Chemicals
POPs	Persistent Organic Pollutants
REACH	Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals
SVHC	Substances of very high concern listed on the REACH Candidate list
TI	Trend Indication
UNESCO	United Nations Educational, Scientific and Cultural Organization
WFD	Water Framework Directive
WP	Work Package
WWAP	World Water Scenario Project

2. Pollution of Tomorrow: Options to act on Future Risks

2.1. Background and scope of this report

Until 2030, many developments having implications on water quality will take place in Europe and all over the world. They range from changes in our environment (e.g. increase in surface temperature) up to an increased level of specific substances or substance groups, such as sweeteners in convenience food, and to changes in legislation in different areas of the world. A successful management of river basins has to address future changes in emerging pollutants. But how can future developments affect emerging pollutants and how can this be predicted?

The aim of work package (WP 6) of the SOLUTIONS project is to predict future emerging pollutants – based on scenarios for developments in society. It has furthermore the objective to discuss and assess future developments in society – regarding potential impacts on pollutants of tomorrow. Results of this analysis and the related discussions are used

- to identify potential trends in pollutants;
- to predict consequences for risks to the aquatic environment;
- to propose specific substances/substance groups for environmental modelling and monitoring;
- to develop management options for future emerging pollutants.

The analysis has been structured in four steps. As a starting point, publicly available scenarios on future developments in society have been analysed regarding implications of these developments for emerging pollutants. In a second steps, a Think Tank "Pollution of Tomorrow" consisting of internal experts from the project team and external scientists has been set up. In a third step, a sequence of four sector-specific workshops has been held. It aimed to get a deeper understanding of future use and emissions of substances in important sectors of society. Developments and consequences have been discussed in four fields:

- Public Health 2030
- Food 2030
- Cities 2030
- Technologies 2030

The content and the main findings of the workshops are documented in chapter 5 of this report. Results and experience from these workshops have been the starting point for the Think Tank "Pollution of tomorrow" for the development of recommendations on how to consider future emerging pollutants in the management of river basins. These recommendations are given in section 3.3.

2.2. Content and structure of this report

This report is the final report of work package 6 of the SOLUTIONS project. It contains recommendations on how to include future emerging pollutants in the management of river basins. In addition, it describes and documents the work of the Think Tank "Pollution of Tomorrow" – on which the recommendations are based.

Therefore, the following part of the report is divided in five chapters.

- The following chapter 3 presents the recommendations for the management of future emerging pollutants in rivers basins.
- Chapters 3 and 5 describe the underlying research activities and their results:
  - Main developments in society (chapter 3),
  - Developments in four specific sectors of society and their implications on future emerging pollutants (chapter 5) and
  - Trend Indications (TI) to include these findings into modelling of future emerging pollutants (chapter 6).

The Think Tank work addressed numerous developments in societies. Especially the discussions in the four sector-specific workshops revealed many additional details. The key findings of these workshops are documented in this report in chapter 5. More details on the presentations given at the workshops are publicly available in an additional documentation (Bunke and Moritz 2016).

3. Recommendations for the management of future emerging pollutants in river basins.

Pollutants in river basins change with time. Over the last decades, increasing numbers of emerging pollutants have been found in European waterbodies (Stefanakis and Becker 2015; Zwiener and Frimmel 2004; Navarro-Ortega et al. 2012a) and also worldwide (Noguera-Oviedo and Aga 2016; Glassmeyer et al. 2016). Around 970 substances of emerging pollutants (EPs) have been detected by the NORMAN Network group in the last 10 years (NORMAN 2016)[1]: pharmaceuticals, biocides, pesticides, industrial chemicals, consumption products and others. The pattern of emerging pollutants is quite different for different types of land use (De Zwart et al. 2018).

It has been shown that EPs affect ecosystems and human health and reduce the quality of water bodies (Stefanakis and Becker 2015; Pal et al. 2010; La Farré et al. 2008). The most important sources of EPs including hospitals, animal husbandries, companies manufacturing chemicals and drugs, wastewater treatment plants and household discharges are shown in Stefanakis and Becker (2015) and Pal et al. (2010). Inputs of *"disposal of municipal, industrial and agricultural wastes, excretion of pharmaceuticals and accidental spills"* also play an important role (La Farré et al. 2008)[2].

According to the Global Chemical Outlook (Kemf 2013) and numerous other predictions of future developments with increased chemical production and use, it is reasonable to assume that these inputs will further increase. A steep increase in production of synthetic chemicals have also been shown by Bernhardt et al. (2017). Therefore, management strategies to ensure a good water quality should endeavour to address the risks of future emerging pollutants beyond those of current concern. Existing scenarios on developments in society can give useful indications for future pollutants. These indications can be a useful starting point for designing pre-emptive management strategies intended to protect the environment even against novel compounds that may be designed and emitted in the future.

The following sections give a short overview on future developments in society and their implications on future emerging pollutants. More details on these developments and their consequences are described in chapter 3 and 5. Based on the findings documented in these chapters, 21 recommendations have been developed for a successful management of future emerging pollutants in river basins (see section 3.3).

3.1. Developments in society which affect future emerging pollutants

Recent developments in society and technology are described in a wide range of different scenarios. Scenarios on climate change are published by the Intergovernmental panel on climate change (IPCC) (IPCC 2013), the international body for assessing the science related to climate change. The WWAP (World Water Scenario Project) (Alcamo and Gallopín 2009) of UNESCO (United Nations Educational, Scientific and Cultural Organization) describe future trends in water consumption and water resources. Other scenarios such as the OECD Environmental Outlook to 2050 (OECD Publishing 2012) or

[1] 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" NORMAN (2016).

[2] A summary about emissions of emerging contaminants found in the urban water cycle is given by Pal et al. (2014).

THOUGHTS Megatrends (Schwenker and Raffel 2012) (see also Tab. 1) address demographic changes in Europe and world population growth, as well as economic and technological changes.

In order to identify trends of importance to emerging pollutants, existing scenarios for developments of society have been identified and analysed. This analysis covered 34 publicly available studies with a large number of scenarios from different sectors which are categorised and presented in Tab. 1 (for more details see chapter 4).

Tab. 1: Documents on developments in society and scenarios analysed (for details see chapter)

No.	Title	Institution / Author	Year of publication	Reference	Main topics/ Comments
1) Scenarios for middle- and long-term 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, Dave Grossmann	2013	UNEP (2013b)	Environmental change-because of two main drivers population growth and economic development
1.2	GEO 5 – Global Environmental Outlook	UNEP – United Nation Environment Programme	2012	UNEP (2012a)	Climate change Population growth Urbanisation Water scarcity - and its impacts
1.3	Millenium Ecosystem Assessment (MA)	Alcamo et al.	2003	Alcamo et al. (2003)	The four MA Scenarios and their direct and indirect drivers
1.4	Measuring Progress – Environmental Goals & Gaps	UNEP – United Nation Environment Programme	2012	UNEP (2012b)	Climate change Chemicals Waste, Water
1.5	The European Environment-State and Outlook 2010	European Environ-ment Agency, Jock Martin, Thomas Henrichs and many more	2010	EEA (2010)	Climate change Nature& 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	Rockström et al. (2009)	Seven planetary bounde-ries: 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	World Water Council	2000	World Water Council and Earthscan Publications (2000)	Future scenarios for water, water business
2.2	Charting our water future Economic framework to inform decision-making	McKinsey 2030 water resources group	2009	McKinsey 2030 Water Resources Group (2009)	Economic framework
2.3	Water in a changing world The United Nations World Water Development Report 3	UNESCO	2009	UNESCO (2009)	Drivers of water Changes of water cycle

No.	Title	Institution / Author	Year of publication	Reference	Main topics/ Comments
2.4	GLOWA - Global Change and the Hydrological Cycle	Federal Ministry of Education and Research (BMBF)	2008	BMBF (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	Alcamo et al. (2007)	Global water resources, global change, water scenarios, water availability, water stress, climate change and water
2.6	Wasser für Menschen/Wasser für Leben	UNESCO World Water assessment programme	2003	UNESCO World Water Assessment Programme (2003)	World Water assessment
2.7	Water resources across Europe — confronting water scarcity and drought	European Environ-ment Agency	2009	EEA (2009)	Future water use, main drivers
3) Developments in use and impact of chemicals					
3.1	Chemicals Action Plan 2010-2013. Safety in Denmark	Government of Denmark	2010-2013, published in 2009	Government of Denmark (2009)	Use of chemicals on a global scale
3.2	Costs on Inaction on the sound managements of chemicals	UNEP	2013	UNEP (2013a)	Impacts of chemicals for health, environmental and development effects
3.3	Harmful substances and hazardous waste	United Nation Environment Programme, Dr David Piper		UNEP (2010)	Hazardous wastes
3.4	Ökotoxikologische Bewertung von anthropogenen Stoffen	Thomas Knacker, Anja Coors, Acatech Materialien Nr. 10	2011	Knacker and Coors (2011)	Pollutants in river sytems and effects
3.5	Organische Spurenstoffe im Wasserkreislauf	Axel Bergmann, Acatech Materialien Nr. 12	2011	Bergmann (2011)	Pollutants in water cycles
4) Specific driver: climate change					
4.1	IPCC Special Report Emissions Scenarios, Summary for Policymakers	Intergovernmental panel on climate change (IPCC) Working group III	2000	Fernández-Alba (2000)	Climate change
4.2	SCARCE – Assessing and predicting effects on water quality and quantity in Iberian Rivers caused by global change	Spanish Council for Scientific Research	2009-2014	IDAEA-CSIC (n.y.)	Change of water quality/quantity
4.3	WATCH – Water and global change	Richard Harding Tanya Warnaars	2011	EU WATCH (2011)	Introduction to the achievements of the WATCH Project Water cycle and its changes
4.4	Modell Deutschland: Klimaschutz bis 2050	Prognos, Öko-Institut e.V.	2009	Kirchner and Matthes (2009)	Climate protection, focus Germany
5) Specific driver: demographic change					
5.1	Die demografische Zukunft Europas – wie sich Regionen verändern	Berlin Institut für Bevölkerung und Entwicklung	2008	Kröhnert et al. (2008)	Demographic change in Europe
5.2	OECD Environmental Outlook to 2050 – The Consequences of Inaction	Kumi.Kitamori@ oecd.org	March 2012	OECD Publishing (2012)	Demographic change and its impact

No.	Title	Institution / Author	Year of publication	Reference	Main topics/ Comments
6) Specific driver: technological / economical changes					
6.1	Trend Report Convenience – Machen Sie es sich bequem	SevenOne media	2007	Ziegler et al. (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		Schwenker and Raffel (2012)	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 (monthly magazine; assessment year: 2012)	European Commission	2012	https://ec.europa.eu/dgs/maritimeaffairs_fisheries/magazine/en	Aquaculture
7.2	The Food Gap – The Impacts of Climate Change on Food Production 2020	Liliana Hisas, Executive Director FEU-US	2011	FEU-US (2011)	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	Seitzinger et al. (2010)	Nutrient flows, MA scenarios included
8.2	World Water Vision - Making Water everybody's business	World Water Council	2000	World Water Council and Earthscan Publications (2000)	Future scenarios for water and waste water
9) Further aspects					
9.1	Late lessons from early warning: the precautionary principle 1896-2000	European Environment Agency	2002	EEA (2002)	Retrospective analysis
9.2	Towards a green economy in Europe – EU environmental policy targets and objectives 2010-2050	European Environment Agency	2013	EEA (2013)	Green economy in Europe with laws and implementations
9.3	World Social Science Report - Changing Global Environment	UNESCO	2013	UNESCO and ISSC (2013)	Social developments
9.4	zPunkt Megatrends	zPunkt GmbH	2012	zPunkt GmbH (2012)	Abstract of different megatrends

An evaluation of these documents has shown that the various scenarios on future developments can be grouped as follows:

- 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);

- 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 (e.g. 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)).

In addition to the aspects listed above, the studies analysed address a number of related aspects such as a retrospective analysis of technological changes (EEA, Late lessons from early warnings) and EU Environmental Policy Targets for 2010-2050. In some cases, studies refer to several of the items mentioned above (see comment fields in Tab. 1 above). Most of the scenarios which have been analysed refer to five important developments:

- Climate change;
- Demographic change;
- World population growth and urbanisation;
- Substitution of problematic chemicals due to regulation;
- Technological developments with new uses of chemicals.

More details on each of these developments are given in the related sections of chapter 3 of this report.

3.2. Key findings from the analysis of developments in society

The rate of change of production of synthetic chemicals is higher than the rate of change of other agents of global change, e.g. nutrient pollution. Despite this, the expected changes in production of synthetic chemicals are often not analysed or discussed in relation to scenarios on future developments (Bernhardt et al. 2017). Our analysis of important studies on developments in society confirmed this finding. Most of the developments taking place in society imply severe consequences on material flows and emissions into the environment. However, in most of the studies investigated, implications on emerging pollutions in river basins are not taken into account in the various scenarios.

Nevertheless, in many cases published scenarios can be linked to knowledge regarding materials and chemicals, e.g. chemicals which are connected with specific types of land use. Based on these “extended” scenarios, a number of specific trends for emerging pollutants can already be predicted (with uncertainties). This approach allows a discussion of risk management options for future developments.

For each of the developments described in the above mentioned scenarios, an evaluation was carried out as to whether there is a causal link to material flows and emissions of new or already known substances to the environment. The evaluation consisted of three elements:

1. an assessment of the direct and indirect consequences of the development (without sectoral differentiation);
2. an analysis of future trends in specific sectors;
3. an evaluation whether specific chemicals or groups of chemicals are affected.

These three elements are illustrated in Fig. 2.

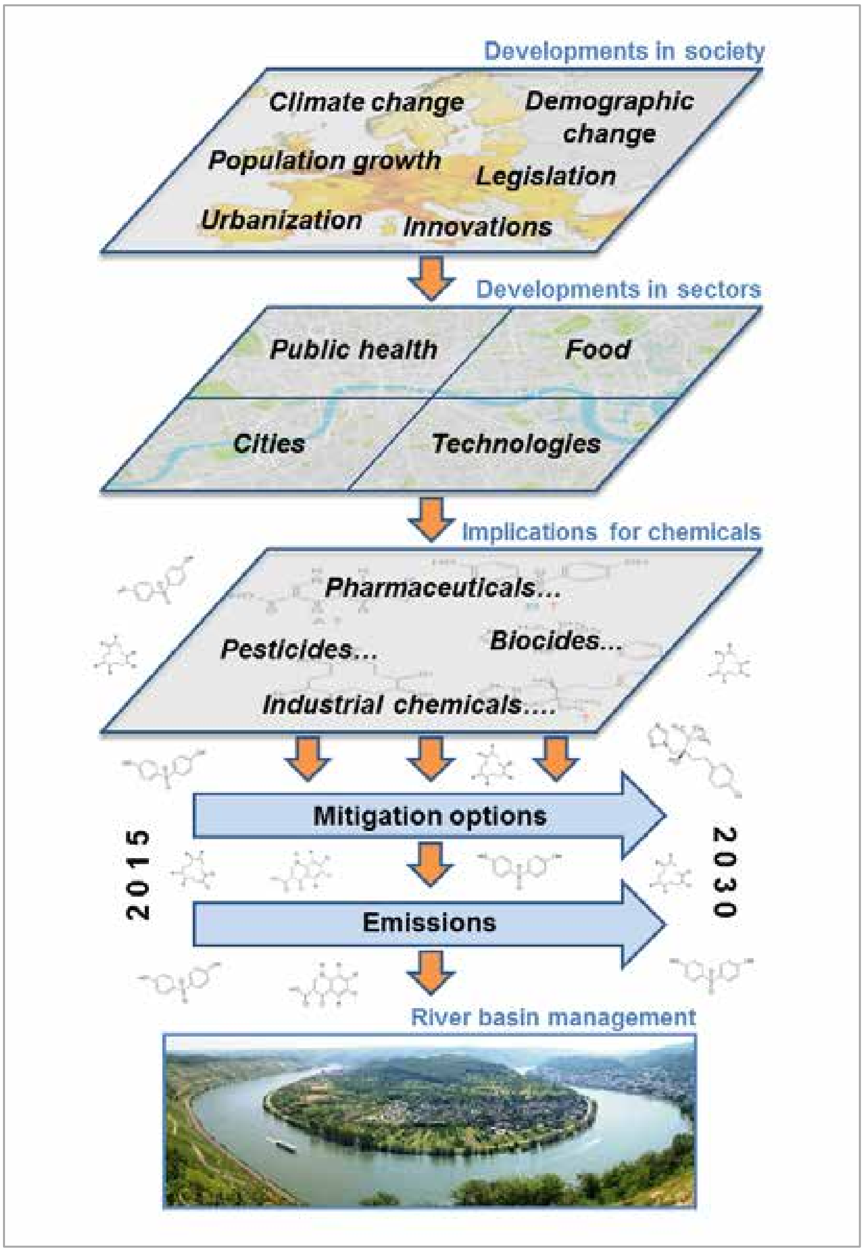


Fig. 2: Implications of future developments on emerging pollutants

The figure illustrates that developments in society (first level) and in sectors of society (second level) influence use and emissions of chemicals and groups of chemicals (third level). These emissions affect future water quality in river basins.

The results of this evaluation are described in detail in chapter 3 and 5 of this report. The results can be summarized in the following ten key findings (further detailed findings are given in chapter 3 and 5).

- Many different developments in society are on-going in Europe with implications on future emerging pollutants in river basins. Some implications are apparent (e.g. increase of consumption of drugs more frequently described to elderly people e.g. beta blockers, due to demographic change). Others are more complex (e.g. change in disease patterns due to climate change).
- Climate change has numerous impacts on future emerging pollutants. The consequences are an increase in surface temperature, extreme weather events, droughts, floods, torrential rainfalls, periods with high temperature and storm events (Sjerps et al. 2016). They cause an increase in chronic diseases already common in the Northern Hemisphere as well as an increase in pathogens and invertebrate vectors. Climate change affects transport, transfer and transformation of chemicals in the environment. Beyond this, changes in land use, increases of water scarcity and increased re-use of untreated waste water are important developments linked to climate change.
- Demographic change could impair EPs. Due to the higher life expectancy in the next decades, the total amount of pharmaceuticals circulating in sewage treatment plants and in river basins is most likely to increase. This is expected especially for therapeutic groups which are mainly used by elderly people, such as lipid regulators (e.g. Bezafibrates), anti-inflammatory drugs (e.g. diclofenac) and diabetic medication, antibiotics, X-ray contrast media and antineoplastics.
- Urbanisation as well as urban sprawl can lead to an increase of emerging pollutants. Problems as waste water, waste management and also traffic regulation in cities will gain in importance. Ground sealing blocks the percolation of rainwater and snowmelt into soil and increases the frequency and intensity of floods. Floods can transport pesticides, surfactants, pharmaceuticals and other emerging pollutants to river systems.
- New compounds for novel technologies such as dye-sensitized solar cells will come up while many already existing chemicals will be used in parallel. Thus, future patterns of pollution – in 2030 and onwards – will be a complex mixture of legacy chemicals, “forgotten” chemicals which are released decades after their use, and new emerging substances.
- At present, it is still too early to ascertain whether a significant increase in mitigation measures will take place by 2030. Under these circumstances, it is reasonable to assume, however, that the total chemical burden, the emissions of future emerging pollutants as well as the complexity of the pattern of pollutants in river basins will further increase.
- The development of future emissions will be quite different for different substances and substance groups. New individual substances will be introduced into the market and some which are already in use will increase by orders of one or two magnitudes (e.g. dimethylfumarat, a pharmaceutical

against multiple sclerosis, shows an increase by a factor of five). In addition, other substances are expected to disappear from the market, e.g. specific pesticides which are subject of reduction plans. Some of the legacy chemicals are still relevant as future pollutants because they may remain stocked in products.

- Strict regulatory control of individual chemicals will cause a decrease in the use of these chemicals and a parallel increase of substitutes (which are not yet regulated). At present, regrettable substitution often takes place introducing new emerging pollutants with similar hazardous properties and it takes several years to restrict the substitutes. Tools to identify safe alternatives are available (Cohen et al. 2018), however, often they are not used. Only in four Nordic countries national product registers are in place that allow to detect changes in substitution patterns.
- Scenarios on societal developments will help to identify future changes in pollution. At least in some fields, specific trends for important groups of substances and for single substances can be predicted (with uncertainties). In many cases it is possible to derive at least a qualitative trend indications ("TI") (see chapter 6). They assess for a given development in society whether it is reasonable to assume an increase or a decrease of emissions of chemicals to the environment. In some cases, quantitative trend indications can be developed (e.g. expected increase of SVHC based on total use data for the time period between 2010 and 2015).
- Instruments and tools for abatement and mitigation are constantly subject to further development. If implemented on a broad scale, nearly all impacts could be mitigated by an efficient combination of measures addressing the whole life cycle of chemicals and products. This requires political, societal and 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.

More specific findings resulted from the analysis of four important sectors of society: public health, food, cities and technologies. They are documented in chapter 5 of this report.

Based on these findings, a number of recommendations for a successful management of future emerging pollutants in river basins can be derived.

3.3. Recommendations: How to manage future emerging pollutants in river basins?

The following recommendations represent conclusions for a successful management of future emerging pollutants in river basins. They are based on the analysis of developments in society and their implications for emerging pollutants.

Note: The following recommendations are quantitative. Within the project SOLUTIONS information on tools have been provided which allow to quantify future trends. Such tools can help to transform the following recommendations into quantitative objectives for a specific region or a specific river basin. They refer to the modelling of chemicals and risk, to the identification of priority pollutants and priority mixtures, to monitoring tools such as effect based monitoring, to a solution solution-focused management of chemicals and risk, to abatement and mitigation options and other important elements for the river basin management of emerging pollutants. Comprehensive information on these elements is provided in a user-friendly form in the decision support system RiBaTox. It is the main result of the SOLUTIONS project. It helps decision makers to find the appropriate instruments for the management of future pollutants in river basins and to implement the necessary efforts (RiBaTox, Version 2018).

-1- INCREASE IN PRESSURE AND CHANGE OF POLLUTANT PATTERN

Recommendation 1: Expect a future increase of the chemical burden in European river basins.

Several developments in society will lead to increased emissions of future emerging pollutants to river basins. Examples are increased releases of biocides from building facades due to an increase in heavy rainfall events, increase of drugs against antiprotozoals due to an increase in the incidence of vector-borne diseases and an increase in emissions from the use of rodenticides in urban areas due to the growth of cities. This increase refers to the total emission, to the number of substances as well as to the complexity of the pollution pattern. Concentrations are expected to temporarily increase as a result of more extreme low river discharges.

Recommendation 2: Expect a future decrease of chemicals which are under strict regulatory control.

A number of industrial chemicals which have been identified as substances of very high concern already exhibit decreasing concentrations in environmental media (e.g. DEHP and PFOS). It can be expected that this trend will continue. If such chemicals have been used in articles or buildings in the past, larger stocks of these chemical may still be present in the urban environment. The REACH candidate list contains the substances that 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. This development is supported by an increasing debate in society on safety of chemicals – as one reason to place more chemicals under strict regulatory control, e.g. endocrine disrupting chemicals.

Recommendation 3: Expect a future increase of substitutes for strictly regulated chemicals.

In general, strictly regulated substances are replaced by other chemicals which have a similar function. Only in rare cases, changes in product design are made to avoid the use of a substance at all. In many cases, these substitutes also have problematic properties and can become future emerging pollutants. For several of such regrettable substitutes, increasing concentrations in the environment are found, e.g. for DINCH and Bisphenol S.

-2- MORE DEMAND FOR INTEGRATED (WASTE) WATER MANAGEMENT

Recommendation 4: Enlarge the capacity of integrated water management systems in urban areas.

The on-going growth of cities will lead to an increase in soil sealing in these urbanized areas. Climate change is expected to cause an increase in the frequency of heavy rain falls and stormy weather events in some regions, and increased droughts in others. Untreated stormwater run-off has been found as an important source of urban pollutants: suspended solids, heavy metals, traffic-related micropollutants, plasticisers, flame retardants and biocides. A combination of centralized and de-centralized technologies will be required to manage these emissions.

Recommendation 5: Improve water management systems in rural areas

In regions with climate induced increases in precipitation, an increase of surface water levels with possible flooding of sewage plants or extruded agriculture land can be expected. It is becoming increasingly important to implement an advanced stormwater management in order to avoid an untreated overflow of sewage treatment plants and to prevent mobilization of pesticides from agricultural land.

Recommendation 6: Prevent /avoid re-use of untreated waste water in areas of water scarcity

Climate change is expected to cause an increase of areas and time periods with water scarcity. As a consequence, the need to use wastewater for irrigation will increase. This leads to an additional emission of contaminants to river basins, if the wastewater is not treated properly. Purification of waste water before re-use will become an even greater challenge in the years to come. In addition, if urban areas are adapted to a more circular economy and higher re-use rates of water, this adaptation should include safe and circular design to prevent risk cycling during the re-use.

-3- REGIONAL DEVELOPMENT PLANNING

Recommendation 7: Include scenarios on future regional developments in the river basin management plans.

