Establishing Environmental Sustainability Thresholds and Indicators
Final report

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The contents and views contained in this report are, however, those of the authors, and do not necessarily represent those of the European Commission or any of the experts mentioned above.

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Abbreviations

CAP	Common Agricultural Policy
CMR	Carcinogenic, Mutagenic, toxic to Reproduction (REACH regulation)
CSR	Chemical Safety Report (REACH regulation)
DMC	Domestic Material Consumption
DMI	Domestic Material Input
DPSIR	Driving Forces-Pressures-State-Impacts-Responses
EBFM	Ecosystem-based Fisheries Management
ECHA	European Chemicals Agency
EEA	European Environment Agency
EMC	Environmentally Weighted Material Consumption
EVIL	Environmental Impact Load
FAO	Food and Agricultural Organisation of the United Nations
FAOSTAT	FAO statistical databases
GLiPHA	FAO Global Livestock and Health Atlas
GLP	Good Laboratory Practices (REACH regulation)
ITQ	Individual Transferable Quota
JRC-ECB	Joint Research Centre – European Chemicals Bureau
LCA	Life Cycle Assessments
LULCC	Land Use and Land cover change
MAC	Maximum Allowable Concentrations
MFA	Material Flow Accounting and Analysis
MSY	Maximum Sustainable Yield
N	Nitrogen
NECD	National Emission Ceilings Directive
NH3	Ammonia
NMVOCs	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen oxide
NSIs	National Statistical Institutes
P	Phosphorus
PBT	Persistent, Bioaccumulative, Toxic (REACH regulation)
RAINS	Regional Air Pollution INformation and Simulation
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemicals regulation
PESERA	Pan-European Soil Erosion