Climate change as well as urbanisation will result in changes in land use. Emission profiles from urban areas are quite distinct from rural areas. Changes in agricultural farming will lead to changes in the emission of pesticides and other agrochemicals which greatly influence the chemical burden and the appropriate abatement measures. The magnitudes of these effects strongly depend on regional conditions. Regional development plans should include predictions of these developments in order to find the most appropriate management option to avoid future emerging pollutants.

-4- MONITOR THE TOTAL BURDEN: CHEMICALS AND EFFECTS

Recommendation 8: Use monitoring approaches which allow an assessment of the total chemical burden and its effects.

The complexity of the pattern of pollutants will further increase in the future (see recommendation 1). Therefore, monitoring approaches are needed, which allow an integrated assessment of the total chemical burden and its effects. Advanced effect monitoring could address specific biological endpoints as well as modes of actions which are expected for future emerging pollutants. The expected increase of emissions of pharmaceuticals should stimulate the monitoring of drug-specific endpoints relevant for both human and ecosystem health, e.g. behavioural changes in fish.

-5- RISK REDUCTION AND ABATEMENT

5.a PRIORITY SETTING IN RISK REDUCTION

Recommendation 9: Identify drivers of chemical pressure and predict their future development.

Due to a continuous increase in the complexity of the exposure situation, priority setting in risk reduction is required. In general, emission profiles of cities, industrial areas and of rural areas are dominated by a limited number of chemicals. Identification of these drivers can support the application of efficient abatement strategies. Future development of these drivers should as far as possible be predicted by quantitative trend indications. The placement of risk reduction measures should relate to the expected future placement of critical or susceptible types of water use.

5.b ABATEMENT TECHNOLOGIES, SOLUTIONS ORIENTED APPROACH

Recommendation 10: Apply abatement technologies in a solution-focused approach to also take into account future emerging pollutants.

Complex patterns of pollutants need an integrated approach for emission reduction. The selection of tools to identify and prioritise pollutants for further action should be guided by the regional or local chemical fingerprints, not on individual substances. Furthermore, risk reduction measures are required to address **multiple exposure**s to legacy, present and emerging pollutants in a solution-focused approach (Munthe et al. 2017). Site-specific abatement packages are required to address the priority pollutants on a regional or local scale (van Wezel et al. 2017).

The following recommendations are addressed to competent national authorities and research institutions.

-6- REDUCE COMPLEXITY

Recommendation 11: Support strategies to reduce the number and the total amount of critical substances

Many technologies are at hand to reduce the total amount of a substance needed for a given purpose, e.g. precision farming and personalized medicine. These options should be supported to reduce the quantity of emissions and the total burden of chemicals in river basins. I addition to the reduction of the total amount used, attention should be given to reduce the complexity of the pollutant pattern by minimizing the number of problematic substances which are used.

-7- TRACK CONSUMPTION OF CHEMICALS OF HIGH CONCERN

Recommendation 12: Monitor the total volumes of critical substances in use

Data on the total use volume and the related uses can be drawn upon to predict critical emissions. Such data (as from the Nordic product registers) furthermore allow us to monitor the success of substitution measures over time. National or EU-wide use data should be requested and used to monitor high priority groups of chemicals. Such data can be aggregated to obtain the total burden related to substances or substance groups with specific modes of actions or with critical properties (e.g. persistent mobile organics) and to predict transformation products. For critical substances it would be important to better understand main drivers of consumption (e.g. the role of marketing) and options to influence these drivers.

-8- LOOK INTO THE FUTURE: HORIZON SCANNING AND MORE. WHAT COMES UP?

Recommendation 13: Predict future emerging pollutants

By 2030, several developments in society will have severe implications on the water quality of river basins. An analysis of these developments provides important indications for future emerging pollutants, e.g. an increase of rodenticides in urban areas. Therefore, developments in society should be systematically analysed, as they are able to reveal future EP on the basis of which water management strategies can be adjusted. Horizon scanning, sector-specific analyses and substitution checks for strictly regulated substances are important instruments available for the prediction of future Emerging Pollutants and the decision which of them should be used.

Recommendation 14: Screen on-going technological innovations regarding new materials and chemicals.

The majority of innovations are based on new materials. The horizon scanning of technologies helps identify new materials and chemicals which can be expected to be used in the future. This work should be accomplished together with materials scientists, involving the industries involved in these developments at an early stage.

-9- PREVENT FROM THE BEGINNING: CONDUCT TECHNOLOGY ASSESSMENTS AT AN EARLY STAGE /DESIGN BY BENIGN

Recommendation 15: Conduct risk and benefit assessments of new technologies at an early stage.

New technologies often entail the use of new chemicals. However, an assessment of potential releases and an identification of more sustainable chemicals has been carried out only very rarely in the early stages of technology development or product development. At a later point in the development process, it can be more difficult to replace problematic substances than in the beginning. Therefore such an assessment should become a key step early in the design process. If risks are checked in advance and minimized from the very beginning, a powerful sales argument for novel technologies could be built up. The Risk Analysis and Technology Assessment – termed RATA – is an example for such an early assessment (van Wezel et al. 2018). It includes a specific tool set to check new business ideas for risks – at the very beginning.

Recommendation 16: Support design and use of better degradable and more sustainable chemicals.

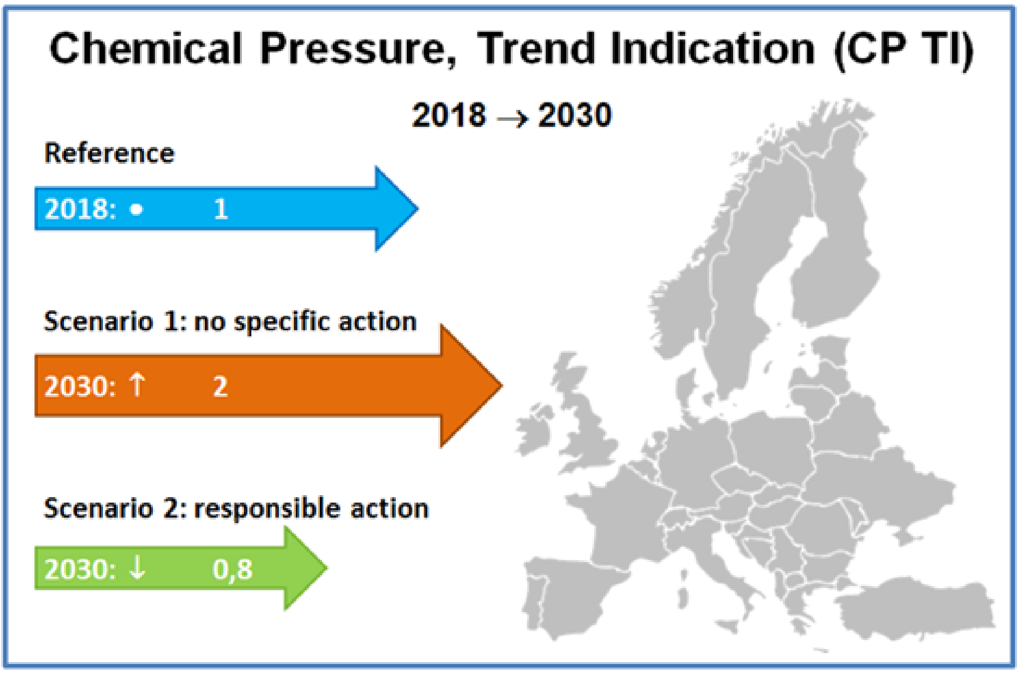
The production and use of more sustainable chemicals should be promoted. The use of better degradable and less hazardous substances avoids problematic emissions at an early stage. This contributes significantly to the avoidance of complex emissions (Arp et al. 2017).

-10- MODEL FUTURE CHEMICAL BURDENS

Recommendation 17: Use quantitative trend indications to model and to predict future emerging pollutants.

Due to differences in land use, population density, climate conditions and other factors, large regional differences can be expected in future chemical burdens (Lindim et al. 2015). Impacts of developments in society on future emerging pollutants can be integrated in exposure and risk modelling. Examples are predictions on demographic change and changes in the consumption pattern of pharmaceuticals during their life-time. The modelling of future emerging pollutants contributes to the identification of appropriate management measures and strategies. Two approaches can be used to model future emerging pollutions: site-specific modelling of future pollutants and chemical footprints.

Site-specific modelling can use Trend Indications (TIs) to show in which way future developments will change chemical pressure. Trend Indications also illustrate the effects of different options to act (see the following figure).



Scenarios for future developments (scenario 1, scenario 2) are compared with the reference situation in 2018.
Note: Numbers in the arrows are indicative for increase of chemical pressure (factor 2) and decrease of chemical pressure (factor 0.8). The real values of these numbers depend on the conditions chosen for the scenarios.

Fig. 1, rept.: Trend Indications ("TI") show in which way future developments change the chemical pressure

To model future chemical burdens, scenarios that are combinations of several trends described above will be developed. They furthermore include assumptions on emission reduction measures taken and on their efficiency.

Chemical footprints visualize chemical burdens, based on the modelling of complex mixtures of pollutants. Chemical footprints are calculated and discussed in relation to planetary boundaries. These calculations reveal the main drivers for chemical burdens. Using the Trend Indications described above, an analysis how developments in society affect these drivers can be made. Scenarios can reflect important objectives as circular economy and different options to reach these goals. This makes it possible to compare present and future chemical burdens – including future emerging pollutants. (Posthuma et al. 2017; Zijp et al. 2014). See also section 6.7 for more details on the use of Trend Indications in modelling.

-11- GROUPING AND FUNCTIONAL SUBSTITUTES

Recommendation 18: Avoid regrettable substitution by grouping approaches.

Problematic substances are frequently replaced by substances with other problematic properties. Future technological progress may help identify suitable alternatives for emerging pollutants that are currently used such as phthalates, PFCs, flame retardants or nanomaterials. These new substances, however, can also have negative impacts on the ecosystem.

Therefore, structurally related substances with similar problematic properties should be placed together in a group. Voluntary activities as well as – if necessary – regulatory actions should address such groups of substances instead of focussing on single substances. Chemicals within a group can have similar structural characteristics or can show the same mode of action (MoA). Grouping helps avoid regrettable substitutions (by chemicals of the same groups) and support functional substitutions.

Recommendation 19: Support identification and use of functional substitutes.

Common substitutes for problematic substances should be systematically assessed regarding their hazard potential and related risks. For important chemicals that are strictly regulated, the development of less hazardous substitutes or non-chemical solutions should be stimulated.

-12- INFORMATION AND BEHAVIOURAL CHANGES

Recommendation 20: Inform downstream users about critical substance properties and critical substances

Downstream users of chemicals have several options to reduce their emissions. They need to be provided with clear information as to which substances are of concern in terms of water quality. For substances of very high concern, identified under REACH, this information is available. For other chemicals with problematic properties such information is still missing, e.g. for the group of persistent and mobile organic chemicals (PMOCS) and the group pf persistent, mobile and toxic chemicals (PMT substances). It is very important for formulators and end users of chemicals to be fully informed about the type of substances which belong to these groups – and should be replaced by less problematic ones.

Recommendation 21: Support awareness-raising actions for consumers

Remarkable reduction of critical emissions could be brought about by behavioural changes, e.g. in drug consumption. Industrialized countries show an increasing prevalence of obesity, diabetes, cancer and depression. This usually results in an increased use of the related pharmaceuticals. In the newly industrialized countries an easier access to pharmaceuticals is given. Novel chemical treatments could support a more effective use of pharmaceuticals with lower emission levels. Between various countries, however, there are large differences regarding the consumption patterns of drugs. Higher emissions are found in the case of over-the-counter drugs which do not require a prescription. Awareness-raising actions for consumers are considered to provide a significant potential for emission reduction in order to support behavioural changes.

3.4. Outlook

Our analysis on developments in society revealed that many changes can be expected that regard future emerging pollutants. It is considered very likely that at least a part of them will occur. This makes it possible to decide on political, societal or technical mitigation efforts to reduce the chemical pressure on river systems.

A careful monitoring of developments in society is needed to develop appropriate mitigation strategies. End-of-pipe technologies, however, are not sufficient to achieve this aim. There is a need for enhanced input reduction and prevention measures. Furthermore, there is a need for horizontal instruments which include approaches for the design and production of more sustainable chemicals and products. A broad variety of abatement technologies is still available (van Wezel et al. 2017). To achieve an effective and successful management of river basins, mitigation options for chemicals of emerging concern have to be applied in a prioritized and solution-focused approach. An extended conceptual framework for the solution-focused management of chemical pollution in European waters has been developed and applied within the SOLUTIONS project (Munthe et al. 2017). The decision support system RiBaTox helps decision makers to find the appropriate instruments to select and implement these efforts (RiBaTox, Version 2018). It includes recommendations how to predict future chemical burdens by modelling of emission profiles and chemical footprints (Zijp et al. 2014; Posthuma et al. 2017).

More details on the analysis of scenarios and the work done in the Think Tank “Pollution of Tomorrow” are described in the following chapters 3 to 6.

3.5. Addition: From single substances to emission profiles.

Chemical finger prints: Complex consumption patterns of products and emissions from buildings cause complex mixtures which are emitted by cities. At present, a reduction strategy is characterised by a chemical-by-chemical approach with a focus on concentrations and on current priorities. In an alternative approach, the emission of a city can be considered as a whole – as a complex chemical mixture. In this respect, cities represent a typical emission entity which is different from other entities such as agricultural land.

Certain types of chemicals (“signatures”) are dominant for specific emission entities. Urban runoffs, domestic discharges and agricultural runoffs have their own typical chemical finger print. Their emission profiles are different in space and time. Urban runoffs show peaks due to rain. Domestic emissions are at a constant level according to the per capita water use. Agricultural emissions vary depending on seasons and crop matter.

If we take a closer look at the emission fingerprints it becomes clear that they can be dominated by agriculture, emissions from wastewater treatment plants or by urban runoff. For each of the three entities, mitigation strategies that take into account the specific chemical finger prints can be developed.

Management strategies will be different for fingerprints that are either dominated by urban or domestic emissions (e.g. with cleaning products, personal care products, pharmaceuticals) or by agricultural emissions (due to insecticides, herbicides, fertilizers and veterinary drugs). The identification of the typical fingerprint can contribute to the setting of priorities on specific groups of chemicals – to reduce the impact on aquatic ecosystems in a more efficient way. An analysis of emission profiles instead of single substance monitoring could support effective risk management measures, guided by priority pollutants and priority impacts (Posthuma et al. 2017).

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

Emerging pollutants 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?

This chapter gives an overview on important developments in society and implications for future emerging pollutants. The overview is based on an analysis of more than 30 publicly available studies with scenarios on future developments. In the first step, an overview about existing scenarios and their main findings on developments in society has been prepared. In the second step it has been assessed whether and which implications can be seen from the scenarios for future emerging pollutants.

4.1. Introduction

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.

The work package on future pollutants in the SOLUTIONS project addresses the question whether predictions of changes in society can be used as an information source for pollutants of tomorrow. The following graph depicts the main approach used to identify future emerging pollutants.

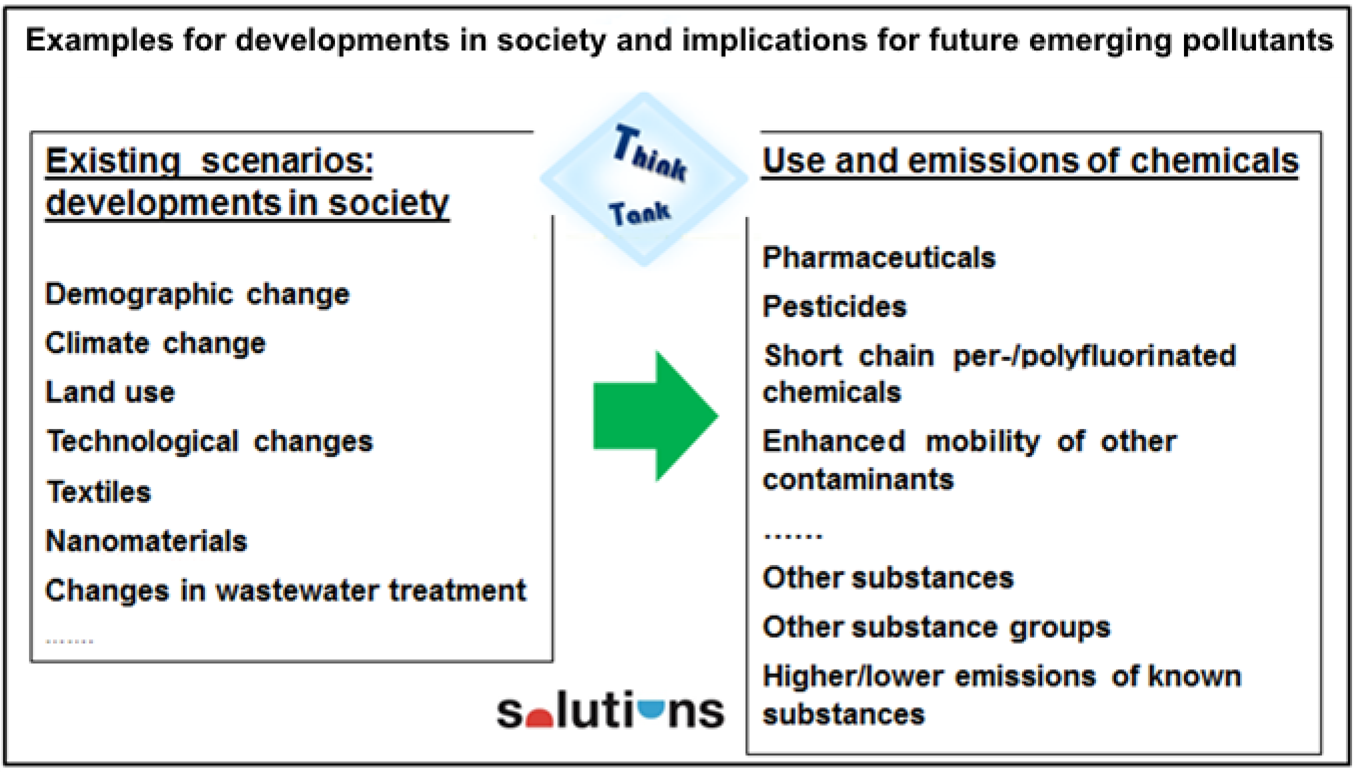


Fig. 3: Analysis of developments in society and implications for the use and emissions of chemicals

The analysis is based on the hypothesis that knowledge on potential future developments can give indications for the future use and emissions of chemicals.

In order to identify trends with importance for emerging pollutants, existing scenarios for developments of society have been identified and analysed. This analysis referred to 34 publicly available studies on developments in society with a large number of scenarios from different sectors. The studies address a broad range of topics. Scenarios on climate change are published by the Intergovernmental panel on climate change (IPCC) (IPCC 2013). Scenarios from UNESCO (United Nations Educational, Scientific and Cultural Organization) in WWAP (World Water Scenario Project) (Alcamo and Gallopín 2009) refer 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. The following table lists the studies which have been analysed for the overview on future developments.

Tab. 1, rept.: Documents on developments in society and scenarios analysed

No.	Title	Institution / Author	Year of publication	Reference	Main topics/ Comments
1) Scenarios for middle- and long-term 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, Dave Grossmann	2013	UNEP (2013b)	Environmental change- because of two main drivers population growth and economic development
1.2	GEO 5 – Global Environmental Outlook	UNEP – United Nation Environment Programme	2012	UNEP (2012a)	Climate change Population growth Urbanisation Water scarcity - and its impacts
1.3	Millenium Ecosystem Assessment (MA)	Alcamo et al.	2003	Alcamo et al. (2003)	The four MA Scenarios and their direct and indirect drivers
1.4	Measuring Progress – Environmental Goals & Gaps	UNEP – United Nation Environment Programme	2012	UNEP (2012b)	Climate change Chemicals Waste, Water
1.5	The European Environment-State and Outlook 2010	European Environ-ment Agency, Jock Martin, Thomas Henrichs and many more	2010	EEA (2010)	Climate change Nature& 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	Rockström et al. (2009)	Seven planetary bounde-ries: 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	World Water Council	2000	World Water Council and Earthscan Publications (2000)	Future scenarios for water, water business
2.2	Charting our water future Economic framework to inform decision-making	McKinsey 2030 water resources group	2009	McKinsey 2030 Water Resources Group (2009)	Economic framework

No.	Title	Institution / Author	Year of publication	Reference	Main topics/ Comments
2.3	Water in a changing world The United Nations World Water Development Report 3	UNESCO	2009	UNESCO (2009)	Drivers of water Changes of water cycle
2.4	GLOWA - Global Change and the Hydrological Cycle	Federal Ministry of Education and Research (BMBF)	2008	BMBF (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	Alcamo et al. (2007)	Global water resources, global change, water scenarios, water availability, water stress, climate change and water
2.6	Wasser für Menschen/Wasser für Leben	UNESCO World Water assessment programme	2003	UNESCO World Water Assessment Programme (2003)	World Water assessment
2.7	Water resources across Europe — confronting water scarcity and drought	European Environ-ment Agency	2009	EEA (2009)	Future water use, main drivers
3) Developments in use and impact of chemicals					
3.1	Chemicals Action Plan 2010-2013. Safety in Denmark	Government of Denmark	2010-2013, published in 2009	Government of Denmark (2009)	Use of chemicals on a global scale
3.2	Costs on Inaction on the sound managements of chemicals	UNEP	2013	UNEP (2013a)	Impacts of chemicals for health, environmental and development effects
3.3	Harmful substances and hazardous waste	United Nation Environment Programme, Dr David Piper		UNEP (2010)	Hazardous wastes
3.4	Ökotoxikologische Bewertung von anthropogenen Stoffen	Thomas Knacker, Anja Coors, Acatech Materialien Nr. 10	2011	Knacker and Coors (2011)	Pollutants in river sytems and effects
3.5	Organische Spurenstoffe im Wasserkreislauf	Axel Bergmann, Acatech Materialien Nr. 12	2011	Bergmann (2011)	Pollutants in water cycles
4) Specific driver: climate change					
4.1	IPCC Special Report Emissions Scenarios, Summary for Policymakers	Intergovernmental panel on climate change (IPCC) Working group III	2000	Fernández-Alba (2000)	Climate change
4.2	SCARCE – Assessing and predicting effects on water quality and quantity in Iberian Rivers caused by global change	Spanish Council for Scientific Research	2009-2014	IDAEA-CSIC (n.y.)	Change of water quality/quantity
4.3	WATCH – Water and global change	Richard Harding Tanya Warnaars	2011	EU WATCH (2011)	Introduction to the achievements of the WATCH Project Water cycle and its changes
4.4	Modell Deutschland: Klimaschutz bis 2050	Prognos, Öko-Institut e.V.	2009	Kirchner and Matthes (2009)	Climate protection, focus Germany

No.	Title	Institution / Author	Year of publication	Reference	Main topics/ Comments
5) Specific driver: demographic change					
5.1	Die demografische Zukunft Europas - wie sich Regionen verändern	Berlin Institut für Bevölkerung und Entwicklung	2008	Kröhnert et al. (2008)	Demographic change in Europe
5.2	OECD Environmental Outlook to 2050 – The Consequences of Inaction	Kumi.Kitamori@ oecd.org	March 2012	OECD Publishing (2012)	Demographic change and its impact
6) Specific driver: technological / economical changes					
6.1	Trend Report Convenience - Machen Sie es sich bequem	SevenOne media	2007	Ziegler et al. (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		Schwenker and Raffel (2012)	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 (monthly magazine; assessment year: 2012)	European Commission	2012	https://ec.europa.eu/dgs/ maritimeaffairs_fisheries/ magazine/en	Aquaculture
7.2	The Food Gap – The Impacts of Climate Change on Food Production 2020	Liliana Hisas, Executive Director FEU-US	2011	FEU-US (2011)	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	Seitzinger et al. (2010)	Nutrient flows, MA scenarios included
8.2	World Water Vision - Making Water everybody's business	World Water Council	2000	World Water Council and Earthscan Publications (2000)	Future scenarios for water and waste water
9) Further aspects					
9.1	Late lessons from early warning: the precautionary principle 1896-2000	European Environ-ment Agency	2002	EEA (2002)	Retrospective analysis
9.2	Towards a green economy in Europe – EU environmental policy targets and objectives 2010-2050	European Environ-ment Agency	2013	EEA (2013)	Green economy in Europe with laws and implementations
9.3	World Social Science Report - Changing Global Environment	UNESCO	2013	UNESCO and ISSC (2013)	Social developments
9.4	zPunkt Megatrends	zPunkt GmbH	2012	zPunkt GmbH (2012)	Abstract of different megatrends

The scenarios can be grouped as follows:

- 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).
- 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 (e.g. 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)).

In addition, to the aspects listed above, the studies analysed address a number of related aspects such as a a retrospective analysis of technological changes (EEA, Late lessons from early warnings) and EU Environmental Policy Targets for 2010-2050. In some cases, studies refer to several of the items mentioned above (see comment fields in Tab. 1).

The rate of change of production of synthetic chemicals is higher than the rate of change of other agents of global change, e.g. nutrient pollution. Nevertheless synthetic chemicals are less intense discussed in scenarios on future developments (Bernhardt et al. 2017). Our analysis of important studies on developments in society confirmed this finding. Most of the developments taking place in society imply severe consequences on material flows and emissions into the environment. However, in most of the studies investigated, implications on emerging pollutions in river basins are not taken into account in the various scenarios.

The analysis shows that the number of studies addressing potential developments in society is quite large. 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, in the following, an overview is given on most important developments in society which are predicted in a broad range of scenarios. Indications for implications of these developments for future emerging pollutants are described. Most of the scenarios which have been analysed refer to the following five important developments:

- Climate change (see section 4.2);
- Demographic change in Europe (see section 4.3);
- World population growth (see section 4.4;
- Substitution of problematic chemicals due to regulation (see section 4.5.1);

– Technological developments with new uses of chemicals (see section 4.5.2).

These developments are described in the following sections.

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. Fig. 4 shows the observed global change in surface temperature from 1901–2012.

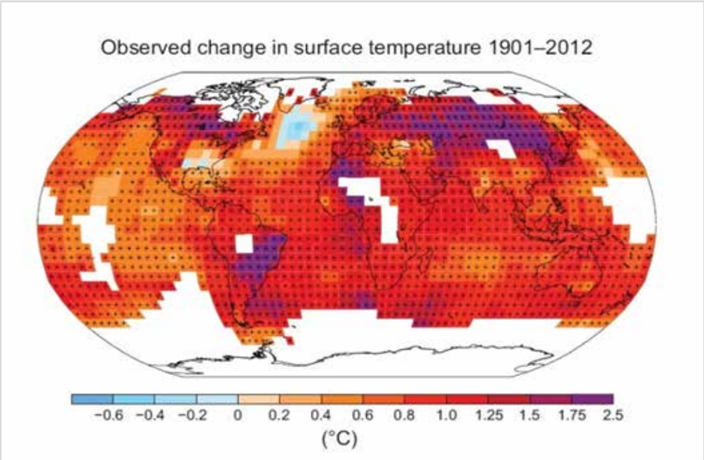


Fig. 4: IPCC: Change in surface temperature due to climate change. Source: IPCC (2013)

Fig. 5 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 et al. (2005).)

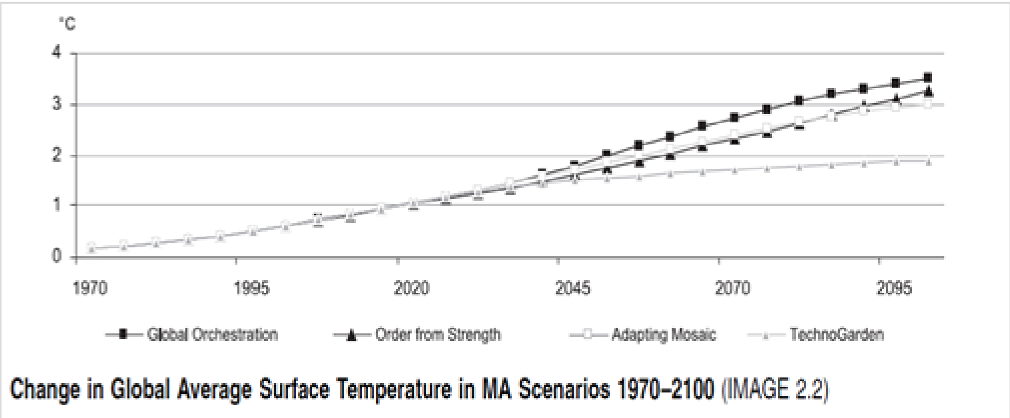


Fig. 5: Predictions of change in global average surface temperature. Predicitions are made for four different scenarios. Source: Alcamo et al. (2005)

"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 et al. 2006; Böhme et al. 2005). Fig. 6 shows the number of people affected by extreme weather events. Fig. 7 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.

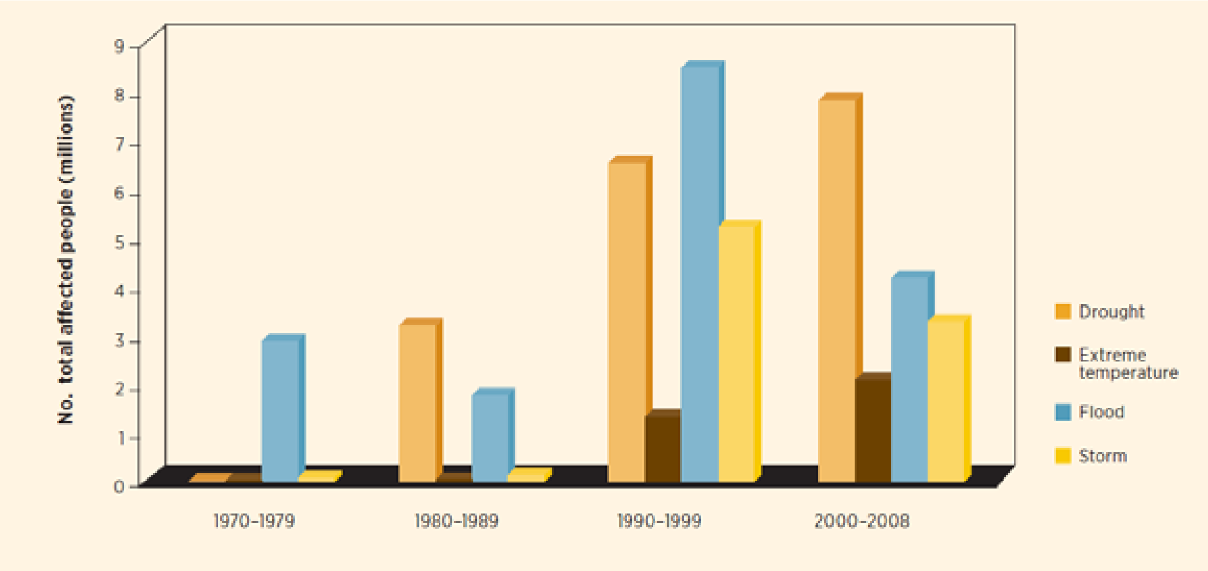


Fig. 6: Number of people affected by extreme weather events in the UNECE region between 1970-2008 Source: UNESCO (2012)

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 change"*. 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. Ribas et al. (2010) also predicts that the average river discharge will decrease. Water temperature and the frequency of large floods will increase in future (Ribas et al. 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.

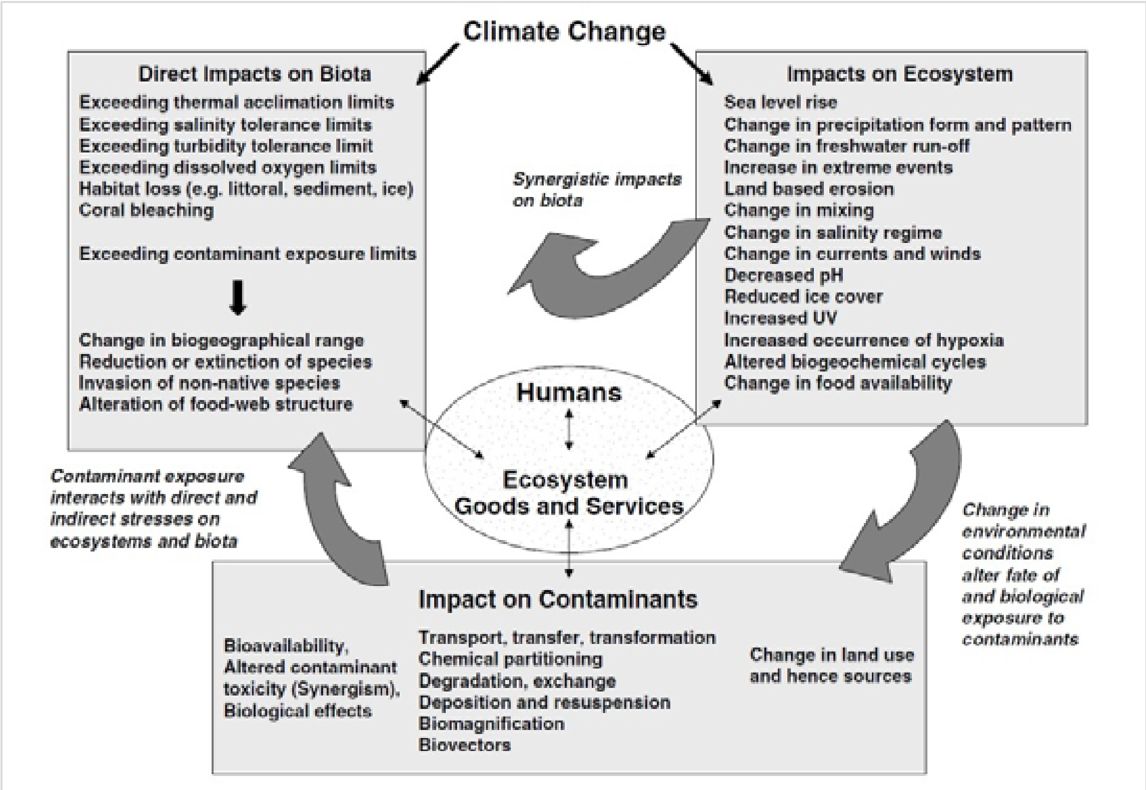


Fig. 7: Overview of climate change impacts on ecosystem and biota. Source: Schiedek et al. (2007)

Noyes et al. (2009) predict that „*Climate change will have a powerful effect on the environmental fate and behaviour of chemical toxicant*". As it can be seen in Fig. 7 there are a lot of biotic and abiotic factors influencing the behaviour 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 et al. (1998) and Schneider (2005), 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 (2005) 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.

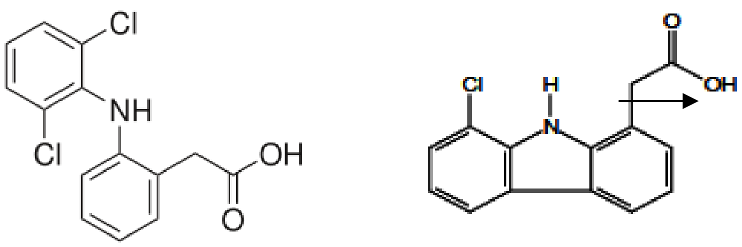


Fig. 8: Phototransformation of Diclofenac to chlorocarbazole acetic acid

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. Fig. 8 shows the chemical process of the phototransformation of Diclofenac.

4.2.1. Consequences of water scarcity and droughts

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

> *„Water scarcity 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. "*
>
> *„Droughts 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."* (EU COM 2016)

Water scarcity will increase and also expected droughts. This development could have negative impacts to the flow river regime (Barceló and Sabater 2010) and also for the chemical quality of water systems (Navarro-Ortega et al. 2012b). Munoz 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 et al. 2012a). Navarro-Ortega et al. (2012b) 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 semi- arid 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 (Navarro-Ortega et al. 2012b). 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 et al. 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 et al. 2012b; Barceló and 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.

4.2.2. Consequences of torrential rainfalls and floods

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 (2008) 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. 2005). 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. Tümpling (Zentrum für Umweltforschung, personal communication, 06/2014) 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 (Fernandez et al. 1999), surfactants (Ying et al. 2002) and hydrocarbons" (Tolosa et al. 1996).* Tümpling added that it can become more difficult to meet the objectives of the Water Framework Directive.

4.2.3. Consequences of elevated water temperatures

Barceló and Sabater (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; Noyes et al. 2009; Silbergeld 1973). 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). Fig. 9 shows the demographic development in Germany (Kirchner and Matthes 2009; Destatis 2011). Also, BPB (2011) predict the same scenario for whole Europe.

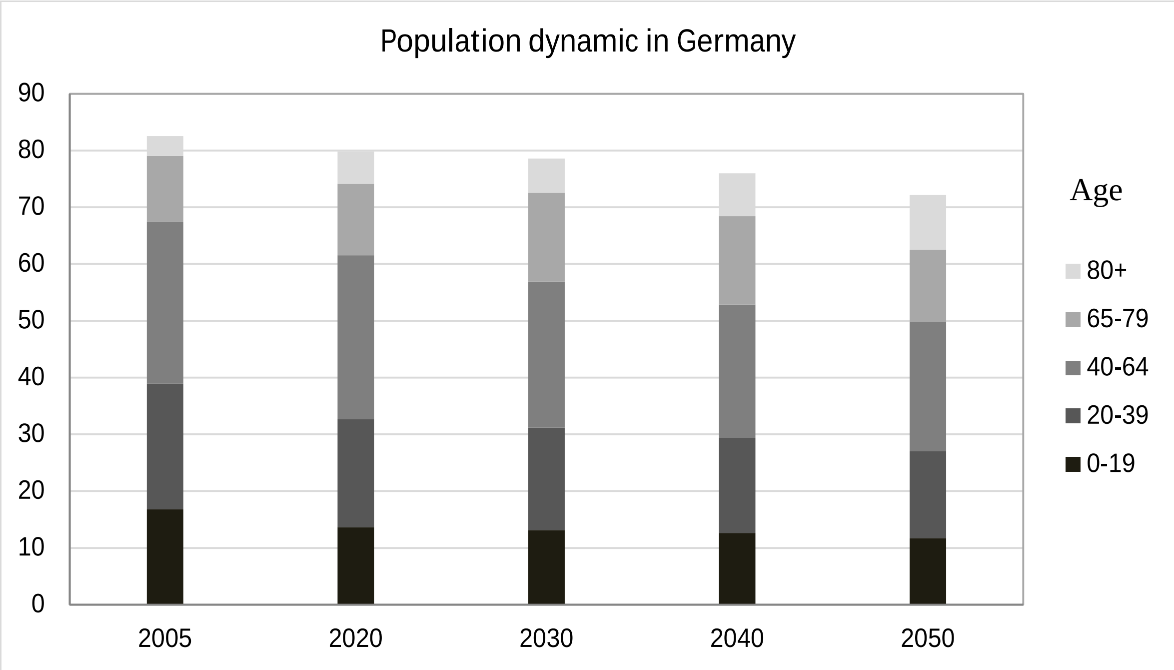


Fig. 9: Total Population and its Demographic change in Germany until the year 2050 in millions. Source: own graph based on Kirchner and Matthes (2009)

Fig. 9 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 et al. 2012). As a consequence, diseases which are typical for elderly people as heart- circulation disease, cancer or diabetes will increase (Schwabe and Pfaffrath 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 (Süddeutsche Zeitung 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 and Pfaffrath 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. RWTH Aachen (2014) 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 2008).

4.4. World population growth and urbanisation

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. Fig. 10 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 (Alcamo and Gallopín 2009). UNESCO forecasts that 60% will live in cities in 2030 (UNESCO 2003).

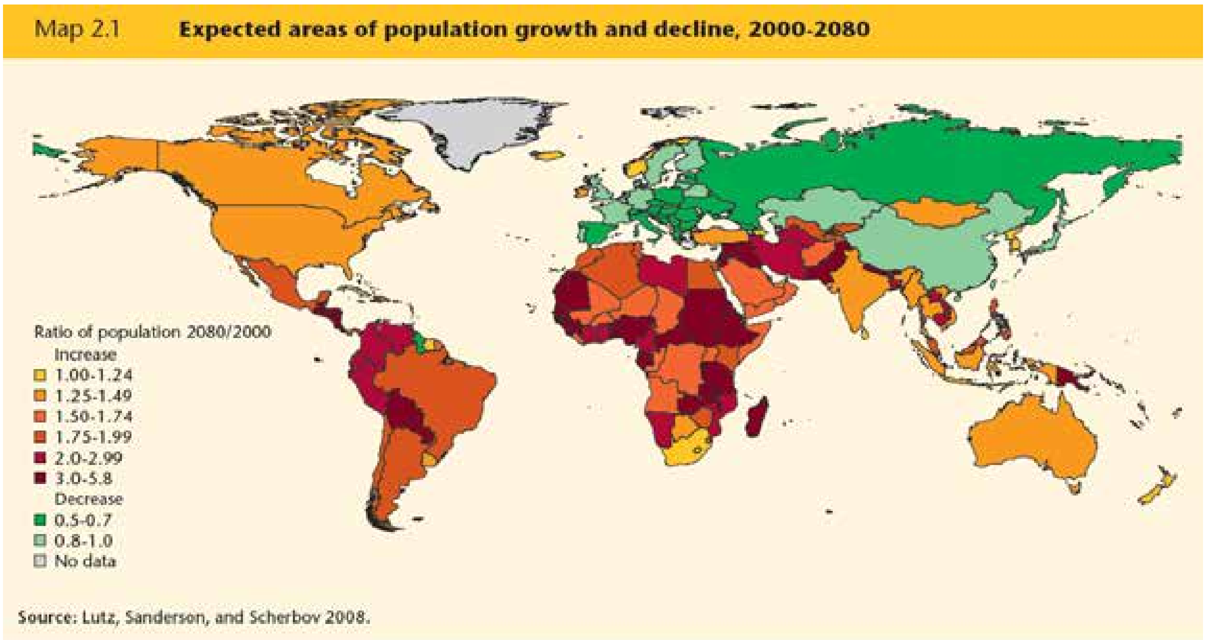


Fig. 10: Population in major areas, estimates and medium scenarios: 2000-2080. Source: Lutz et al. (2008) as cited in UNESCO & Earthscan (2009)

This phenomenon is called urbanisation and will entail many problems for the environment. In the following the linkage and impacts of urbanisation 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 & 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 (Fernandez et al. 1999; Ying et al. 2002; Tolosa et al. 1996) (see also section 4.2).

Urbanisation 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 2012a). 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 section 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 urbanisation (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 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 (UBA 2007).

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 2013; UBA 2007). Substitutes for DEHP are DEHT (Fig. 11), DINCH (Fig. 12), DOZ or TEHTM (Brutus et al. 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 (Becker 2013). Brutus et al. (2013) report that there are even naturally substitutes as bio plastics derived from renewable biomass sources (e.g. vegetable oils).

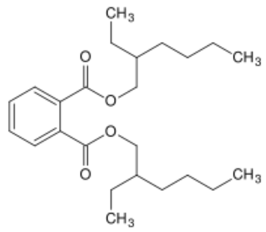


Fig. 11: Structure formula of bis(2-etyhlhexyl)phthalate (DEHP)

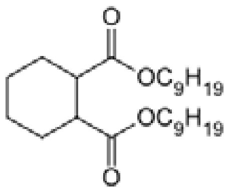


Fig. 12: Structure formula of 1,2-cyclohexane dicarboxylic acid diisononyl ester (DINCH/hexamoll)

Similarly, long-chain per- and polyfluorinated hydrocarbons (PFCs) (see Fig. 13) are replaced by short-chain 2- 4 PCFs (Greenpeace 2012; 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 (La Farré 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.

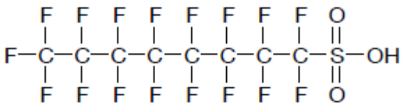
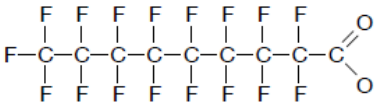
Group[12]	Example for a compound	Chemical Structure
Perfluorinated sulfonic acids	PFOS	
Perfluorinated carboxylic acids	PFOA	

Fig. 13: Chemical structures of PFOS and PFOA. Source: Greenpeace (2012)

The third group of substitutes belongs to the group of flame retardants. Hexabromobenzene (HBB) (Fig. 14) 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 (Møskeland 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 section 4.5.2.1

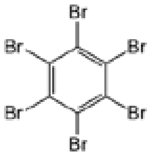


Fig. 14: Structural formula of the flame retardant hexabromobenzene

4.5.2. Technological developments with new uses of chemicals

4.5.2.1. Substances for insulation

Some substances used for insulation materials are already emerging pollutants according to the NORMAN list. Examples are HBCDD hexabromocyclododecane (Fig. 15) and biocides such as terbutryn used as a Herbicide and 2-Octyl-2H-isothiazol-3-on (Walser et al. 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.

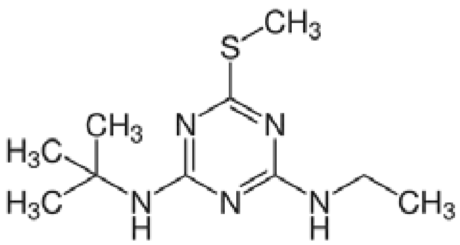


Fig. 15: Structural formula of terbutryn, a biocide used for insulation

4.5.2.2. 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 et al. 2007). For these convenience products, substances as Sucralose (Fig. 16) or triacetin (Fig. 17) are used as food additives and as aroma. This could increase the consumption of products containing these substances. As per the report of Ziegler et al. (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. 2009). Triacetin is used as an aroma in chewing gums and as a food additive.

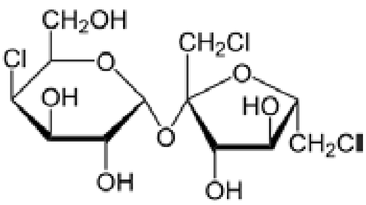


Fig. 16: Structural formula of sucralose

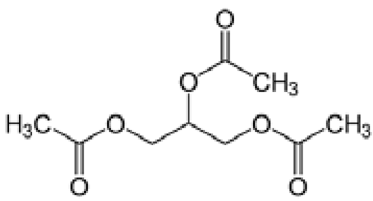


Fig. 17: Structural formula of triacetin

Two other factors supporting the application of sucralose and other sweetener are probably demographic change and also urbanisation. As described in section 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 (Detzel et al. 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 societal trend is and will be the increased use of triclosan. It is professionally used as a biocide, but also in household products and cosmetics such as toothpastes, or in textiles. Thus, the presence of triclosan will increase in surface water (Rüdel 2012).

4.5.2.3. 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. Fig. 18 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 (Möller et al. 2013):

- carbon-Nano-Tubes (CNTs);
- carbon black;
- titania (titanium dioxide);
- ferrous oxide;
- silver;
- silica;
- zinc oxide.

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, 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 (Möller et al. 2013). Möller 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"* (La 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:

Fig. 18, taken from Keller and Lazareva (2014), 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.

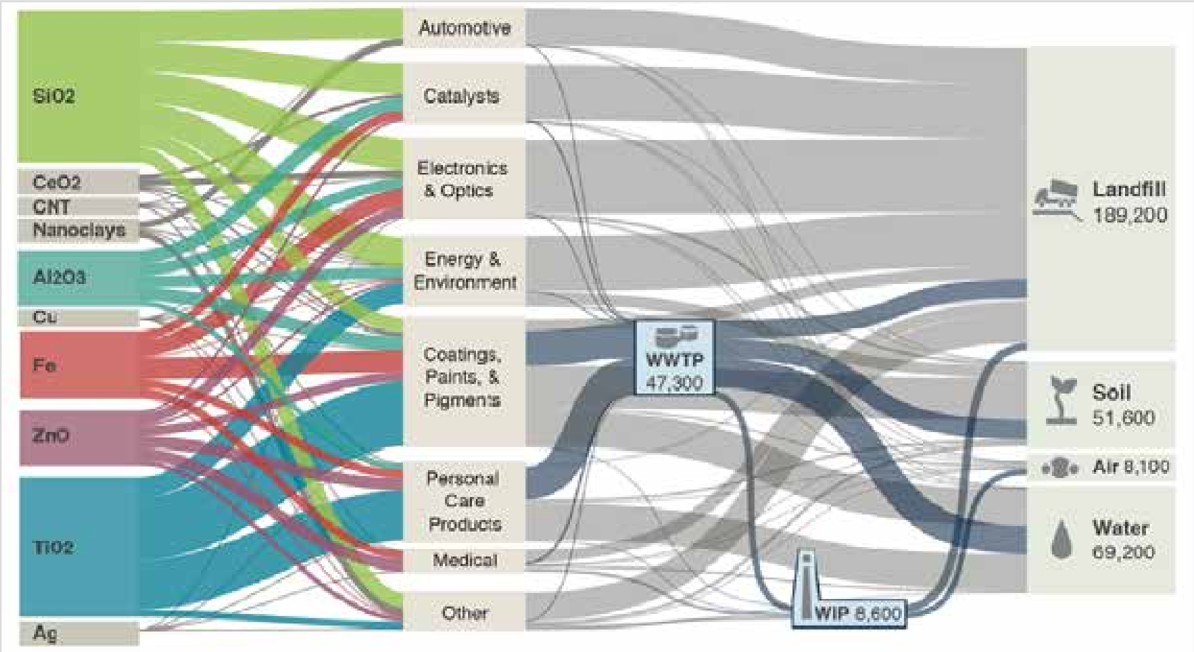


Fig. 18: Estimated global mass flow of engineered nanomaterials (in metric tons per year) from production to disposal or release, considering high production and release estimates as of 2010. Source: Keller and Lazareva (2014)

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 and Lazareva 2014). 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) 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 (La 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) and Gerde et al. (2001).

In addition, Neukum et al. (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.

4.6. Conclusions

In this report, 35 sources on developments in society (see Tab. 1 above) 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 urbanisation 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 accompanied 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 has been organised within the project SOLUTIONS which focus on developments in important sectors of society and their implications for future emerging pollutants (see the following chapter 5).

5. Developments in specific sectors and implications for future emerging pollutants

Based on the analysis of a broad range of scenarios, five main developments in society have been identified which can be expected in future (see section 4.1). They have specific consequences for different sectors of society. The first analysis for the identification of the main developments did not take into account sector-specific consequences of these developments. Therefore, a think tank has been set up for a deeper, sector-specific analysis of future developments and their implications on emerging pollutants.

Objectives of the sector-specific analysis

The Think Tank "Pollution of Tomorrow" consisted of approx. 10 permanent members and 5 sector-specific experts (which differ from sector to sector). The core element of the work of this Think Tank has been a sequence of four sector-specific workshops (they took place from February 2015 to November 2015). The objectives of these workshops have been

- to discuss sector-specific developments and their consequences on future emerging pollutants;
- to identify potential trends in pollution,
- to predict consequences for risks to the aquatic environment
- to propose specific substances/substance groups for environmental modelling and monitoring
- to develop management options for future emerging pollutants[3].

Based on the first analysis of main developments in society, the following four sectors have been selected for the workshops:

1. "Health Care", including human pharmaceuticals and veterinary drugs (see section 5.1)
2. "Food", including pesticides, antibiotics and convenience products (see section 5.2).
3. "Cities", including land use change and urban mining (see section 5.3).
4. "Technologies", including key enabling technologies (see section 5.4).

In the following sections, the main content of the discussions and the key findings are described for each of the four sectors.

5.1. Sector 1: "Health Care"

5.1.1. Background and objectives of the sector specific analysis

How health care will look like in 2030 – and what are the consequences for pollutants in surface waters? Different aspects of this question have been discussed for the sector Health Care.

Pharmaceuticals and their transformation products are one of the most important groups of emerging pollutants in surface waters. Demographic changes in Europe will have direct consequences on the use and emission pattern of these substances. Climate change is expected to have impacts on the disease

[3] These options are also described in the decision support instrument RiBaTox, the main product of the SOLUTIONS project.

patterns. Technological developments address the challenge to develop more sustainable drugs – and to minimise emissions to the environment.

The workshop on Health Care 2030 aimed to develop a broader picture of future trends and developments in Health Care – and implications for human health and the environment. The exchange between the participants and experts from different disciplines had the objective to lead to a better understanding of future impacts of health care activities on surface waters and our options to act for a cleaner environment.

5.1.2. Important topics in the sector "Health Care"

The following topics have been discussed in the sector-specific analysis:

- Potential Changes in Disease Patterns and Pharmaceutical Use in Response to Climate Change. Michael Depledge (University of Exeter Medical School).
- Health care associated infections, multidrug-resistant pathogens and expected developments in prevention and control technologies. Christian Brandt (Hospital University Frankfurt)
- Demographic challenges and change in health care: Future release of pharmaceuticals into the environment. Engelbert Schramm (ISOE, Institut für sozial-ökologische Forschung, Frankfurt).
- Drugs in the environment: Future developments in contamination pattern and innovative approaches for sustainable drug design. Klaus Kümmerer (Leuphana University, Lüneburg)
- Reduce the risk – technological approaches to minimise drug emissions. Hans-Christian Schäfer (Deutsche Bundesstiftung Umwelt, Osnabrück).

The presentations are documented in the separate Part II of this document (there: chapter 1.1).

5.1.3. Future developments in the sector "Health Care"

Following the presentation of model on future climate change and its consequences for future health care by Michael Depledge from the University of Exeter, the "Health Care 2030" workshop discussed potential changes in human disease patterns and pharmaceutical use considering projections by the Intergovernmental Panel on Climate Change (IPCC). At present, climate change is one of the most intensely discussed factors to potentially affect our future environments. Climate-related environmental alterations are expected to be associated with an increase in chronic diseases already common in the Northern Hemisphere – such as cardiovascular, respiratory and mental illnesses – potentially leading to a greater need for chemical medications, such as vasodilators, anticoagulants, anti-inflammatories, antidepressants and analgesics, which then will potentially be circulated into the environment.

Changes in climate are also expected to prompt an increase in pathogens and invertebrate vectors (such as mosquitos) for disease. As new disease threats emerge, higher pharmaceutical use seems inevitable, and is likely to include medical drugs not commonly employed at present, such as antiprotozoals for malaria, amoebiasis and others. Further factors expected to affect future pharmaceutical consumption are global societal health trends (increased prevalence of obesity, diabetes, cancer and depression), increased production and access to drugs (e.g. in newly industrialized countries), novel chemical treatments, biodiversity loss and emerging diseases.

In terms of predicting future freshwater chemical pollution, such developments need to be viewed in the context of other environmental changes, such as fluctuations in river flows as a result of droughts, floods and storms, which can disturb historical ‘legacy’ pollutants from sediments. Similarly, an increase in surface water temperature can also alter the environmental fate of emitted chemicals, influencing their mobility and bio-accumulation.

5.1.3.1. Chemical pollution from healthcare and agriculture

Following presentations at “Health Care 2030” workshop given by Christian Brandt (University Clinical Center Frankfurt) and Engelbert Schramm (ISOE, Institute for Social-Ecological Research, Frankfurt), workshop participants discussed the current and future role of health care systems – especially hospitals – as sources of environmental pollution. In general, health care personnel are educated about how to correctly dispose of waste in hospitals with largely well-structured waste management plans, thus reducing the risk of contamination of other patients and the environment. Nevertheless, infectious microorganism agents from gut flora and multi-drug resistant bacteria do represent a serious threat to the environment, and this may become more serious in the future if current trends in the use of antibiotics continue.

This threat posed by chemical pollution is enhanced by industrial livestock farming involving high and potentially improper antibiotic use. Drug emissions from hospitals are of local relevance but are easily exceeded by diffuse emissions from households, thereby posing spatial challenges for pollution management. Another key issue is the increasing requirement for cleaning and disinfection to safeguard hospital hygiene, for example in the cleaning of surfaces and surgical instruments. In this respect, and taking into account global population growth, the emissions of chemicals from household cleaning products are also expected to increase in coming decades.

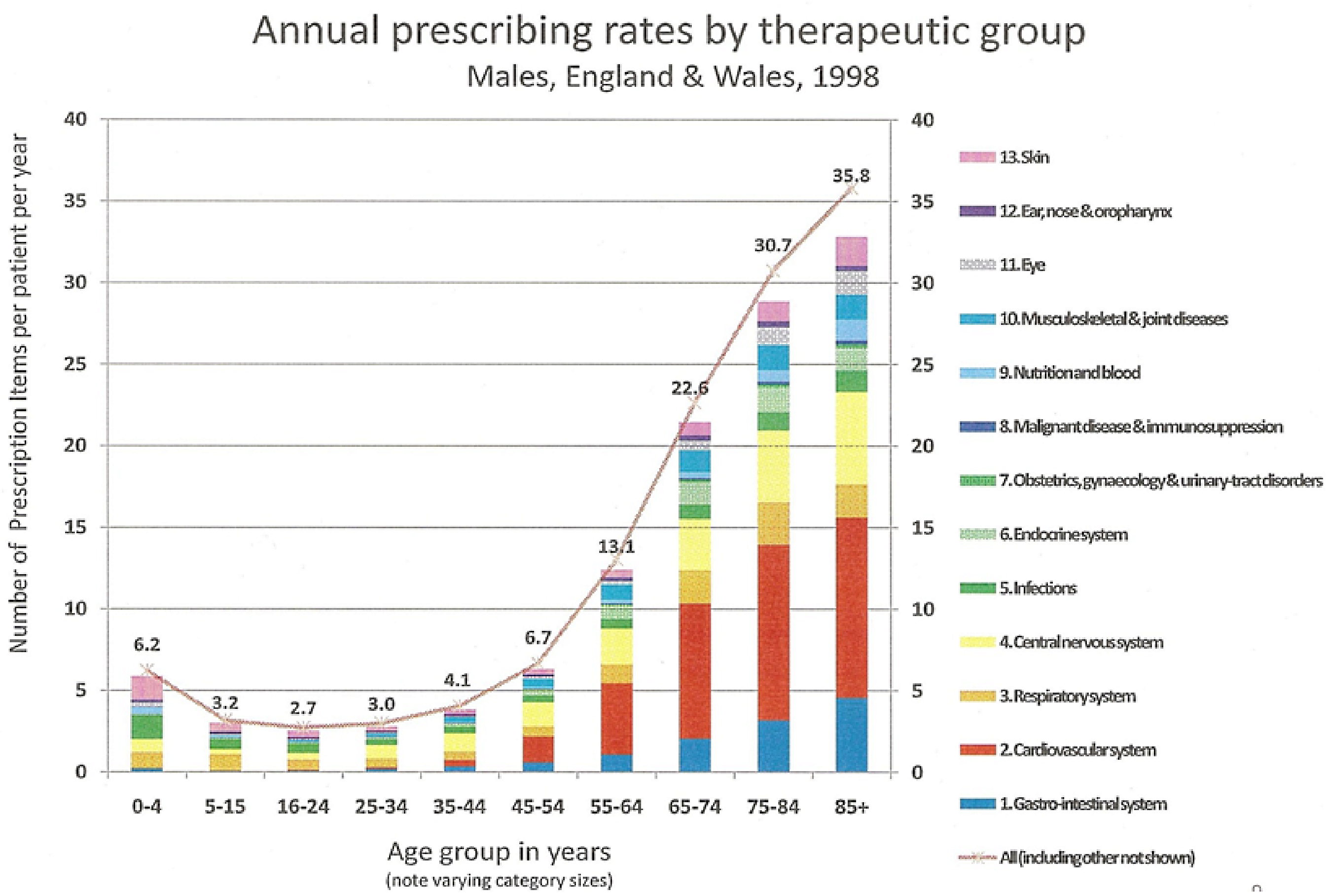


Fig. 19: Annual prescribing rates by therapeutic group in males from England and Wales in the year 1998. Image: Royal Commission on Environmental Pollution report on "Demographic Change and the Environment" February 2011; information used under UK Open Government Licence v3.0.

5.1.3.2. Identifying and managing the causes of future chemical emissions related to Health Care 2030

As a result of discussions at the SOLUTIONS workshop, the key drivers of future "Health Care 2030" chemical emissions were identified as: (i) an increase in pharmaceutical production and consumption; (ii) environmental politics (i.e. how pollution is managed by policy); (iii) demographic change; and (iv) developments in human health systems and veterinary practices. Participants at the workshop discussed possible "options to act", suggesting palliative measures to manage the impact of drugs released into the environment.

Hans-Christian Schäfer (Deutsche Bundesstiftung Umwelt) reported on several technological approaches to minimize drug emissions. This involves the advancement of effluent treatments (e.g. the removal of micro-pollutants via sludge or charcoal absorption, membrane filtration, and the advanced oxidation or UV-photolysis of molecules). Similarly, Schäfer outlined societal incentives to encourage the pharmaceutical industry to achieve a business model combining entrepreneurial interests, higher efficiency of pharmaceuticals and a sustainable "benign by design" model of drug production.

Taking into account the uncertainties associated with future developments in chemical use and emissions from the pharmaceutical industry, the best option for action may be optimisation in small steps along the whole supply chain: from the design and production of a certain pharmaceutical, to its legal authorization and environmental regulation, and finally its consumption and use. Education may help to avoid bad practices in drug use such as the disposal of pills and tablets via toilets or sinks.

Klaus Kümmerer (University Leuphana Lüneburg) presented innovative strategies for sustainable drug design, including practical examples of the "benign by design" approach. Such drug-design safeguards against environmental degradation by avoiding persistent and toxic transformation products. Further important tasks in the future will include the promotion of behavioural changes such as: increasing public exercise; reducing exposure to hazardous substances and pathogens; and raising awareness on the correct use and dosage of pharmaceuticals, for example this environmental product labelling in Sweden.

5.1.4. Key findings for the sector "Health Care"

The following points have been identified as being important regarding future developments in the sector "Health Care":

- Beyond the obvious: future developments are complex. Combination of trends / Combine data from different scenarios (different climates, demographics) to predict the 2020 – 2030 situation.
- Unregulated use of antibiotics. This has to be tackled.
- Climate change: appearance of new diseases, use of new pharmaceuticals for treatment.
- Households are main emission sources for drugs, not hospitals.
- Urbanisation: cities as hot spots for contamination with pharmaceuticals. Offer good options for efficient centralised treatment.
- Use pattern of drugs differs regionally.
- Large differences between countries regarding consumption patterns of drugs. Options for improvements.
- Personalised care/ treatment: better control of dosage, personalised mixture of drugs.
- Veterinary drugs are a priority threat. Need for stricter regulation.
- Missing: the industry perspective / difficult to get. How we can get the whole picture, LCA.
- Gap in antibiotic development. Industry has no commercial interest in new antibiotics (Risk of resistance formation).
- Abatement options are known for every step of the life cycle of a drug: legislation / benign by design / personalised medicine / behaviour around prescription, use and disposal / possibilities for recycling / optimised waste water treatment.
- Abatement: technical measures. Several technical options available for waste water treatment plants. Single methods not efficient for all substances (depending on substance properties). Efficient emission control needs combination of techniques.
- Uncertainty about degradation products – which compounds? Which effects?

- Abatement: non-technical measures: information campaign to public – don’t flush pharmaceuticals / information to prescribing doctors about environmental impact. This should stimulate the selection of less problematic substances / nudging, incentives / salutogenesis.
- Benign by design: feasible, if pharmaceutical industry is interested in.
- Future trends: benign by design. – develop molecular structures. Same medical effect, less impact on the environment (better degradable). Approach promising, if pharmaceutical industry is interested in.
- Implication for tool development: Mode of action directed tools.
- Mixture of pollutants requires approaches beyond the single substance risk assessment. Need for an advanced effect monitoring: Monitoring of drugs: use drug specific biological endpoints (effects on human, ecological effects).

The list of participants of the sector analysis “Health Care” is given in Annex 4, section 7.4.1 of this report.

5.2. Sector 2: “Food”

5.2.1. Background and objectives of the sector specific analysis

How production and consumption of food in Europe will look like in 2030 – and what are the consequences for pollutants in surface waters? Different aspects of this question have been discussed for the sector “Food”.

Significant changes in the conditions for food production can be expected for the coming twenty years. Climate change will alter land use pattern in Europe. Technological developments in animal farming have consequences for the use of veterinary drugs. Formulations, active substances and application technologies for pesticides will be further developed. A growing importance of convenience food could result from demographic changes and changes in food consumption behaviour. These and more activities can increase or reduce the amounts of emerging pollutants found in surface water.

The workshop on “Food 2030” aimed to develop a broader picture of future trends in production and consumption of food – and implications for the environment. The exchange between the participants and experts from different disciplines had the objective to achieve a better understanding of future impacts of food and nutrition on surface waters and our options to act for a cleaner environment.

5.2.2. Important topics in the sector “Food”

The following topics have been discussed in the sector-specific analysis:

- Nutrition 2030: Global trends, consumption pattern and consequences. Lieselotte Schebek, TU Darmstadt.
- Future trends in nutrition / convenience food: perspectives from Nestlé Deutschland AG, Frankfurt. Lieselotte Schebek, TU Darmstadt.

- Agriculture and crop production 2030: Trends and consequences. Lars Neumeister, Pesticide Action Network, Hamburg.
- Animal farming 2030: Developments and consequences for the environment. Christine Chemnitz, Heinrich Böll Stiftung Berlin.

The presentations are documented in the separate Part II of this document (there: chapter 1.2).

5.2.3. Future developments in the sector "Food"

Food – a rare good.

Liselotte Schebek from the Technical University of Darmstadt explained transition processes in nutrition at the end of the 20th century. From 1963 to 2013, consumption of meat increased globally from 75 million t to 250 million t. Production and trade with food are characterised by globalisation and technological developments. The share of food produced in industrialised processes is more than 90%. New technologies are used to produce new kinds of food, e.g. functional food and products with specific ingredients tailor-made for subgroups of consumers. Objectives of food technologies are efficiency increase of production, improvement of product characteristics, improvement of fitness for transport and storage. In parallel, technologies for food packaging have been further developed. In this respect, innovations in packaging materials and increase of efficiency of packaging machines are key elements. It includes modified atmospheric packaging as well as active packaging (it emitted substances or takes substances up). Food from industrial production is decoupled from the timing of natural processes. It can be supplied at any time.

On a global scale, food is a rare good. According to projections of the Food and agriculture Organisation of the United Nations (FAO), agricultural production must become more efficient. *"To meet global food demand in 2050, agricultural production must be 60% higher by weight than in 2005"* (Alexandratos and Bruinsma 2012). In parallel, water demand is projected to increase by 55% globally between 2000 and 2050. Increase in demand will come mainly from manufacturing, electricity and domestic use. Due to these competing demands, there is little scope for increasing water for irrigation.

Food production and consumption have a large impact on the environment. The amount of resource consumption, emission of greenhouse gases, emission of fertilisers and pesticides are largely depending on the type of food and its production. Meat, food delivery independent from seasonal production and food from highly processed production sites have significant higher impacts. Despite of these high impacts, globally around one third of produced food is going to waste. In Europe, annual food waste has been around 90 kg per person (in USA 110 kg/person, in South and Southeast Asia 18 kg/person) (Shrink that footprint n.d.). In Europe, at least 170 million tons of carbon dioxide equivalents are emitted because of food waste. This figure is between the total emissions of greenhouse gases of Romania and the Netherlands in 2008. It represents approximately 3% of total EU27 emissions in 2008.

The discussion of consequences of food production on surface water quality refers mainly to impact of nutrients. Impact of pesticides and veterinary drugs are only rarely taken into account. In her second presentation, Liselotte Schebek presented a recent study on nutrition habits in Germany (see presentation in section 1.2.3 of the workshop documentation (Bunke and Moritz 2016).

5.2.3.1. Agriculture – a human made and managed production system

Recent developments and trends in agriculture have been presented by Lars Neumeister from Pesticide Action Network. Apart from labour, seeds and machinery, around 10.000 or more chemicals are part of the input into the existing agricultural production system. Fertilizers, pesticides and biocides, veterinary drugs, feed additives, adjuvants and carriers are used. Main current trends are intensification of the agricultural production, de-democratisation, market concentration, externalisation of costs and support of free trade. Consequences are at present resource depletion (especially phosphorous), loss of soil biodiversity, soil degradation, acidification, increased resistance and decrease of genetic diversity. Regarding seeds in Europe, five companies own 50% of all plant patents.

Increased demand for phosphorous will lead to the use of more contaminated phosphorus sources. Due to climate change, increase in drought frequency can be expected on a global scale. Pesticides and other pollutants can more easily reach groundwater if the soils are dried out and cracked. Under droughts, surface run-off of pesticides will increase too. Due to loss of soil diversity, degradation of pesticides will decline.

In a recent study from Norway no linear relationship between climate change, spread of new diseases and pesticide use has been found. Significant reductions in the amount of pesticides have been achieved by a regulation which introduces fees. They depend on problematic properties of active ingredients and the amounts used.

5.2.3.2. Animal farming – development and consequences for the environment

On a global scale, consumption of meat increases continuously within the last three decades. For 2013, in total 308 million tons of meat has been produced globally. The global “hunger for cheap meat” has two main drivers: the available income (not the population growth), and urbanisation (citizen show a higher meat consumption than rural population). The present meat production already exceeds the planetary boundaries regarding climate protection. Increased food consumption requires increased production of animal feedstuff. Natural areas are converted to arable land – and lose their biological functions. Several natural areas, especially moors, are stocks for carbon. Conversion leads to the release of additional greenhouse gases. Soy bean production for animal farming caused a high increase in pesticide use. E.g. in Argentina, amount of pesticides (mostly glyphosate) sold raised from 120 million kg in 1997 to 320 million kg in 2013.

Loss of soil fertility endangers three sustainability goals: keep global warming below 2 degree Celsius, protection of biodiversity and adequate food for all people.

5.2.4. Key findings for the sector "Food"

The following points have been identified as being important regarding future developments in the sector "Food":

- Pesticide use: it is difficult to determine a quantitative baseline of the amounts used.
- Climate change will lead to droughts and more mobility of pollutants.
- In Germany, decrease of meat consumption runs parallel to increase of meat production for export.
- Increase in animal farming is expected to cause increase in use and emission of veterinary drugs and food additives.
- Animal farming leads to increase of acidification and increase of mobility of pollutants.
- FAO projections can be the base for modelling of future developments of use of agricultural chemicals.
- Trends in food production can be of high relevance not to exceed the planetary boundaries.

The list of participants of the sector analysis "Health Care" is given in Annex 7.4.2 of this report.

5.3. Sector 3: "Cities"

5.3.1. Background and objectives of the sector-specific analysis

At present around 50% of the world population lives in cities. It is predicted that this will increase to 60-70% by 2030. How urbanisation will change the face of Europe in the next two decades– and what are the consequences for pollutants in surface waters? Different aspects of this question have been discussed for the sector "Cities".

Even if there are no megacities, urbanisation and land use change will become important developments in Europe in future. Adaptation of cities to climate change, changes in the materials used for buildings, urban mining and new challenges for water supply and water treatment are some of the aspects which are connected with urbanisation. They can influence the patterns of pollutants in urban environments in several ways.

The workshop on Cities 2030 gave different views on urbanisation and future living in large cities in Europe - and implications for the environment. Can we expect that future cities will be smart cities? What options exist to ensure a clean urban environment? A central objective of the exchange between the experts from different disciplines has been a better understanding of future impacts of urbanisation on surface waters.

5.3.2. Important topics in the sector "Cities"

The following topics have been discussed in the sector-specific analysis:

- Urbanisation: general trends in Europe. Harald Kegler, University of Kassel.
- Urban developments in Europe – and consequences for the environment. Marie Cugny-Seguin, European Environmental Agency, Copenhagen.
- Emerging Contaminants and Technologies – Monitoring Cities of the Future: Experience from CAPACITIE. Lorraine Youds, University of York, York.
- Land use/cover projections for Europe for the period 2010-2050. Claudia Baranzelli, Joint Research Centre, Ispra.
- Consequences of urbanisation in the larger Moscow Region, Slava Vasenev, Wageningen University.
- Urban mining and consequences for the environment. Georg Mehlhart, Oeko-Institut, Darmstadt.
- Urban water demands: trends in supply and treatment technologies. Tove Larsen, eawag, Dübendorf.
- Emerging pollutants in urban environments: Overview. Eva Broström-Lunden, IVL, Göteborg
- Climate change, building products and emerging pollutants. Christian Scherer, Fraunhofer Institut für Bauphysik, Valley
- City Emission profiles: chemical and risk finger printing. Leo Posthuma, RIVM, Bilthoven.

The presentations are documented in the separate Part II of this document (there: chapter 1.3).

5.3.3. Future developments in the sector "Cities"

Urbanisation in Europe by 2030 can be characterised by two general trends: growing cities and shrinking regions. Harald Kegler from the University of Kassel gave an overview on global trends, urban history, European trends and planning principles. In Europe, expansion of cities started around 1800. Important steps in the urbanisation process from 1900 to 1975 have been decentralisation, followed by a car-oriented transformation process. Starting around 1950, urban sprawl started. Compared to cities, urban sprawl leads to a high consumption of land for housing. Around 1975, the process of reurbanisation started. At present, sustainability of cities and urban resilience are the main discussion lines for cities of the future in Europe. A walkable grit of the city, diversity of land use, stable social-cultural networks and a specific culture typical for the region and its landscape are elements of a progressive European city. If such objectives are not part of the city planning, privatization of city areas and social segregation can take place. Social separation can be seen as a kind of "re-urbanisation" for poor people. The social divided city requires gated communities to be stable – as it is known for several cities already today. The concept of the "resilient" city developed as an answer to peak oil and climate change. It describes the capacity of a city to absorb disturbances – and still retain its basic function and structure.

The expected urban developments in Europe will have severe consequences for the environment. Marie Cugny-Seguin from the European Environment Agency started with a projection showing that urban areas will absorb most of the global population increase. The global number of (resource intensive) middle class consumers is expected to grow by 170% by 2030. Despite considerable improvements in the past decades, air pollution is still responsible for more than 400 000 premature deaths in Europe each year. It continues to damage vegetation and ecosystems. Beyond 2030, only slow progress is expected regarding the long-term objectives of air pollution (fine particulate matter, ozone). Similar, still a high percentage of the European citizen are exposed to harmful levels of air pollution. The 2050 visions in the 7 Environmental Action Plan will be much more difficult to reach than the earlier goals of 2015 and 2020/2030.

Cutting-edge approaches for pollution assessment in cities have been presented by Lorraine Youds, from the University of York. Moving beyond the traditional pollutants, nowadays, urban emission profiles are characterised by a more complex picture. Human pharmaceuticals, domestic products as well as transformation products can be found as emerging pollutants. The research project CAPACITIES aims to generate a new generation of researchers which are trained with up-to-date technologies to monitor such pollutants in the urban environment. In addition, they should have the understanding of the social and ethical issues around the adaption and use of new technologies. One objective is to engage the public and other stakeholders in monitoring. Use of robots and crowd sourcing are new elements for a direct urban monitoring of pollutants. For monitoring city systems, water- and air-borne robotic systems are under development.

5.3.3.1. Land use/ cover projections for Europe and the urban environment

Trends in urbanisation are predicted from the Joint Research Centre using a land-use based system. Claudia Baranzelli from the EU Commission (JRC) presented the principles of the modelling and main results – regarding urban trends and urban indicators (land functions). The LUISA modelling Platform uses a territorially disaggregated approach with a high resolution (100 x 100m), yearly steps and 17 land use/cover classes. More than 50 spatially explicit indicators describe the land functions. Indicators on territorial performances refer to economic performances (e.g. GDP, sectoral employment, investment in innovation.), access to services (e.g. public structures, recreational and cultural sites…), infrastructure (for housing, transport, energy) and environmental performance. The last item includes indicators which address pollution levels and mitigation measures. In addition, natural capital and ecosystem services are characterised by specific indicators.

As a general trend, decreasing land use can be seen in rural areas, together with a high increase in population density in cities. The “Functional Urban Area” (FUA) consists of a city and its commuting zone (previously called “Larger urban zone” – LUZ). Cities can not been seen as isolated structures. These densely populated areas are connected with towns and suburbs (intermediate urbanised areas) and rural areas (thinly populated). The macro-economic trends seen so far needed to be broken down on a sub-regional level. An example for such trends of urbanisation on a regional scale has been shown in the presentation of Viacheslav Vasenev. He reported about consequences of urbanisation in the larger Moscow Region.

Urbanisation in general alters matter and energy fluxes, vegetation and soil cover. Driving anthropogenic factors behind urban soil formation are slope terracing, urban heat islands, plant species introduction, wastes and landfills, soil construction and soil sealing. The ratio of impervious (sealed) areas in cities varies from 5 – 90%.

The resulted urban ecosystems are substantially different from agricultural and natural counterparts. Compared to natural reference soils, urban soils show a decrease in microbiological activity, an increase in topsoil organic carbon and nutrient content, low acidity, a reduced depth of organic horizon, a shift to light soil texture (sandy loam, loamy sand) and –often- increased concentrations of heavy metals and oil products. At present spatially explicit data on urban soils are lacking. Urban soils show a high heterogeneity at short distances – due to the combination of contrast small-scale functional zones. In addition, urban soil shows a high temporal dynamic.

Soil carbon is an essential characteristic of urban soils. 30 – 50% of distinguished soil functions are directly or indirectly related to soil carbon balance. In the vast majority of studies on urbanisation, soil carbon is neglected. For a pilot study, the Russian government project “New Moscow Project” has been selected. It aims to decentralise the Moscow region and started in 2011. Interim results of the analysis show: carbon stocks in urban soil are comparable or higher than in natural or agricultural ones. From 1980–2014, the total extent of urbanized areas in the Moscow region increased on 25%. Consequences for soil carbon differ regarding fertility of zonal soils. Urbanisation can have a positive net effect on soil carbon stocks.

5.3.3.2. Urban mining

Georg Mehlhart presented consequences of two activities typical for cities: presence of consumer goods with short life time and investments. Short life time (less than 1 year) results in large amount of waste (from electric and electronic equipment, waste from vehicles, packaging waste and industrial as well as production waste). Despite of waste collecting systems, the lost material from electric and electronic equipment has been estimated as 1,08 million tons only for Germany for the period from 2006–2008 (3 years). Investments are made in housing and commercial buildings, for infrastructure of industry and technical infrastructure as streets, bridges, channels, power- and IT networks. Large volumes of construction waste and mixed municipal waste are built up. Sometimes they are combined with deposits from mining and industry. Urban mining tries to deal more carefully with natural resources. First indicative assessments demonstrate that potentials are high for recycled materials from landfills and (industrial) deposits. Economic viability for recycling is hampered by competition with incinerations. However, “urban stocks” have still lots of contaminants like heavy metals, flame retardants and others which are often not separable with reasonable efforts. Therefore, more attention, at least globally, is necessary to take care of pollutant free design, ready for re-use and recycling.

5.3.3.3. Urban water demands

On a global scale, increase of water stress is a challenging trend. Tove Larsen gave an overview on drinking water supply and waste water (transport and treatment) and what is expected for the future. "Future" in this context means: not only the period until 2030, but beyond, 2050 and later. From 2007–2050, world population living in river basins with severe water stress will increase from 1,600 million people to 4,900 million people. Increasing water stress results in a higher load of wastewater in surface waters, without treatment in sewage treatment plants. The need to remove micropollutants may push the upgrading of wastewater treatment plants (WWTP). At present, only nitrifying plants can be upgraded. For the management of the WWTP, water scarcity is the most problematic situation.

Future technologies are discussed to ensure water supply for water sensitive urbanisation. They cover innovative technologies for fit-for-purpose water production, resource recovery from diluted wastewater, managing interactions between decentralized and centralized water systems, integrated multi-functional urban water systems (wetland and stormwater biofilters) as well intelligent urban water systems (mainly sensors). As an alternative to sewers, on-site treatment of waste water is further developed. On-site treatment aims to recover water (and energy) (from greywater), to recover nutrients (from urine) and to recover energy (from faces). Urine contains 2/3 of the pharmaceuticals which enter surface water systems – an additional reason for on-site treatment.

5.3.3.4. Emerging pollutants in urban environments

Cities can be considered as a specific, man-made environmental compartment. Eva-Brorström-Lunden from IVL Swedish Environmental Research Institute presented main sources of emerging pollutants in cities, trends in pollution patterns and initiatives towards a non-toxic urban environment.

Building activities in cities as well as products used by citizens lead to an urban accumulation of chemicals. Emerging pollutants in urban environment are flame retardants, plasticisers, antioxidants, biocides, personal care products as well as pharmaceuticals. Point sources and diffuse sources are building materials, articles, chemical products as well as combustion processes. Indoor emissions are released to the environment (air, water and soil). Emissions can be enhanced by stormwater. Time trends for the emission of plasticisers from vinyl flooring show the substitution of regulated phthalates (DINP, DEHP) by substances with similar structures (DINCH, DEHA). Different strategies have to be applied for a future non-toxic urban environment. They reach from legislation (ban, restrictions on use), the implementation of best available techniques and substitution to voluntary reduction actions (information, eco-labelling) and benign-by-design approaches (green chemistry and sustainable chemistry). Guidance to sustainable construction materials is developed in the project BASTA (www.bastaonline.se).

Emissions from buildings are influenced by climate change. Christian Scherer from the Fraunhofer Institute for Bauphysik explained six factors which are linked to climate change. Formation of urban heat islands, increasing surface temperatures, occurrence of urban moisture excel, increased frequency of inversion, of ozone concentration and PAN formation. Climate change leads to changes in rain and wind which increase the pressure on building materials. In growing cities, emissions of chemicals are further enhanced by new buildings, retrofitting and demolition, redensification and conversion. Examples for pollutants which can be released from demolition and recycling are hexabromocyclododecane (HBCDD) from EPS-based insulation materials, glass wool with WHO fibers and microplastics. From buildings, biocides can be released by leaching and evaporation. Examples for relevant product groups are in-can preservatives, film preservatives in renders, pains and varnishes, as well as radicides in liner sheets. Increase in surface temperature, evaporation rates, mobility, solubility and degradation rates lead to a higher emission of substances, a lower period of use and an increased frequency of application. Heavy rainfalls and hail storms cause a higher release of biocides from coatings and an enhanced degree of abrasion. In order to avoid enhanced emissions, less persistent chemicals and optimised techniques of applications are needed. Cities of the future need not only to be resilient and smart, but also application areas for a greener and more sustainable chemistry.

5.3.3.5. From single substances to emission profiles.

Complex consumption patterns of products and emission from buildings cause complex mixtures which are emitted by cities. At present, a reduction strategy is characterised by a chemical-by-chemical approach. With the focus on concentrations and on current priorities. Leo Posthuma proposed an alternative approach. It considers the emission of a city as a whole – as a complex chemical. In this respect, cities represent a typical emission entity which is different from other entities such as agricultural land. Certain types of chemicals (“signatures”) are dominant for specific emission entities. Urban Run-offs, domestic discharges and agricultural run offs have their own typical chemical finger print. Their emission profiles are different in space and time. Urban Run-offs show peaks due to rain. Domestic emissions are continuous, per capita water use. Agricultural emissions vary depending on seasons and crop matter. A closer look at the emission fingerprints shows that they can be dominated by agriculture, emissions from wastewater treatment plants or by urban run-off. For each of the three entities, mitigation strategies can be developed which take into consideration the specific chemical finger print. Management strategies will be different for fingerprints dominated by urban or domestic emissions (e.g. with cleaning products, personal care products, pharmaceuticals) or by agricultural emissions (due to insecticides, herbicides, fertilizers and veterinary drugs). Identification of the typical fingerprint can help to set priorities on specific groups of chemicals – to reduce the impact on aquatic ecosystems in a more efficient way.

5.3.4. Key findings for the sector “Cities”

The following points have been identified as being important regarding future developments in the sector “Cities”:

- Complex and conflicting trends. Urbanisation and sprawl. Shrinking cities and suburbs.
- Urbanisation can lead to social divided cities.
- Complex city planning required to achieve more sustainable (“resilient”) cities
- Urban development range from collapse of cities up to ruralised, more sustainable cities.

- Cities offer option for more efficient use of resources and more centralised treatment of waste (waters), compared to urban sprawl.
- Urban water cycles, front runners: water saving, short water cycles, separation at sources, recovery of nutrients, efficient removal of pharmaceuticals
- Urban water cycles: combine centralised and de-centralised technologies.
- EU long-term objectives of environmental protection and human health are difficult to reach, compared to the middle term objectives. They need answers for systemic problems which are more difficult to solve (e.g. need to change existing infrastructures).
- Climate change, Building products: surface run off is expected to increase due to climate change.
- Climate change: Stormwater management becomes more important (untreated overflow of STTP).
- Water scarcity drives technology developments.
- Urban mining: potential benefits are partially quantified. For specific metals more efficient than primary mining.
- Urban mining could re-circulate contaminants of the past. Guidance needed to avoid cross-contamination of products.
- Building products: hidden known pollutants and new groups of chemicals, e.g. hardeners
- Cities: particle bounded contaminants.
- Design materials and product ready for recycling.
- Opposite trend: composite materials, difficult to recycle.
- Analysis of emission profiles instead of single substance monitoring could support effective risk management measures (guided by priority pollutants and priority impacts).
- Check the potential of chemical fingerprint in the SOLUTIONS case studies.
- Project CAPACITIES could become project partner with strong synergies (e.g. referring to bio-electronic sensors).

The list of participants of the sector analysis “Health Care” is given in Annex 4, section 7.4.3 of this report.

5.4. Sector 4: “Technologies”

5.4.1. Background and objectives of the sector-specific analysis

Innovations in technologies play a central role to enhance efficiency of processes and products. New materials are constantly developed - the majority of product innovations are based on them. Printable electronics, metallic matrix composites, technical textiles and switchable shading systems are only some examples. Does this automatically mean that we can expect in parallel release of new substances to the environment? Are there links between new technologies and future emerging pollutants? Different aspects of this question have been discussed for the sector “Technologies”.

The workshop addressed a broad range of applications and materials. It included developments in energy supply systems, organic semiconductors, nanomaterials and more. In addition, it raised the question how a horizon scanning can work – to detect at an early stage materials and substances which could have a high adverse impact on the environment.

The exchange between the participants and experts from different disciplines aimed to achieve a better understanding of future technologies. What can we expect? How we can use these materials and at the same time ensure not to get new pollutants in our river basins?

5.4.2. Important topics in the sector "Technologies"

The following topics have been discussed in the sector-specific analysis:

- Horizon Scanning: Overview on technologies of the future and emerging pollutants. Michael Depledge, University of Exeter Medical School.
- Early identification of chemical aspects for innovative materials and technologies. Wolfgang Luther, VDI Technologiezentrum GmbH, Düsseldorf
- New Technologies for energy supply and related materials. Andreas Müller, chromgruen, Velbert-Langenberg.
- The future of photovoltaic-based solar energy applications. Jonas Bartsch, Fraunhofer-Institut for Solar Energy Systems, Freiburg.
- NANONext: Experience with technology development in combination with risk screening. Annemarie van Wezel, KWR Watercycle Research Institute, Nieuwegein.

The presentations are documented in the separate Part II of this document (there: chapter 1.4).

5.4.3. Future developments in the sector "Technologies"

The workshop's systematic search for incipient trends, opportunities, challenges and constraints that might affect societal goals and objectives began with a "horizon scanning" presented by Michael Depledge. What is the future of chemical pollution in freshwaters? What will be the new and emerging pollutants, and where will they come from? The following figure gives an illustrative example for a technology-driven increase of consumption of products: the development of mobile phone subscribers per 100 inhabitants for the last two decades.

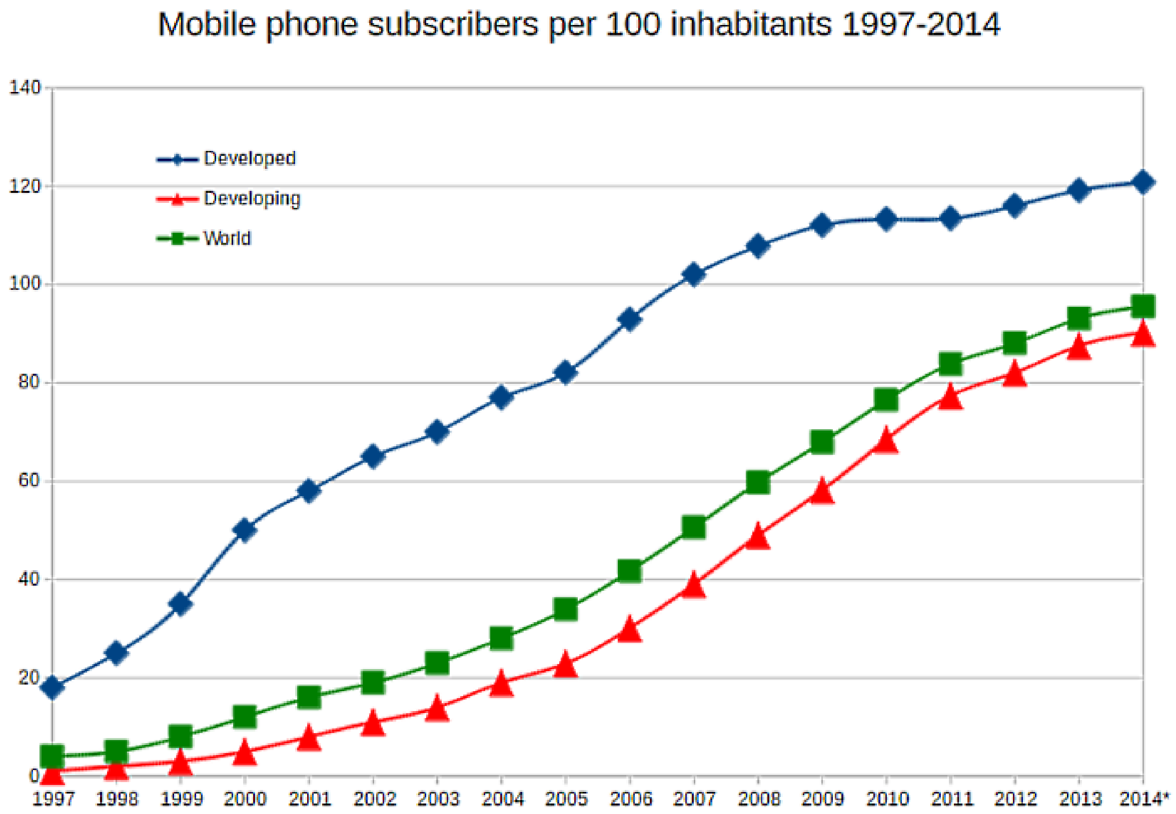


Fig. 20: Mobile phone subscribers per 100 inhabitants distinguishing developed and developing countries. Figures for 2005-2014 taken from International Telecommunication Union – ITU. Source: Wikimedia Commons.

All predictions of future developments show a degree of uncertainty, nevertheless Depledge gave an overview about practical experience in scanning for global environmental issues. The Massachusetts Institute of Technology identified in a similar approach the following candidates as important new technological trends: Nano-Architecture, Car-to-Car Communication, Project Loon (connecting billions of people to the Internet), Liquid Biopsy, Megascale Desalination, Brain Organoids, Supercharged Photosynthesis and Internet of DNA.

Regarding future chemicals and potential pollutants, the key questions are: What kind of chemicals will we need in future worlds? In what amounts? In which regions of the world? From 1940 up to today, the amount of chemicals produced has increased several hundred folds. In part, consumption of chemicals can be directly predicted from product sales – for example, the trace elements needed for smartphones.

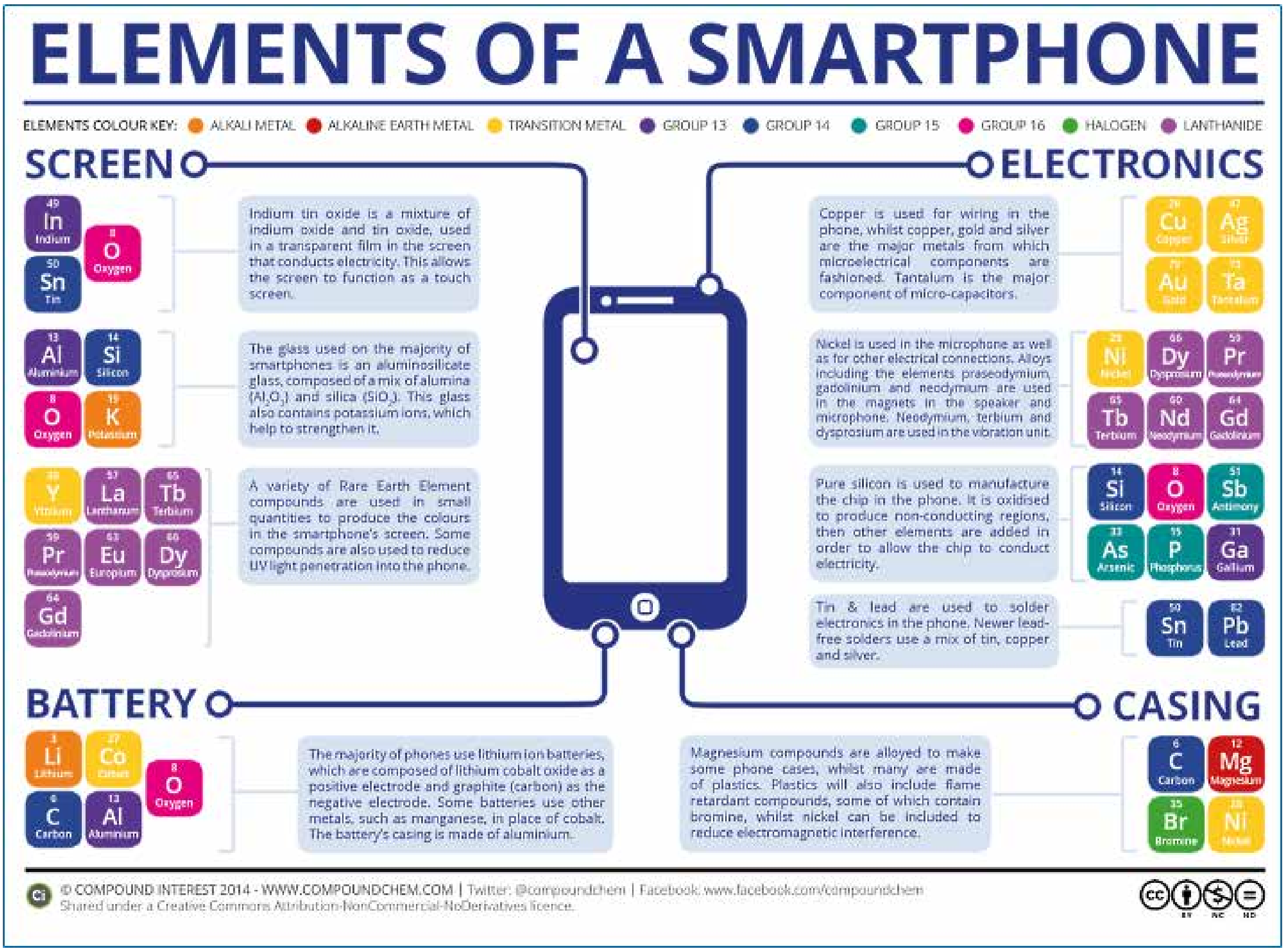


Fig. 21: Trace elements needed for a smartphone. Source: Compound Interest (2014)

5.4.3.1. Existing chemicals

It is estimated that two-thirds of future chemical production growth will be as a result of already-existing chemicals. Parallel to the projected growth in chemical production, new approaches to reduce emissions come up. For example: automated agricultural vehicles in Precision Agriculture minimizing wastage of fertilizers, pesticides and other agrochemicals. However, at present, precise long-term visions about how the future in Europe and the world will look like with respect to new products and chemicals are still lacking.

5.4.3.2. New material developments

Approximately 70% of all product innovations in Europe are based on new material developments. Wolfgang Luther from the VDI Technology Center, Germany, presented an overview on the early identification of chemical aspects for innovative materials and technologies. Materials innovations comprise new substances, substance and material modifications (e.g. surface functionalization), new material combinations (e.g. multi-material systems, composites) and new application context of established substances.

A key driver for material innovations are substitutions. Substitutions may take place for different reasons: rare or cost intensive raw materials, hazardous and toxic substances, change to more sustainable technologies, change to better technical performance and/or cost reduction.

The VDI Technology Center has identified more than a hundred innovative technologies and materials, selecting 20 of them for a deeper analysis. They belong to the following six groups: new production technologies (such as 3D printing), electronics (such as OLEDs and printable electronics), construction and lightweight engineering, energy and environmental engineering (as organic photovoltaics), textile technologies and functional materials and coatings (as polymeric foals). Many of the 470 substances compiled for these new technologies were polymers, a class of compounds, which is not registered under REACH.

5.4.3.3. Energy supplies

One of the major developments in the near future addresses technologies for energy supply. As discussed by Andreas Müller from chromgruen and Jonas Bartsch from the Fraunhofer Institute for Solar Energy Systems ISE, Germany, all technologies of energy transition, including energy production, storage and saving, come along with their specific chemical footprints, which require careful assessment.

Hydraulic fracturing (i.e. Fracking) might be the technology with the largest diversity of chemicals used involving more than a thousand individual compounds. Solar heat requires isocyanates for PU (polyurethane) foams and adhesives, organohalogen and organophosphorous flame retardants, and a range of metals and other inorganic materials.

Bisphenol A-based epoxy resins are used for rotor blades and might be emitted during manufacturing, use and destruction. Hydropower plants can be considered as stocks for legacy chemicals such as asbestos and polychlorinated biphenyls, which may be released to the environment as and when these plants are refurbished.

5.4.3.4. Photovoltaics

One of the key technologies of future energy production is photovoltaic (PV). A wide variety of designs have been developed to save the energy of excited electrons using a range of (mostly silicon-based) semiconductors. Apart from silicon semiconductors, organic solar cells using compounds of complex structure, such as fullerenes and hexalthiophene, dye-sensitized solar cells and mixed types are available but are not expected to replace silicon based PV within the next decade.

During use, the current technology shows only limited risk due to a low release potential. Recycling is desirable – for economic savings and pollution prevention. During production, typically hazardous substances are used. However, this takes place under “clean room conditions” with the aim of closed material cycles.

5.4.3.5. Nanotechnologies

Nanotechnology is another key enabling technology with potentially high benefits for social and economic development, yet which at the same time poses risks to the environment and human health. Both technological development and risk assessment have been interlinked in the Dutch project Nanonext[4] (as presented by Annemarie van Wezel).

The project developed a specific method for Risk Analysis and Technology Assessment – termed RATA – including a specific tool set to check new business ideas for risks – really at the beginning. This "Golden-egg check" may be seen as an example for other novel technologies and is publicly available. Checking for risks in advance and minimizing them from the very beginning may become a selling point for novel technologies.

5.4.3.6. Horizon scanning at Technologies 2030

The SOLUTIONS workshop on "Technologies 2030" and their impact on future pollution highlighted the strongly chemical-related nature of many novel technologies including electronics, energy, nanotechnology and many more.

New compounds for novel technologies such as dye sensitized solar cells will come up but at the same time many already existing chemicals will be used. Thus, future patterns of pollution – in 2030 and onwards – will be a complex mixture of legacy chemicals, "forgotten" old chemicals which are released decades after their use, and new emerging substances.

5.4.4. Key findings for the sector "Technologies"

The following points have been identified as being important regarding future developments in the sector "Technologies":

- High dynamics in technology development
- Huge demand of chemicals. Huge growth of chemical production in Asia and South America, not in Europe
- Chemical pollution: no long-term vision available for a cleaner environment (e.g. climate protection: 2 degree Celsius goal).
- No overarching legislation on chemicals. Specific regulations for pesticides, biocides, industrial chemicals, specific product groups.
- SOLUTIONS product RiBaTox could give the overarching perspective on chemicals.
- Automated agriculture with robots could lead to a reduction of the emission of pesticides
- Photovoltaic modules; lead free alternatives available
- Old hydropower plants: often contaminated sites
- Existing ("old") chemicals are still in used and often the base for new materials
- 2/3 of chemicals production are chemicals known since a long time

4 www.nanonextnl.nl

- Fracking: more than 7 500 substances in use (on different sites)
- Renewable energy does not automatically mean more sustainable energy
- Battery technologies and fuel cells: more information required about substances used
- Interrogate industry more often
- Material scientist can support identification of “new” substances
- Risk Analysis and Technology Assessment (RATA) for “new” materials in technology developments should be done at an early stage of product design (van Wezel et al. 2017).

The list of participants of the sector analysis “Technologies” is given in Annex 7.4.4 of this report.

5.5. Conclusions from the sector-specific analysis

Trends in society and consequences for emerging pollutants have been discussed on four sector-specific workshops. 24 presentations were given and have been discussed. They are documented in Part II of the deliverable D 6.2.

The analysis presented here shows that scenarios for developments in society help to identify future changes in pollution. At least in some fields specific implications for groups of substances can be predicted (with uncertainties). In many areas legacy chemicals will contribute significantly to the future impact on the environment – together with really unexpected new substances. This refers not only to substances which have been used in society decades ago and are still present in stocks, e.g. buildings. It refers also to a large number of “new materials and formulations”, which are often based on the use of already existing chemicals. Furthermore, completely new molecules and materials have to be expected with not yet known usage, field of application and properties. Recent research has shown that chemical compounds resulting from incomplete mineralization of chemicals in effluent treatment and processes in the environment, so called transformation products, will gain more and more attention. 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 survey on future developments in society (see chapter 3) and the results of the sector specific analysis (see chapter 5) have been the basis to derive recommendations for the management of future emerging pollutants. They are described in chapter 3.

6. Trend Indications to model future emerging pollutants

The sector-specific analysis (see chapter 5) has confirmed that numerous developments in society can be expected with implications for future emerging pollutants. Some developments are directly connected to consumption and emission of specific substances. Other developments, such as those associated with climate change, have more complex implications for the pattern of pollutants.

Modelling of emissions, exposures and risks caused by chemicals is an important management tool. If such modelling should consider future developments, qualitative descriptions of developments need to be translated into quantitative figures. In the following sections options are described to develop such trend indications (TI) for chemical pressure (CP).

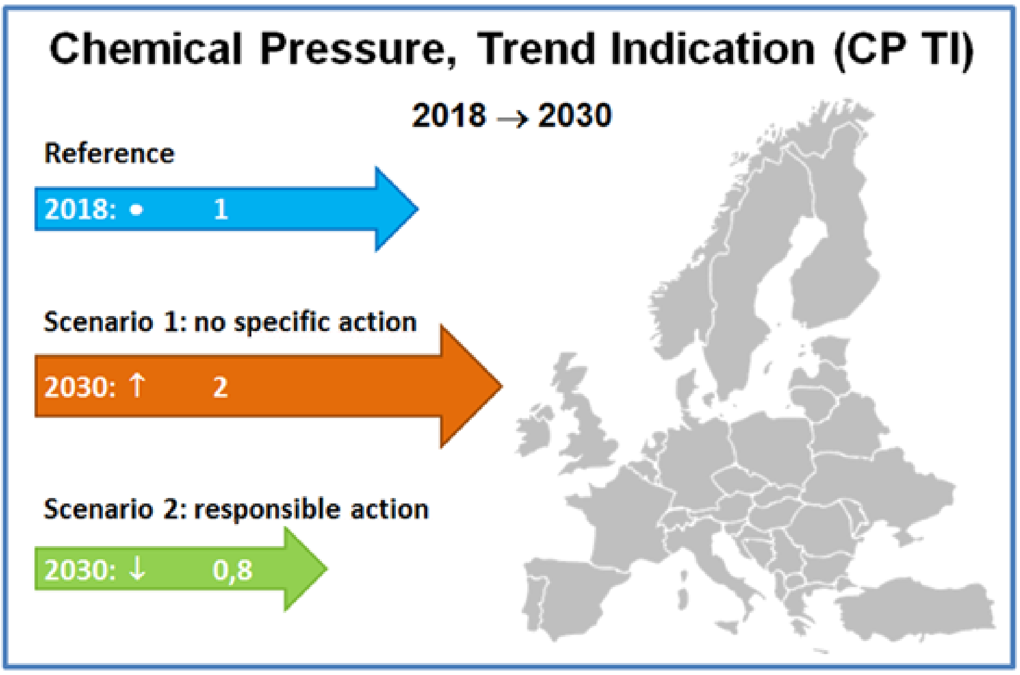
6.1. Quantitative descriptions of future developments

By 2030, implications of several developments in society on the water quality of river basins will become visible (see sections 4.1, and chapters 5 and 6). They range from changes in our environment (e.g. increase in surface temperature) up to increased level of specific substances or substance groups, such as sweeteners in convenience food. Some of these developments can be described in quantitative terms, e.g. the growth of the population in Europe, or the demographic change in Europe by 2020, 2030 or 2050. Other developments are certain too, e.g. increased frequency of heavy rainfall events with an increase in emissions from chemicals used in building facades and an increase of particle emissions from traffic. But for these trends it is difficult to give quantitative terms which could be used for emission modelling. At least, it can be described in a qualitative way, whether a decrease or an increase of emissions can be expected.

The development of emissions will be quite different for specific substances and substance groups. There are clear indications that individual substances will be introduced in the market. Some, which are already in use, will increase by orders of one or two magnitudes (e.g. dimethylfumarat, a pharmaceutical against multiple sclerosis, shows an increase by a factor of five). Consumption of pharmaceuticals used by elderly people will increase due to demographic change, e.g. beta blockers. In addition, several substances are expected to disappear from the market (though they may remain in stocks which have been built up in the past).

For a number of developments, which are relevant for water quality, trends are difficult to describe. Examples are the increased application of wastewater treatment technologies, the enhanced use of more sustainable chemicals, the change of use-patterns by consumers as well as the occurrence of substances resulting from incomplete mineralization of chemicals in effluent treatment and processes in the environment (transformation products).

In the following, four sections important developments (from the two previous chapters) are described in quantitative terms as far as possible. These quantitative terms are called Trend Indications (“TI”). They are derived for individual substances and for groups of substances (e.g.1.5 fold increase of leaching of biocides from building facades). They can be used in modelling to describe different scenarios for the future development of chemical pressure in a quantitative manner. Such scenarios can be developed for individual sites of river basins or for more complex chemical footprints of larger areas. They can compare different options for risk mitigations measures, as shown in the following picture.



Scenarios for future developments (scenario 1, scenario 2) are compared with the reference situation in 2018.
Note: Numbers in the arrows are indicative for increase of chemical pressure (factor 2) and decrease of chemical pressure (factor 0.8). The real values of these numbers depend on the conditions chosen for the scenarios.

Fig. 1, rept.: Trend Indications ("TI") show in which way future developments change the chemical pressure

Trend Indications are described and proposed for the following four fields:

- Developments which can be described in quantitative terms (section 6.1)
- Developments which can be described more in a qualitative way (section 6.2
- Developments which are difficult to foreseen (section 6.3) and
- Trends for individual substances and substances groups (section 6.4).

6.2. Developments in society, which can be described in quantitative terms

For the following fields, developments can be described with a high certainty and in a quantitative manner:

- Population growth in Europe
- Demographic change in Europe
- Age-dependency of drug consumption
- Urbanisation: increase in share of population living in large cities

6.2.1. D1: Population growth in Europe

For the next 30 years, population in Europe is expected to continue to increase. The following figure shows the predicted number of inhabitants in the EU 28 member states, based on statistical data from EUROSTAT.

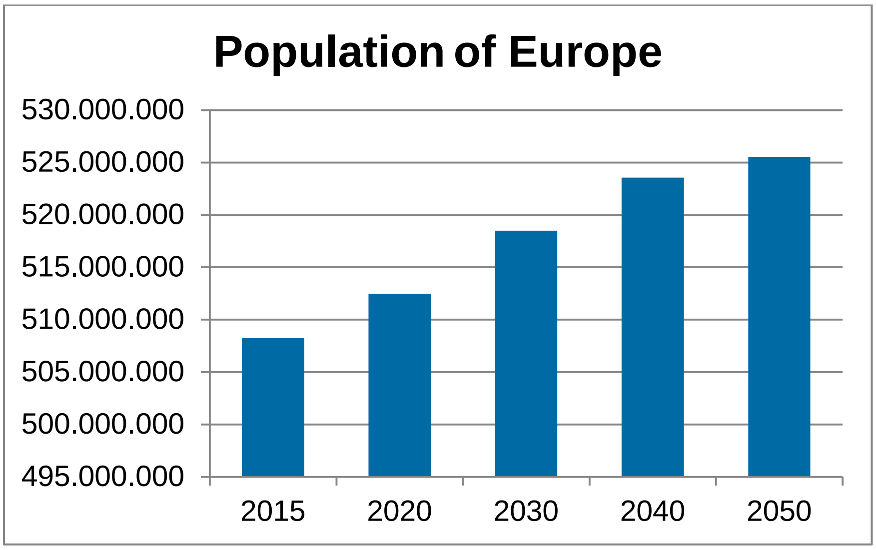


Fig. 22: Population growth in Europe, EU 28 member states. Source: Figures from EUROSTAT (2016)

Between 2015 and 2030, an increase by 10 million inhabitants is predicted. Between 2015 and 2050, the difference is around 17 million.

The following table shows the absolute numbers. In addition, it gives the so-called “trend index”: the value for the years 2030 and 2050, compared to the reference year 2015.

Tab. 2: Increase in population in Europe. Number of inhabitants in the EU 28 Member States. Population in 2030 and 2050, compared to the reference year 2015.

Year	Population	Increase compared to 2015
2015	508.000.000	1
2030	518.000.000	1.02
2050	525.000.000	1.033

The comparison of the numbers shows that the absolute change is comparatively small. The increase is below 10 percent – on a European scale. On a regional scale, changes in population can be more pronounced.

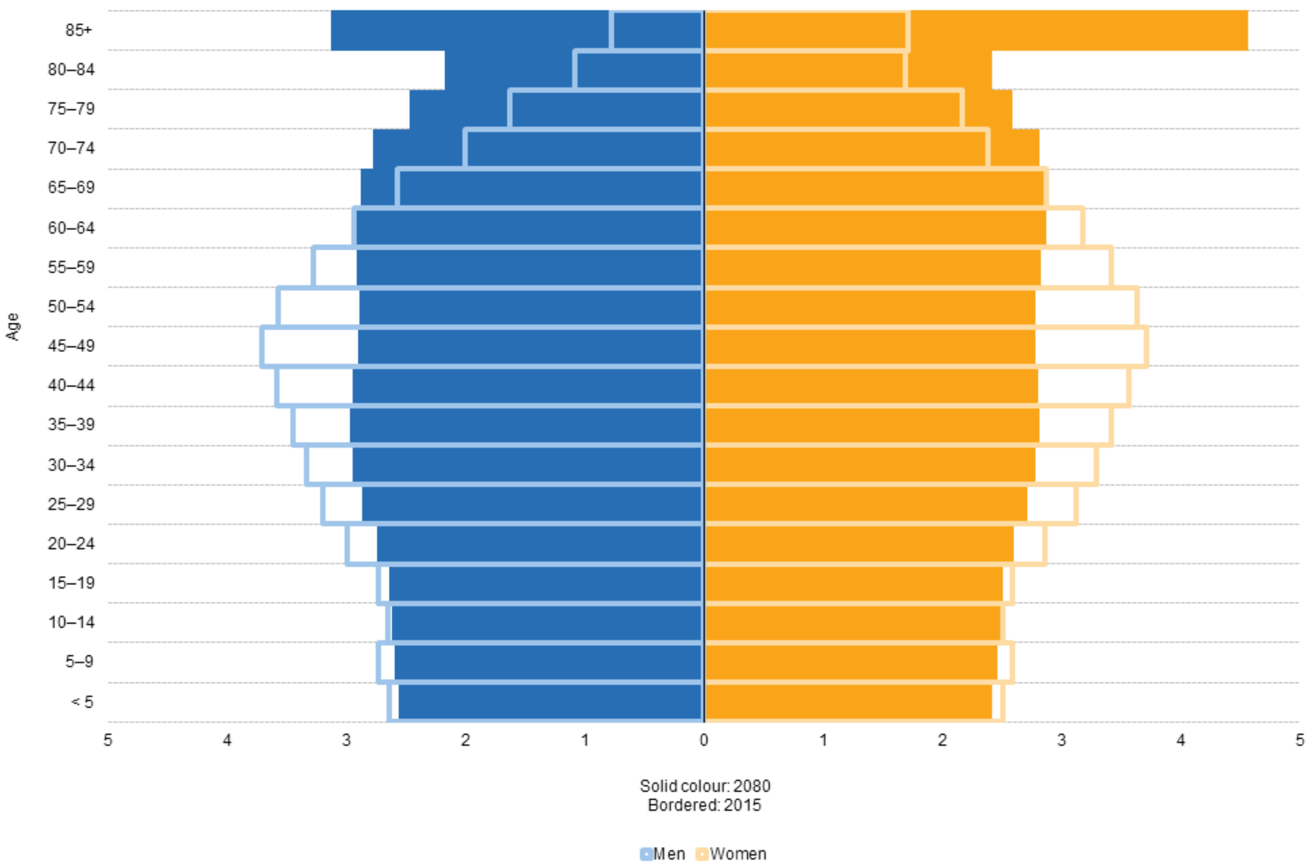
For substances used in private households, such as domestic cleaning agents and cosmetic products, it is reasonable to assume a linear correlation between the emitted amounts and the number of inhabitants. A recent survey on active biocidal substances in urban environments has shown that these substances are not found primarily in biocidal products (Wicke et al. 2015). They are used in personal care products, in washing agents and cleaning agents. Also for these products, an increase can be expected if population increases.

- Conclusion: **Population growth, European Scale**. For modelling of chemical pressure on a European scale, population growth can be neglected.
- Conclusion: **Population growth, regional scale**. Changes in the number of inhabitants on a regional scale should be considered in urban modelling, e.g. in predictions for future drinking water needs.
- Proposal: **Include population growth in regional modelling**. If available on a regional scale, predictions of changes in number of inhabitants could be included in the modelling.

6.2.2. D2: Demographic change in Europe

A significant increase is predicted for the share of people older than 65 in the whole population. This age group is expected to grow by 38% until 2030. The fraction of people below 20 years will show a decrease by 17%.

For the EU 28 Member States, Fig. 23 shows the percentages of inhabitants for each age group for the year 2080, compared with the situation in 2015.



(¹) 2015: provisional; estimate. 2080: projections (EUROPOP2013).
Source: Eurostat (online data codes: demo_pjangroup and proj_13npms)

Fig. 23: Demographic change for EU 28 member states. Expected distribution of inhabitants in age groups for 2080, compared to 2015. Source: EUROSTAT (2016)

The following figure shows data for Europe, for the years 2015, 2030 and 2050.

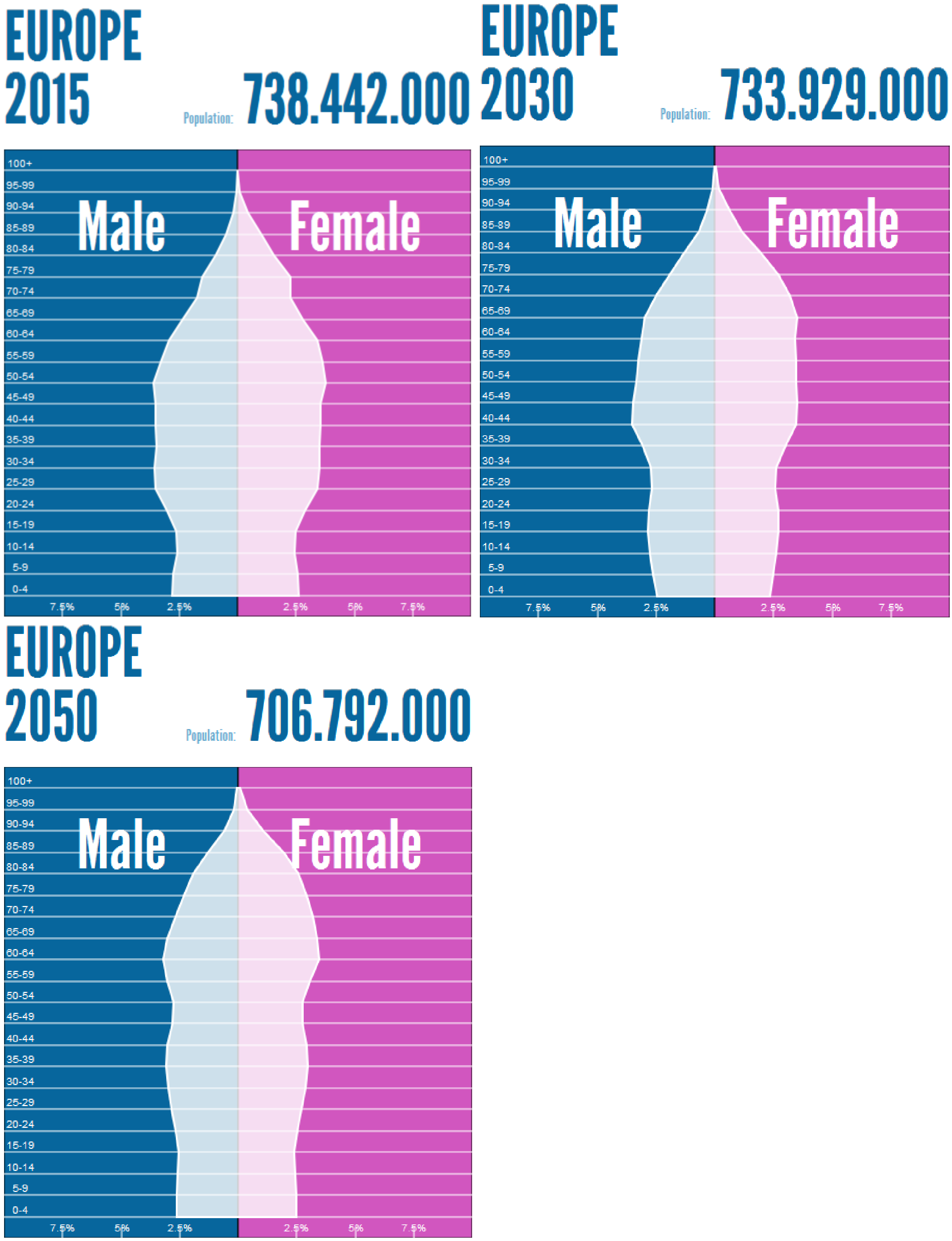


Fig. 24: Demographic change, Europe. Distribution of inhabitants in age groups from 2015 to 2030. Source: United Nations (2015)

The following table shows these developments in absolute numbers. The trend index gives the ratio of the value for the year 2030 and the reference year 2015.

Tab. 3: Demographic change in Europe: number of inhabitants between 15 and 65 years old, and above 65, in the year 2030, compared to the reference year 2015

Year	Total number	compared to 2015
Inhabitants between 15 and 65 years old		
2015	335.000.000	1
2030	283.000.000	0.84
Inhabitants 65 years old and older		
2015	86.800.000	1
2030	151.500.000	1.7

The comparison of the numbers show that the absolute change is significant. The increase for the group of older people is more than 50% (increase by 70%).

- Proposal: For pharmaceuticals preferentially used by older people, an increase of used amounts and emission by a (trend indication) factor of 1.7 can be expected.
- Need for clarification: Demographic change should be considered in emission predictions for chemicals, which are used in different amounts by different age groups. Does this take place already in our models?

6.2.3. D3: Age-dependent increase in prescription of drugs

With increasing age, the number of drugs prescribed for medical treatment increases. The following figure shows how many so-called “defined daily doses” (“DDD”) are prescribed for the age groups from below 5 years up to above 100 years. The numbers are shown for German males; they differ slightly from the numbers for females. There is a continuous increase from age group 20 - <25 years (with around 110 defined daily doses) to age group 80 -<85 years (with around 1.890 defined daily doses). For the very old people – age groups from 85 until above 100 years – between 1.530 and 990 defined daily doses are given.

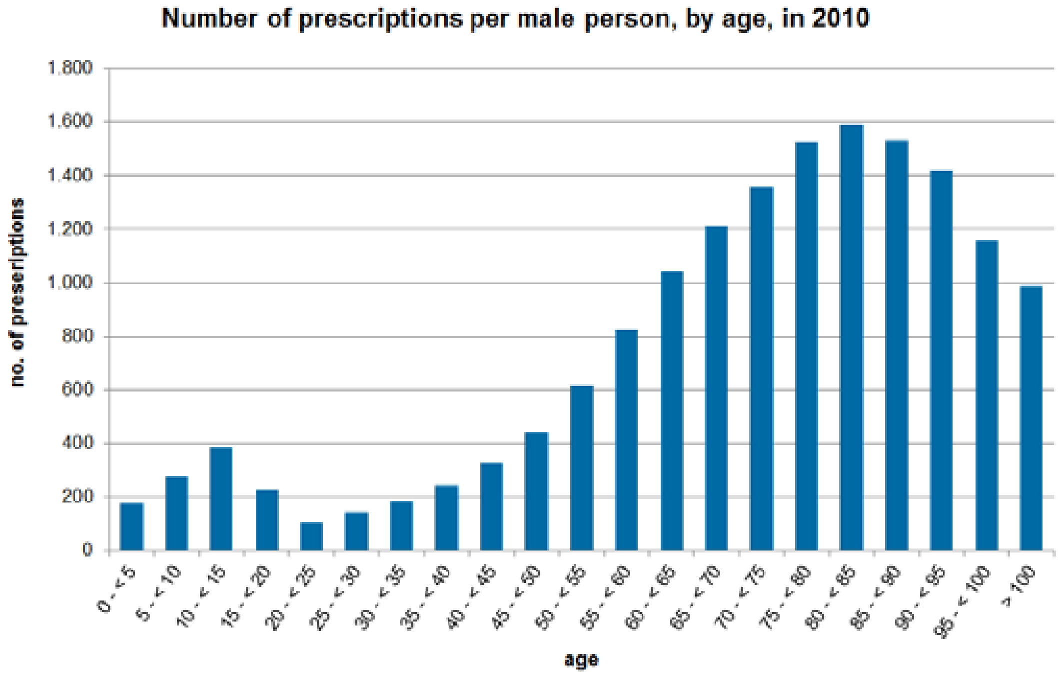


Fig. 25: Age-group specific use of pharmaceuticals. The figure shows how many prescriptions of drugs are made for age groups from below five years up to above 100 years. Numbers are given in defined daily doses ("DDD"s) per year. The numbers refer to male inhabitants in Germany. Source: Wissenschaftliches Institut der AOK as cited by Statista (2016)

The age-dependent increase in prescribed dosages can be combined with:

- data on the increase in population in Europe by 2030 (see section 6.2.1 (the increase is small) and
- data on the demographic change, which leads to a higher number of inhabitants from the older age groups (with more daily doses than the younger age groups).

The following table shows the predicted development of defined daily doses, taking into account the increased population, demographic change and increased prescriptions, between 2015 and 2030.

Tab. 4: Development of use of human pharmaceuticals, taking into account the increased population, demographic change and increased prescriptions. Prescribed defined daily dosages per male inhabitant per years. Numbers for 2015 and 2030

Year	Total number	Compared to 2015	In %
Prescribed defined daily doses per male inhabitant			
2015	264	1	
2030	277	1.05	5%
Prescribed defined daily doses, EU 28 population (2015: 507 Mio inhabitants, 2030: 510 Mio inhabitants)			
2015	1.34 Billion DDDs	1	
2030	1.41 Billion DDDs	1.06	6%

Source: Own compilation

For the total number of prescriptions, an increase is expected for Europe by around 6% from 2015 to 2030.

- Proposal: In emission predictions for pharmaceuticals, a generic value (trend indication factor) of 1.06 can be applied as an estimate for the increase of consumption. More precise trend indications can be made if consumption data for specific therapeutic groups or for individual active ingredients are known.

6.2.4. D4: Urbanisation: increase in share of population living in large cities

At present, 50% of the global population are living in cities. It is expected that by 2030 this number will increase by a factor of 1.32 to 66%. This process of “urbanisation” can also be seen in Europe. At present, no exact number can be given for the degree of urbanisation in Europe.

Urbanisation can trigger increased concentrations of emerging pollutants in the urban environment if it is not counterbalanced by an improvement of mitigation measures. Increase of inhabitants in cities will lead to an increase in the consumption of chemicals used in private households. For example, compared to rural areas, in cities rhodenticides are used more frequently to control rats. Therefore they can appear as emerging substances in run-off water, typical for city emission profiles.

- Proposal: In emission predictions for cities, a generic value (trend indication factor) of 1.3 can be applied as an estimate for the increase of emissions due to urbanisation. This factor reflects the global process of urbanisation without specification for Europe. More precise trend indications can be made for individual cities if exact data are available for the expected change in number of inhabitants in the future.
- Proposal: Trends for biocides, including rhodenticides, should be included in the monitoring of micropollutants from urban environments.

6.3. Trends in society which can be described more qualitatively

For the next two decades, at least five developments with implications for water quality can be seen which are more difficult to describe in quantitative terms:

- Climate change, water scarcity and re-use of untreated wastewater
- Climate change and stormwater run-off
- Climate change, heavy rain falls and leaching of chemicals from building facades
- Climate change, incidence of (new) diseases and use of (new) drugs
- Convenience food: sweeteners and other food additives

6.3.1. D5: Climate change, water scarcity and re-use of untreated waste water

Climate change is expected to cause an increase of areas with water scarcity. As a consequence, more frequently untreated wastewater will be used for irrigation. This leads to an additional emission of contaminants to river basins. The magnitude of this effect will strongly depend on regional conditions and is difficult to predict.

- Proposal: Effects of water scarcity on water quality have been seen in the case study of the Ebro river basin. This will be used to derive first trend indications.

6.3.2. D6: Climate change and stormwater run-off

Untreated stormwater run-off has been found as an important source of urban pollutants: suspended solids, heavy metals, traffic related micropollutants, plasticisers, flame retardants and biocides (Wicke et al. 2015). An extended list of substances, typical for urban emissions, is given in Annex 1 (section 7.1).

- Proposal: In emission predictions for cities, increased climate pressure on city-specific substance groups is expressed by a trend indication factor of 1.25 (moderate increase of emissions) or 2 (strong increase of emissions). These generic values can be replaced by values from experimental studies.

6.3.3. D7: Climate change, heavy rainfalls and leaching of chemicals from building facades

Climate change is expected to cause an increase in the frequency of heavy rain falls and stormy weather events (Moritz et al. 2017). Different types of biocides are used in construction in order to prevent growth of fungi and algae as antifouling paints of facades. They are leached out of the material through contact with wind-driven rain (Bollmann et al. 2014). The mass load of biocides during rain water has been found to be highest during heavy rain periods.

Emissions of these biocides are also found in dry water periods (when leaching from facades do not occur), because they are applied in these periods. Examples for biocides used for surface protection areterbutryn, cybutryne, propiconazole and N-octylisothiazolinone. Beside biocides, other chemicals are used for surface coating and surface protection too, e.g. flame retardants. Examples are given in Tab. 5 in Annex I (section 7.1).

- Proposal: In emission predictions for cities, increase of leaching of chemicals from facades is expressed by a trend indication factor of 1.25 (moderate increase of emissions) or 2 (strong increase of emissions). These generic values can be replaced by values from experimental studies.

6.3.4. D8: Climate change, incidence of (new) diseases and use of (new) drugs

A more frequent occurrence of different diseases due to climate change has been observed in the last decade (Redshaw et al. 2013). For specific vector-borne diseases, food-borne diseases and non-transmittable diseases it can be assumed that the amount of pharmaceuticals needed for their treatment will grow. In some cases, new pharmaceuticals will be required. The extent of this development is disease-specific with regional variations.

- Proposal: Due to the large number of diseases which are effected and due to regional variations, this development is difficult to describe in quantitative terms. In parallel, robust data for the consumption of pharmaceuticals is available for several European countries. Therefore, we propose to describe this development by consumption values for the related pharmaceuticals – see section 6.5.3. These values include already the influence of climate change.

6.3.5. D9: Convenience food: sweeteners and other food additives

During the last decade, consumption of so-called "lifestyle products" has increased steadily (Bunke and Moritz 2014; Moritz et al. 2017). Important products groups are convenience food and convenience in human care products. In both product groups, often sweeteners and specific food additives are used (Loos et al. 2009). Some of these substances are already found as micropollutants in surface water. It is reasonable to assume that the increase of consumption of these product groups lead to a parallel increase of emissions of these additives.

- Proposal: In emission predictions, the increase in use of convenience food can be expressed by a trend indication factor of 1.25 (moderate increase of amounts used) or 2 (strong increase of amounts used). If for individual additives robust data on use and consumption are available, they can replace these generic values.

6.4. Development which are difficult to foreseen

For the following fields, with implications on water quality, future developments are difficult to predict:

- Pesticides: changes due to climate change and land use change
- New substances from new technologies and innovative materials
- Abatement technologies: use and developments
- Substitution by less problematic substances
- National reduction plans and voluntary stewardships
- Design of less problematic substances ("benign by design")

The fields are described in the next six sections.

6.4.1. D10: Pesticides: changes due to climate change and land use change

At present, it is unclear to which extent climate will influence the use of pesticides, e.g. due to land use change and changes in the weather conditions (Steffens et al. 2015; Kattwinkel et al. 2011; Neumeister 2010). On the other hand, for many pesticides robust data on used amounts are available.

- Proposal: In order to describe changes in pesticide use, a trend indication can be derived based on data for the amount of pesticides used (see section 6.5.3), as long as no site-specific data are available.

6.4.2. D11: New substances from new technologies and innovative materials

Innovations in technologies are of central importance to enhance the efficiency of processes and products. New materials are constantly developed. A recent survey covered 34 fields of "new" technologies (Eickenbusch et al. 2015). More than 300 substances have been reported to be used in these developments. In addition, a specific survey was made on new technologies for energy supply (Müller et al. 2014). Also in this field a high number of substances are used, partially new substances.

- Proposal: At present, it is quite difficult to predict which substances will change due to technological developments or energy transition processes without further specification. A generic trend indication is not proposed in this field. It can be derived if specific technologies are assessed in detail.

6.4.3. D12: Abatement technologies: use and development

A broad range of abatement technologies is available for different sectors. Recently, an overview on efficiencies of technical abatement options at emission points and at receptor locations with reference to the life cycle stages has been prepared within SOLUTIONS (van Wezel et al. 2017). The efficiencies have been compared to non-technical abatement options. New abatement technologies are under development. Data for application of specific abatement technologies for waste water treatments are available for several countries. Removal efficiencies are substance-specific and often show – for a given substance – a wide variation.

- Proposal: Trend indications for the use and development of abatement technologies should be sector- and substance specific. For the description of developments in this field, we propose to use as trend indication two generic values: a factor of 0.8, assuming a moderate increase in the application of abatement technologies (leading to a reduction of emission by this factor), and a factor of 0.5, assuming an intense increase in removal efficiency. If actual values for the development of abatement technologies are available, they should replace these generic values.

6.4.4. D13: Substitution by less problematic substances

For a large number of problematic substances substitutes are available, which have less problematic properties. At present, no information is available to which extent substitutions of problematic substances take place if it is not triggered by restriction of substances. In the latter case, the regulated substances are frequently replaced by substances of a similar structure – and similar problematic properties (a so-called "regrettable" (1:1 substitution), see section 6.5.2). The use of less problematic substances could give significant contributions to lower the chemical pressure.

- Proposal: In order to calculate the effects of the use of less problematic substances, we propose for the trend indication two generic values: a factor of 0.9, assuming a moderate use of substitutes, and a factor of 0.5, assuming an intense use of substitutes. In modelling, the amounts used of specific problematic substances are reduced by these factors.

- In parallel, the amounts used of substitutes with less problematic are increased to ensure that the required amounts of the substances are still available.

It is assumed that for both substances (the problematic substance and its substitute) the amount is the same which is needed to fulfil a specific function.

6.4.5. D14: National reduction plans and voluntary stewardships

In several EU Member States quantitative reduction goals are in place for problematic groups of substances, such as antibiotics used in animal farming. They supplement regulatory restrictions set for individual substances. In Germany, a reduction goal for antibiotics, together with a monitoring of the amounts sold, resulted in a 50% reduction of this substance group within four years.

There are several examples for voluntary action plans (stewardship programmes) of industrial sectors addressing individual problematic substances such as PFOS (before regulatory actions), or substance groups, such as poorly biodegradable organics in detergents. At present, those activities only exist for a small number of substances and substance groups.

- Proposal: In order to calculate the effects of national reduction plans and similar measures on the chemical pressure, we propose for the trend indication two generic values. A factor of 0.9 for a moderate success of a “50% reduction goal”. This moderate success results in a 10% reduction of the emission, 90% are remaining. A factor of 0.5 assuming a successful implementation of the reduction goal. This results in a 50% reduction of the emissions, 50% are remaining. In modelling, the amounts used of problematic substances addressed in these measures are reduced by these factors.

6.4.6. D15: Design of less problematic substances (“benign by design”)

Since more than two decades, possibilities have been developed to design substances which are more biodegradable and have less problematic properties (Kümmerer 2007). These design principles have not only been applied to pharmaceuticals, but also to industrial chemicals such as detergents. At present, it is not known to which extent these possibilities are used. They would avoid the use and emission of problematic substances.

- Proposal: In order to calculate the effects of the application of benign-by-design strategies, we propose for the trend indication two generic values: a factor of 0.9, assuming a moderate use of substitutes, and a factor of 0,5, assuming an intense use of substitutes. In modelling, the amounts used of specific problematic substances are reduced by these factors.

6.5. Trends for individual substances and substance groups

For a number of substances and groups of substances, it is reasonable to assume a change in their production, use, or emission over time – for different reasons. In the following three sections we distinguish between:

- Substances expected to decrease in volume
- Substances expected to increase in volume
- Data-rich substances expected to change in volume.

6.5.1. D16: Substances expected to decrease in volume

By regulatory measures, problematic substances can be forbidden or restricted in their use. As a consequence, emissions to the environment are reduced too. Under REACH, substances can be restricted (one or more uses are no longer allowed) or become subject to authorisation. This means that in general the placing on the market and the uses of these substances are forbidden. With the exemption of uses for which an authorisation has been granted. This requires a comprehensive assessment of the risks and benefits of these uses and of available substitutes.

In a similar way, the use of specific pesticides and biocides can be forbidden under the respective regulation. This also counts for substances identified as persistent organic pollutants (POPs) under the Stockholm Convention or for substances which are restricted under another product- or substance-related regulation (for a worldwide overview on regulations specifically aimed at chemicals, see Geiser (2015)).

Prior to restriction or authorisation, substances of very high concern (SVHC), as defined under REACH, can be placed on the REACH Candidate List. These substances eventually will be subjected to authorisation. Already the placing on the Candidate List triggers communication obligations in the supply chain and to consumers (the latter only on request). For candidate substances it is reasonable to assume that production and use will significantly decrease in time.

In case of persistent substances, emissions from stocks can occur for longer time periods, even if the further use of the substance has been forbidden by law.

To summarize, for the following substances reductions of the amounts used can be expected:

- Substances on the REACH Candidate List
- Substances subject to authorisation under REACH (REACH Annex XIV)
- Persistent organic pollutants, Stockholm Convention
- Restricted or prohibited biocides, pesticides and pharmaceuticals
- Substances which are restricted under other regulations (e.g. Toy Safety Directive).

- Proposal: For the most important substances found so far in modelling and monitoring activities in SOLUTIONS, it is checked whether they are already restricted by law. In this case, a significant decrease of the amount used is assumed within the next years (scenario 1: decrease by 50% within 5 years / scenario 2: decrease by 100% by 5 years, or decrease rate specific for a substance due to a given sunset date).

For a limited number of substances, precise data on the amounts used, and sometimes even predictions for trends, are publicly available. Examples are pharmaceuticals, biocides and pesticides . For some of these substances, a decrease in the used amounts has been found. More details on these substances are given in section 6.5.3. One example is shown in Fig. 26: triotropium bromide, a pharmaceutical against pulmonary diseases.

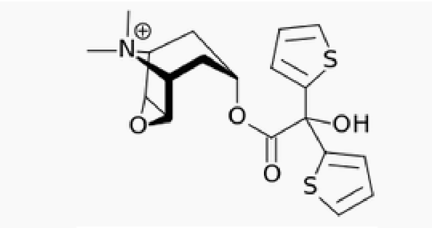


Fig. 26: Structure of triotropium bromide, a pharmaceutical against pulmonary diseases. Amount of use is expected decrease more than 2 fold from 2014 to 2030.

6.5.2. D17: Substances expected to increase in volume

Experience from the last three decades show that substances which became restricted by law, are very frequently replaced by substances with an identical function and a similar structure. Therefore, it is reasonable to assume that these substitutes will increase in use and also in it´s emissions to the environment. This has been the case for brominated flame retardants, plasticisers, per- and polyfluorinated chemicals, as well as for endocrine disrupting chemicals.

- Proposal: We propose to assume that substitutes, which are known to replace restricted substances, increase significantly (to the same amount as the replaced substances decrease).

For the following groups of substances an increase in use (and related emissions) can be expected:

- Substances used as sweeteners in convenience food (see section 6.3.5 for details and proposals how to describe trends)
- Biocides and other chemicals used for facades of buildings, increased release and repeated application due to increased weather stress by climatic change (see section 6.3.3 for details and proposals how to describe trends)

As mentioned in the previous section, for a limited number of substances precise data on the amounts used, and sometimes even predictions for trends, are publicly available. Examples are pharmaceuticals, biocides and pesticides. For some of these substance groups an increase in the used amounts has been found. More details on these substances are given in section 6.5.3, together with a proposal how to derive the trend indications. One example is shown in Fig. 27: the anti coagulant afixaban.

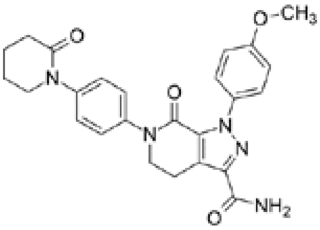


Fig. 27: Structure of afixaban, an anti coagulant which amounts of use are expected to increase more than 2 fold from 2014 to 2030.

6.5.3. D18: Data-rich substances expected to change in volume

For several groups of substances robust data on amounts used or produced are available for several EU Member States and globally. This is the case for:

- Pharmaceuticals, including antibiotics
- veterinary drugs, including antibiotics
- biocides and
- pesticides

For individual substances from these groups, predictions on the future amounts are available too. The following figure shows as an example the predicted global development of the amounts sold for the 50 top-sold pharmaceuticals. Between 2015 and 2030, some products will increase more than 10 fold, other ones will completely disappear from the market. From the set of 50 pharmaceutical assessed, 38 shows an increase, 12 a decrease. The increases range between 2 up to more than 200 fold.

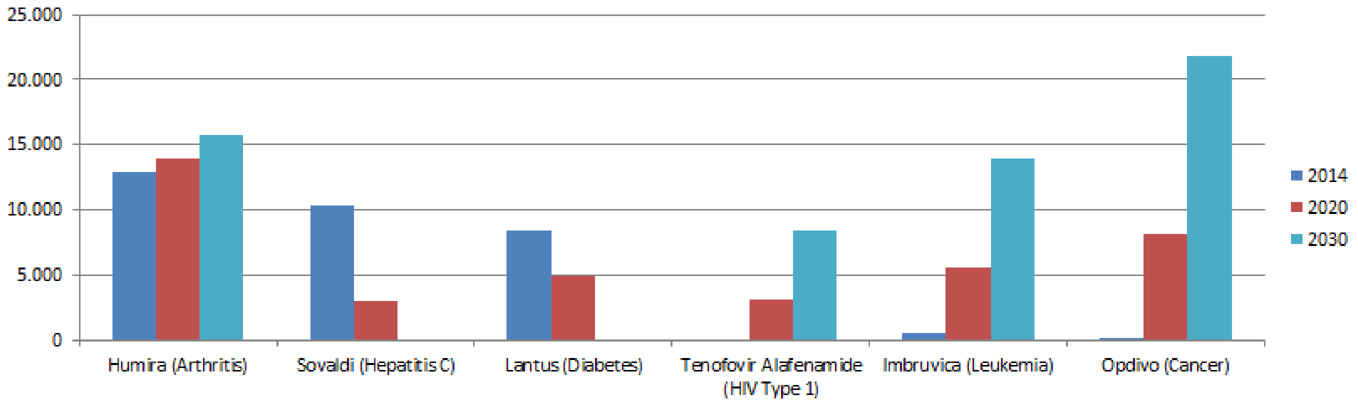


Fig. 28: Development of the amounts used for pharmaceuticals which are of global importance. Numbers are given for the years 2014, 2020 and 2030, in billion $. Source: Statista (2016)

- **Proposal**: Whenever robust figures on consumption trends for individual substances are available, they could be used to derive substance-specific values for the trend indications (TIs).

6.6. Endpoints for effect based monitoring

Specific groups of pharmaceuticals are more frequently prescribed for elderly people. Due to demographic change, it is expected that the following therapeutic groups will increase significantly:

- lipid regulators
- anti-depressants
- anti-inflammatory drugs
- diabetic medicaments
- antibiotics

It is reasonable to assume that also the concentrations of substances from these groups (and their metabolites and transformation products) in surface water will increase. At present, it is not clarified whether the modes of action of these substances are already covered by effect based tools, and whether they are included in the effect based monitoring within SOLUTIONS.

- Proposal: It should be checked whether available bioassays already address the therapeutic groups which are expected to increase in future. These groups of substances should be included in environmental monitoring activities.

6.7. Summary and outlook

By 2030, implications of several developments in society on the water quality of river basins will become visible. Some of these developments can be described in quantitative terms, e.g. the growth of the population in Europe, or the demographic change in Europe by 2020, 2030 or 2050. Other developments are certain too, e.g. increased frequency of heavy rainfall events with an increase in emissions from chemicals used in building facades and an increase of particle emissions from traffic. But for these trends it is difficult to give quantitative terms which could be used for emission modelling. At least, it can be described in a qualitative way, whether a decrease or an increase of emissions can be expected.

The development of emissions will be quite different for specific substances and substance groups. There are clear indications that individual substances will be introduced in the market. Some, which are already in use, will increase by orders of one or two magnitudes (e.g. dimethylfumarat, a pharmaceutical against multiple sclerosis, shows an increase by a factor of five). Consumption of pharmaceuticals used by elderly people will increase due to demographic change, e.g. beta blockers. In addition, several substances are expected to disappear from the market (though they may remain in stocks which have been built up in the past).

For a number of developments, which are relevant for water quality, trends are difficult to describe. Examples are the increased application of wastewater treatment technologies, the enhanced use of more sustainable chemicals, the change of use-patterns by consumers as well as the occurrence of substances resulting from incomplete mineralization of chemicals in effluent treatment and processes in the environment (transformation products).

As far as possible, at least qualitative trend indications (“TI”) are described in this report for the effect of an individual development on future pollutants. They show whether an increase or a decrease of the emissions of chemicals to the environment is expected. In some cases, it seems possible to quantify the potential effect of a development by numbers (quantitative trend indications).

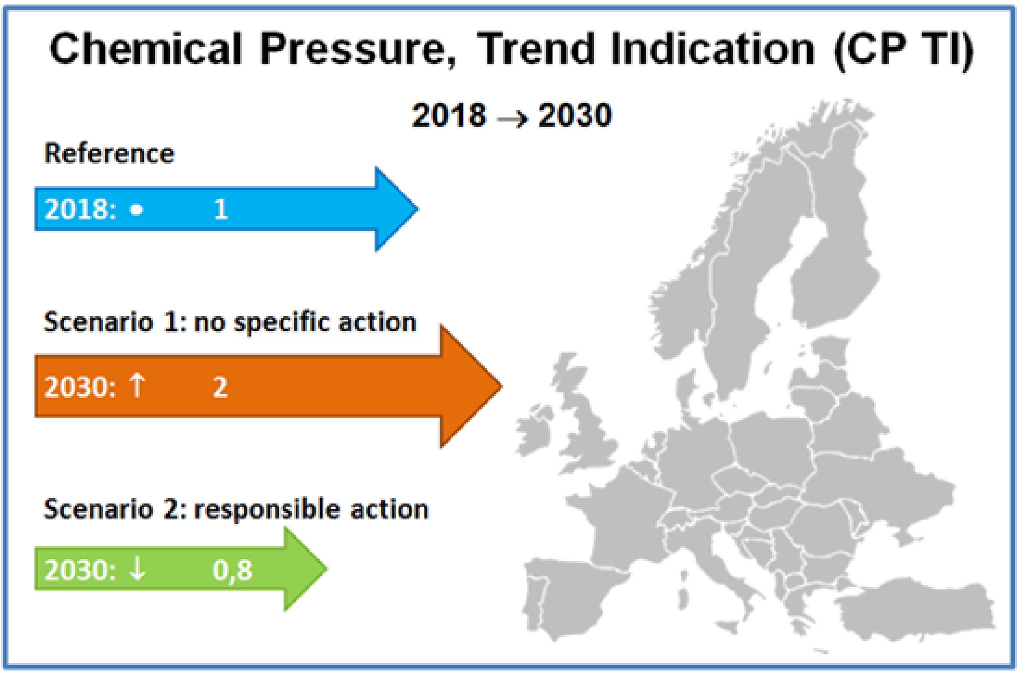
The developments described above do not affect all groups of substances and individual substances in the same direction and to the same extent. For other activities of SOLUTIONS, groups of substances have already been defined, e.g. household chemicals, personal care products, sweeteners, industrial chemicals, pharmaceuticals, biocides, pesticides. These groups are further divided in subgroups. For each group of chemicals it can be assessed to which extent they are affected by different developments in society.

Application of trend indications in modelling

In SOLUTIONS, from the case studies and from the tool development, different lists of problematic substances have been derived. For the most important substances on these lists the trend indications can be determined. This allows an estimation how these substances will develop in future. Two approaches can be used for this purpose.

- Site-specific development of future pollutants: Application of the trend indications in modelling.

The trend indications (TIs) can be used to show in which way future developments change the chemical pressure. They can also illustrate the effects of different options to act, as shown in the following figure.



Scenarios for future developments (scenario 1, scenario 2) are compared with the reference situation in 2018.
Note: Numbers in the arrows are indicative for increase of chemical pressure (factor 2) and decrease of chemical pressure (factor 0.8). The real values of these numbers depend on the conditions chosen for the scenarios.

Fig. 29: Trend Indications ("TI") as a way to show potential future developments of chemical pressure

In order to model future chemical burdens, scenarios can be developed. These scenarios are combinations of several trends described above. They include in addition assumptions on emission reduction measures taken and their efficiency.

- How can chemical footprints develop? Application of trend indications in backward analysis

Chemical footprints visualises chemical burdens, based on modelling of complex mixtures of pollutants. Within SOLUTIONS, chemical footprints are calculated and discussed in relation to planetary boundaries. These calculations will show the main drivers for chemical burdens. Using the Trend Indications described above, it can be analysed how developments in society affect these drivers. Scenarios can be chosen which reflect important objectives as circular economy and different options to reach these goals. This will allow comparing present and future chemical footprints (Posthuma et al. 2017; Zijp et al. 2014).

7. Annexes

7.1. Annex 1: Substances in run off from urban areas

The following table lists substances which can be found in run off from urban areas. They are emitted from buildings. These emissions can increase if frequency of heavy rain fall events increases.

Tab. 5: Substances in run off from urban areas, emitted from buildings

	CAS Number	Substance	Function	Comment	substance group	Reference
1	3194-55-6	Hexabromocyclododecane	Most important flame retardant for insulation materials (expanded polystyrene), in addition used in textiles for furnitures and housings. coatings from plastics for		flame retardant	Breuer et al. (2012)
2	886-50-0	Terbutryn (2-Methylthio-4-tert-butylamino-1,3,5-triazine)	active ingredient in hydrophobic facade coatings	necessary partial water solubility for efficacy (mg/L:25), encapsulated 59% less elution highest elution: first 10-20 rain events	biocide	Breuer et al. (2012)
3	330-54-1	Diuron (DCMU, 3-(3,4-dichlorophenyl)-1,1-dimethylurea)	active ingredient in hydrophobic facade coatings	necessary partial water solubility for efficacy (mg/L:35), encapsualted 85% less elution highest elution: first 10-20 rain events; The diuron concentrations were considerably lower than in French urban river water (Blanchoud et al., 2004)., first flush behaviour	biocide	Breuer et al. (2012)
4	55406-53-6	IPBC (3-Iodoprop-2-ynyl-N-butylcarbamate)	active ingredient in hydrophobic facade coatings	necessary partial water solubility for efficacy (mg/L: 168), encapsulated 44% less elution highest elution: first 10-20 rain events	biocide	Breuer et al. (2012)
5	26530-20-1	OIT (2-n-Octyl-isothiazolin-3-one)	active ingredient in hydrophobic facade coatings	necessary partial water solubility for efficacy (mg/L: 480), encapsulated 59% less elution highest elution: first 10-20 rain events	biocide	Breuer et al. (2012)
6	64359-81-5	DCOIT (4, 5-Di-chloro-2-n-octyl-isothiazolin-3-one)	active ingredient in hydrophobic facade coatings	necessary partial water solubility for efficacy (mg/L: 14), encapsulated 23% less elution highest elution: first 10-20 rain events	biocide	Breuer et al. (2012)

	CAS Number	Substance	Function	Comment	substance group	Reference
7	217487-17-7	Isoproturon	-	herbicide effect	biocide	Breuer et al. (2012)
8	886-50-0?	Terbutryn	active ingredient in hydrophobic facade coatings/ laquers	herbicide/ algaecide effect; The results obtained for terbutryn from Swiss surface water (median < 10 ng L 1 (Wittmer et al., 2010)) agree well to those found in the present study (median 52 ng L 1), while it was lower as found by Quednow and Püttmann (2007, 2009) in German surface waters (50e5000 ng L 1), first flush behaviour	biocide	Breuer et al. (2012)
9	28159-98-0	Cybutryne	-	biocide and fungicide effect, first flush behaviour, post flush behaviour, labelled as "former NORMAN" compounds, suspected endocrine disruptor	biocide	Breuer et al. (2012)
10	107534-96-3	Tebuconazole	active ingredient in laquers	fungicide effect	biocide	Breuer et al. (2012)
11	10605-21-7	Carbendazim	-	fungicide effect, not accredited in EU, first flush behaviour	biocide	Bollmann et al. (2014)
12	60207-90-1	Propiconazole	active ingredient in facade coatings/ wood preservers	fungicide effect	biocide	Breuer et al. (2012)
13	2682-20-4	Methylisothiazolinone	-	micobicide effect, Bactericide/Fungicide, first flush behaviour	biocide	Bollmann et al. (2014)
14	2634-33-5	Benzoisothiazolinone	active ingredient in laquers/ latex paint	microbicide and fungicide effect	biocide	Bollmann et al. (2014)
15	26530-20-1	N-octylisothiazolinone	active ingredient in wood preservers/ roof paint	Bactericide/Fungicide	biocide	Bollmann et al. (2014)
16	93-65-2/ 7085-19-0	Mecoprop	roofprotection	not accredited in Germany	biocide	Breuer et al. (2012)
17	28553-12-0	Di-iso-nonyl phthalate (DINP)	vinyl flooring additive	According to the model predictions, substitution of DEHP with DINP in vinyl flooring clearly results in reduced annual plasticizer emissions; DINP seems to be less toxic than DEHP	plasticizer	Holmgren 2015
18	117-81-7	Diethyl-hexylphthalate (DEHP)	vinyl flooring additive	Compared to DINP, DEHP has a smaller molecular size and is more volatile, which explains why ist rate of release was faster.	plasticizer	Holmgren 2015
19	-	Diethyl-hexyl isosorbate (isdeh)	vinyl flooring additive	the model predicts that substitution of DEHP with isDEH and DEHA would give higher emissions than DINP, whereas substitution with DINCH would lead to almost the same emissions	plasticizer	Holmgren 2015

	CAS Number	Substance	Function	Comment	substance group	Reference
20	166412-78-8	1,2-cyclohexanedi-carboxylic acid di-iso-nonyl ester (DINCH)	vinyl flooring additive		plasticizer	Holmgren 2015
21	103-23-1	Diethyl-hexyladipate (DEHA)	vinyl flooring additive		plasticizer	Holmgren 2015
22	108-95-2	Phenol	vinyl flooring additive		plastics manufacturing	Holmgren 2015
23	629-59-4	Tetradecane	vinyl flooring additive			Holmgren 2015
24	629-62-9	Pentadecane	vinyl flooring additive			Holmgren 2015
25		Propiconazole (PPZ)		Fungicide, not sure wether it is a product name or the name of an actual chemical- couldn't find the CAS number	biocide	Holmgren 2015
26	37853-59-1	1,2-Bis(2,4,6-tribromo-phenoxy)ethane (BTBPE)	flame retardant	Overall, fish from rivers receiving effluent fom wastewater treatment plants (WWTP) had higher PBDE levels. Meanwhile, levels of non-BDE flame retardants were highest in lakes receiving a mix of WWTP effluent and atmospheric deposition (Mayfield Lake) or atmospheric deposition alone (Pierre Lake)	flame retardant	Holmgren 2015
27	84852-53-9	Decabromodiphenylethane (DBDPE)	flame retardant	was present in the highest concentrations	flame retardant	Holmgren 2015
28	87-82-1	Hexabromobenzene (hbbz)	flame retardant	was detected most frequently	flame retardant	Holmgren 2015
29	85-22-3	Pentabromoethylbenzene (PBEB)	flame retardant	The flame retardant is used as a direct replacement for Deca-BDE, sharing a similar structure. The report describes the substance as behaving similarly to Deca-BDE in the environment, “exhibiting environmental persistence and long-range atmospheric transport characteristics”.	flame retardant	Holmgren 2015
30	52315-07-8	Cypermetryne	insecticide	"former NORMAN" compounds	biocide	Wicke et al. (2015)
31	62-73-7	Dichlorvos	insecticide	"former NORMAN" compounds	biocide	Wicke et al. (2015)
32	52918-63-5	Deltamethrine	insecticide		biocide	Wicke et al. (2015)
33	105827-78-9/ 138261-41-3	Imidaclopride	insecticide	neonicotinoids		Wicke et al. (2015)

	CAS Number	Substance	Function	Comment	substance group	Reference
34	3380-34-5	Triclosan	bactericide	detected in surface water and sewage water; under realistic conditions, triclosan transformation in sludge include methylation to triclosan methyl, cleavage of ether bonds to form 2,4-dichlorophenol, and a catechol, oxidation of the aromatic rings to form hydroxy-and bihydroxy-triclosan as well as triclosan sulfate; a part of the triclosan and methyl-triclosan is bound to sewage sludge and may reach soil if sewage sludge is spread on agricultural land as fertilizer, methyl-triclosan not found as much as triclosan	biocide	Wicke et al. (2015)
35	79127-80-3/ 72490-01-8	Fenoxycarb	insecticide	additional monitoring data needed	biocide	Wicke et al. (2015)
36	731-27-1	Tolylfluanid	wood preservation agent, sulfonamide fungicide, pesticide, antifoulant biocide	additional monitoring data needed, banned from use in pesticides, authorization for use as wood preservation agent	biocide	Wicke et al. (2015)
37	1085-98-9	Dichlofluanid	wood preservation agent, sulfonamide fungicide, pesticide, antifoulant biocide		biocide	Wicke et al. (2015)
38	68359-37-5	Cyfluthrin	wood preservation agent, pesticide	analytical performance should be improved	biocide	Wicke et al. (2015)
39	52645-53-1	Permethrin	insecticide, acaricide	analytical performance should be improved	biocide	Wicke et al. (2015)
40	134-62-3	N,N-diethyltoluamide	transformationproduct of sulfonamide fungicides	already sufficiently monitored, no evidence of risk, high polarity--> removal from wastewater poor	biocide	Wicke et al. (2015)
41	62-75-9	N-nitrosodimethylamine (NDMA)	genotoxic, mutagenic, carcinogenic substance	result of ozonation of drinking water, NDMA is an industrial by-product or waste product of several industrial processes	waste product	Wicke et al. (2015)
42	60207-90-1	Propiconazole (DMI)	triazole fungicide, azole fungicide	already sufficiently monitored, no evidence of risk, no significant emission of the selected biocides by WWTP into surface water systems	biocide	Wicke et al. (2015)
43		Organo-phosphates				Wicke et al. (2015)
44		Pyrethroides				Wicke et al. (2015)
45	101-20-2	Triclocarban	bactericide mostly in soaps and body care products	detected in lake sediments	biocide	Wicke et al. (2015)
46	111988-49-9	Thiacloprid	neonicotinoids, insecticide		biocide	Wicke et al. (2015)

	CAS Number	Substance	Function	Comment	substance group	Reference
47	210880-92-5	Clothianidin	neonicotinoids, insecticide		biocide	Wicke et al. (2015)
48	1085-98-9	Dichlofluanid	fungicide, wood preservation		biocide	Wicke et al. (2015)
49	46 40-01-1	Methyltriclosan		transformation product of triclosan, doesn't get fully dismantled in purification plat--> in surface water	biocide	Wicke et al. (2015)
50	107534-96-3	Tebuconazole	azole fungicide	no significant emission of the selected biocides by WWTP into surface water systems	biocide	Wicke et al. (2015)
51	35554-44-0	Imazalil	azole fungicide	no significant emission of the selected biocides by WWTP into surface water systems	biocide	Wicke et al. (2015)
52	148-79-8	Thiabendazole	azole fungicide	no significant emission of the selected biocides by WWTP into surface water systems	biocide	Wicke et al. (2015)
53	94361-06-5	Cyproconazole	azole fungicide	no significant emission of the selected biocides by WWTP into surface water systems	biocide	Wicke et al. (2015)
54	81-81-2	Warfarin	anticoagulant rodenticide	low aquatic toxity was observed using Daphnia magna as amodel aquatic organism, chiral	biocide	Wicke et al. (2015)
55	5836-29-3	Coumatetralyl	anticoagulant rodenticide	low aquatic toxity was observed using Daphnia magna as amodel aquatic organism	biocide	Wicke et al. (2015)
56	6805-34-1	Ferulenol	anticoagulant rodenticide	low aquatic toxity was observed using Daphnia magna as amodel aquatic organism	biocide	Wicke et al. (2015)
57	152-72-7	Acenocoumarol	anticoagulant rodenticide	low aquatic toxity was observed using Daphnia magna as amodel aquatic organism	biocide	Wicke et al. (2015)
58	90035-08-8	Flocoumafen	anticoagulant rodenticide	low aquatic toxity was observed using Daphnia magna as amodel aquatic organism, second generation anticoagulant rodenticide	biocide	Wicke et al. (2015)
59	56073-10-0	Brodifacoum	anticoagulant rodenticide	low aquatic toxity was observed using Daphnia magna as amodel aquatic organism, most ferquently detected rodenticide	biocide	Wicke et al. (2015)
60	28772-56-7	Bromadiolone	anticoagulant rodenticide	low aquatic toxity was observed using Daphnia magna as amodel aquatic organism, second generation anticoagulant rodenticide at all test sites	biocide	Wicke et al. (2015)
61	56073-07-5	Difenacoum	anticoagulant rodenticide	low aquatic toxity was observed using Daphnia magna as amodel aquatic organism, second generation anticoagulant rodenticide	biocide	Wicke et al. (2015)

	CAS Number	Substance	Function	Comment	substance group	Reference
62	8001-54-5	Benazalkonium chloride	for roofs, bactericide, fungicide, against yeast and algae and also slightly anti-viral	level of leching dempends on roofing material, mass balance calculations indicated that a large part of the mass of benzalkonium compounds applied to the tiles was lost, probably due to the biodegradation processes, significant stormwater ccontamination	biocide	Wicke et al. (2015)
63	1071-83-6	Glyphosate	pesticide applied in green areas	highest in catchment of one-family houses with gardens	biocide	Wicke et al. (2015)
64		Idocarb		imidocarb / no further substances found		Wicke et al. (2015)
65	104653-34-1	Difethialone	second generation anticoagulant rodenticide	2008, the United States Environmental Protection Agency banned the use of difethialone in consumer-use rodenticide products and also for exterior use by commercial applicators (Wikipedia)	biocide	Wicke et al. (2015)
66		Tributyltin (TBT)	umbrealla term for a class of organotin compounds which contain the (C4H9)3Sn group	toxic and estrogenic effective, prominent example: tributyltin oxide- biocide in anti-fouling paint		Wicke et al. (2015)
67	66603-10-9	Cyclohexylhydroxydiazene 1-oxide, potassium salt (K-HDO)	fungicide		biocide	Sacher and Thoma (2015)
68	90-43-7	Biphenyl-2-ol	agricultural fungicide	It is generally applied post-harvest. It is a fungicide used for waxing citrus fruits. It is no longer a permitted food additive in the European Union, but is still allowed as a post harvest treatment (in only 4 EU countries) (Wikipedia)	biocide	Sacher and Thoma (2015)
69	124-65-2	Sodium dimethylarsinate	herbicide		biocide	Sacher and Thoma (2015)
70	420-04-2	Cyanamide	fertilizer	cyanamide is a common agricultural rest-breaking agent (Wikipedia)	fertilizer/ biocide	Sacher and Thoma (2015)
71	556-61-6	Methyl isothiocyanate (MITC, hydrolysis product of Dazomet)	general biocide used to control weeds, nematodes, and soil and wood fungi (http://www.cdpr.ca.gov/docs/emon/pubs/mitc/augfinl02/augparta.pdf), pesticide		biocide	Sacher and Thoma (2015)
72	2682-20-4	2-Methyl-2H-isothiazol-3-one (MIT)	microbicide effect		biocide	Sacher and Thoma (2015)

	CAS Number	Substance	Function	Comment	substance group	Reference
73	15879-93-3	Chloralose	avicide, rodenticide		biocide	Sacher and Thoma (2015)
74	35575-96-3	Azamethiphos	insecticide		biocide	Sacher and Thoma (2015)
75	52304-36-6	Ethyl N-acetyl-N-butyl-beta-alaninate	insecticide		biocide	Sacher and Thoma (2015)
76	42 99-07-4	2-Butylbenzo(d)isothiazol-3-one (BBIT)	?		biocide	Sacher and Thoma (2015)
77	153719-23-4	Thiamethoxam	insecticide, neonicotinoids		biocide	Sacher and Thoma (2015)
78	72963-72-5	Imiprothrin	insecticide	ingredient in some commercial and consumer insecticide products for indoor use. It has low acute toxicity to humans (Wikipedia)	biocide	Sacher and Thoma (2015)
79	66603-10-9	K-hdo	wood preservation agent, fungicide		biocide	TZW (2012)
80	124-65-2	Natriumdimethylarsinat	abatement of ants		biocide	TZW (2012)
81	148-79-8	Thiabendazole	fungicide		biocide	TZW (2012)
82	556-61-6	Methylisothiocyanat	insecticide, fungicide		biocide	TZW (2012)
83		Butylbenzisothiazolinon	fungicide		biocide	TZW (2012)
84	7175-41-2	Abamectin	abatement of flies		biocide	TZW (2012)
85	107-02-8	Acrolein	slimicide		biocide	TZW (2012)
86	20859-73-8	Phosphinfreisetzendes aluminiumphosphid	rodenticide, insecticide		biocide	TZW (2012)
87		Bti am65-52	insecticide	microorganism	biocide	TZW (2012)
88	82657-04-3	Bifenthrin	fungicide, insecticide		biocide	TZW (2012)
89	1303-86-2	Boroxid	fungicide, insecticide		biocide	TZW (2012)
90	10043-35-3	Borsäure	fungicide, insecticide		biocide	TZW (2012)
91	3691-35-8	Chlorophacinon	rodenticide		biocide	TZW (2012)
92	533-744-4	Dazomet	wood preservation agent		biocide	TZW (2012)
93	64359-81-5	4,5-Dichlor-2-octyl-2H-isothiazol-3-on	fungicide		biocide	TZW (2012)
94	134-62-3	Deet	insecticide, repellent		biocide	TZW (2012)
95	104653-34-1	Difenthialon	rodenticide		biocide	TZW (2012)

	CAS Number	Substance	Function	Comment	substance group	Reference
96	12280-03-4	Dinatriumoctaborat tetrahydrat	fungicide, insecticide		biocide	TZW (2012)
97	1330-43-4	Dinatriumtetraborat	fungicide, insecticide		biocide	TZW (2012)
98	80844-07-1	Etofenprox	insecticide		biocide	TZW (2012)
99	67564-91-4	Fenpropimorph	fungicide		biocide	TZW (2012)
100	120068-37-3	Fipronil	insecticide		biocide	TZW (2012)
101	173584-44-6	Indoxacarb	insecticide		biocide	TZW (2012)
102	124-38-9	Kohlendioxid	rodenticide, insecticide		biocide	TZW (2012)
103	8001-58-9	Kreosot	wood preservation agent		biocide	TZW (2012)
104	91465-08-6	Lambda-cyhalothrin	insecticide		biocide	TZW (2012)
105	12057-74-8	Magnesiumphosphid	insecticide		biocide	TZW (2012)
106	240494-71-7	Methoflutrine	insecticide		biocide	TZW (2012)
107	112-05-0	Nonanacid	repellent for cats		biocide	TZW (2012)
108	60207-90-1	Propiconazole	fungicide		biocide	TZW (2012)
109	168316-95-8	Spinosad	insecticide		biocide	TZW (2012)
110	7727-37-9	Nitrogen	insecticide		biocide	TZW (2012)
111	2699-79-8	Sulfurfluoride	wood preservation agent, insecticide		biocide	TZW (2012)
112	81-81-2	Warfarinnatrium	rodenticide		biocide	TZW (2012)
113	30507-70-1	(Z,e)-tetradeca-9,12-dienylacetat	repellent		biocide	TZW (2012)

7.2. Annex 2: Trends in drug consumption worldwide (figures in million US $) (BPC 2016)

The following table shows for the 50 most important human drugs the development in amounts sold.

Tab. 6: 50 most important human pharmaceuticals. Amounts sold globally. Figures in million US $, for the years 2014, 2020 and 2030. Source: BPC as cited in Statista (2016)

	Name of drug	2014	2020	2030	growth factor	Therapeutic group/	Active substance/
1	Orkambi (Vertex Pharmaceuticals)		5.082	13.552	13.552	cystic fibrosis	a) Lumacaftor/ b) Ivacaftor
2	GS-9857/ SOF/ GS-5816 (Glilead Sciences)		4.578	12.208	12.208	chronic hepatitis C	Sofosbuvir
3	LCZ696 (Novo Nordisk)		4.156	11.083	11.083	heart failure	a) Valsartan/ b) Sacubitril
4	Ibrance (Pfizer)		3.830	10.213	10.213	breast cancer	Palbociclib
5	Tenofovir Alafenamide (Gilead Sciences)		3.126	8.336	8.336	HIV Type 1	Tenofovir Alafenamide
6	Grazoprevir/ Elbasvir (Merck & Co)		3.055	8.147	8.147	chronic hepatitis C	a) Grazoprevir b) Elbasvir
7	PB272 (Puma Biotechnology)		2.956	7.883	7.883	cancer	Neratinib
8	Repatha (Amgen + Astellas)		2.445	6.520	6.520	LDL (low-density lipoprotein)	Evolocumab
9	Opdivo (Bristol-Myers Squibb + Ono)	29	8.182	21.770	751	cancer	Nivolumab
10	Imbruvica (Pharmacyclics + JNJ)	547	5.586	13.984	26	leukemia	Ibrutinib
11	Keytruda (Merck & Co)	55	4.988	13.210	240	skin cancer	Pembrolizumab
12	Revlimid (Celgene)	4.980	9.640	17.407	3	multiple myeloma	Lenalidomide
13	Xarelto (Bayer + JNJ)	3.366	7.466	14.299	4	anticoagulant	Rivaroxaban
14	Tecfidera (Biogen)	2.909	6.804	13.296	5	multiple sclerosis	Dimethylfumarat
15	Xtandi (Astellas Pharma)	1.254	5.147	11.635	9	prostate cancer	Enzalutamide
16	Harvoni (Gilead Sciences)	2.127	5.751	11.791	6	chronic hepatitis C	a) Ledipasvir/ b) Sofosbuvir
17	Soliris (Alexion Pharmaceuticals)	2.234	5.462	10.842	5	hemoglobinuria	Eculizumab
18	Tivicay (GlaxoSmithKline)	558	3.647	8.795	16	HIV Type 1	Dolutegravir
19	Eliquis (Bristol-Myers Squibb)	774	3.730	8.657	11	venous throboembolic events	Apixaban
20	Eylea (Regeneron + Bayer + Santen)	2.972	5.826	10.583	4	macular degeneration	Aflibercept
21	Perjeta (Roche)	918	3.427	7.609	8	HER2-positive breast cancer	Pertuzumab
22	Stribild (Gilead + Torii)	1.215	3.524	7.372	6	HIV	Elvitegravir
23	Xgeva/Prolia (Amgen)	2.411	4.438	7.816	3	bone tumor	Denosumab
24	Botox (Allergan + GSK)	2.496	4.518	7.888	3	neurological disease	Botulinum toxin
25	Victoza/Saxenda (Novo Nordisk)	2.393	4.040	6.785	3	type 2 diabetes	Liraglutide

	Name of drug	2014	2020	2030	growth factor	Therapeutic group/	Active substance/
26	Prevnar 13 (Pfizer + Daewoong)	4.297	5.833	8.393	2	pneumococcal vaccine	Diphtheria CRM_{197} Protein
27	Simponi (Merck & Co + JNJ)	1.876	3.388	5.908	3	Immunosuppressive drug	Golimumab
28	Stelara (Johnson & Johnson)	2.072	3.531	5.963	3	Interleukin 12, Interleukin 23	Ustekinumab
29	Januvia/Janumet (Merck & Co + Daewoong)	6.358	7.525	9.470	1	diabetes mellitus type 2	Sitagliptin
30	Vyvanse (Shire + Shionogi)	1.449	2.554	4.396	3	ADHD (hyperactivity) and eating disorder	Lisdexamfetami ne
31	Humira (Abbvie + Eisai)	12.890	13.934	15.674	1	arthritis, spondylitis, Crohn's d., colitis, psoriasis	Adalimumab
32	Tysabri (Biogen)	1.960	2.928	4.541	2	multiple sclerosis, Crohn's d.	Natalizumab
33	Gammagard Liquid (Baxter International)	2.224	3.169	4.744	2	humoral immune-deficiency, multifocal motor neuropathy	immune globulin infusion
34	NovoRapid (Novo Nordisk)	3.109	3.848	5.080	2	diabetes mellitus	Insulin aspart
35	Privigen (CSL)	1.986	2.665	3.797	2	immunodeficiency treatment	immune globulin infusion
36	Gilenya (Novartis + Mitsubishi)	2.506	2.897	3.549	1	multiple sclerosis	Fingolimod
37	Levemir (Novo Nordisk)	2.533	2.794	3.229	1	diabetes mellitus	insulin detemir
38	Humalog (Eli Lilly)	2.785	2.908	3.113	1	diabetes mellitus Typ 1&2	insulin lispro
39	Lucentis (Novartis + Roche)	4.301	3.507	2.184	1	age-related macular degeneration	Ranibizumab
40	Avastin (Roche)	7.018	6.202	4.842	1	cancer	Bevacizumab
41	Spiriva (Boehringer Ingelheim)	4.300	3.231	1.449	0	pulmonary disease	Triotropium bromide
42	Symbicort Turbuhaler (AstraZeneca)	3.820	2.652	705	0	asthma and COPD	a) Budesonide/ b) Formoterol
43	Neulasta (Amgen + Kyowa Hakko)	4.599	3.113	636	0	cancer	Pegfilgrastim
44	Herceptin (Roche)	6.863	5.313	2.730	0	breast cancers	Trastuzumab
45	Enbrel (Amgen + Takeda + Pfizer)	8.915	7.219	4.392	0	autoimmune d., arthritis	Etanercept
46	Remicade (JNJ + Merck & Co + Mitsubishi)	8.807	6.511	2.684	0	tumor necrosis factor alpha, autoimmune diseases	Inflixmab
47	Rituxan (Roche)	7.547	5.096	1.011	0	cancer and autoimmune diseases	Rituximab
48	Lantus (Sanofi)	8.428	4.935	-887	0	diabetes	Insulin glargine
49	Seretide/Advair (GlaxoSmithKline + Almirall + Faes)	7.058	2.793	-4.315	-1	asthma and COPD	a) Fluticason-propionate b) Salmeterol
50	Sovaldi (Gilead Sciences)	10.283	2.926	-9.336	-1	hepatitis C	Sofosbuvir

7.3. Annex 3: Antibiotics for animal farming, amounts used

The following table shows the development of amounts used of veterinary antibiotics. The numbers are given for groups of antibiotics for the years 2011 to 2015, for Germany.

Tab. 7: Antibiotics used in Germany for animal farming. Consumption (in tons) from 2011 to 2015. Difference between 2011 and 2015 and decrease in %. Source: BVL (2016)

Group	2011	2012	2013	2014	2015	Difference 2011-2015	Ratio	%
Macrolide	173	145	126	109	**52**	-121	0,36	-64
Folic acid antagonists	30	26	24	19	**10**	-20	0,38	-62
Tetracycline antibiotics	564	566	454	342	**221**	-343	0,39	-61
Sulfonamide	185	162	152	121	**73**	-112	0,45	-55
Penicillin	528	501	473	450	**299**	-229	0,60	-40
Pleuromutilins	14	18	15	13	**11**	-3	0,61	-39
Aminoglycoside	47	40	39	38	**25**	-22	0,63	-38
Polypeptide antibiotics	127	124	125	107	**82**	-45	0,66	-34
Lincosamides	17	15	17	15	**11**	-6	0,73	-27
Cephalosporin 4. gen	1,5	1,5	1,5	1,4	**1,3**	-0,2	0,87	-13
Fenicole	6,1	5,7	5,2	5,3	**5**	-1,1	0,88	-12
Cephalosporin 3. gen	2,1	2,5	2,3	2,3	**2,3**	0,2	0,92	-8
Cephalosporin 1. gen	2	2	2	2,1	**1,9**	-0,1	0,95	-5
Fluoroquinolones	8,2	10,4	12,1	12,3	**10,6**	2,8	1,02	2
Fusidic acid*								
Ionophore*								
Nitrofuran*								
Nitroimidazole*								
Total	1.706	1.619	1.452	1.238	**805**	-901	0,50	-50

* data not available, due to confidentiality

7.4. Annex 4: Participants of the workshops

7.4.1. Participants of Workshop 1: Health Care

- Werner Brack, Umweltforschungszentrum (UFZ), Leipzig, Germany.
- Michael Brandt, University Hospital Frankfurt, Germany.
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7.4.3. Participants of Workshop 3: Cities

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- Dirk Bunke, Öko-Institut e.V., Freiburg, Germany
- Michael Depledge, University of Exeter Medical School.
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- Christiane Heiss, German Federal Environment Agency, Dessau, Germany
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8. Literature

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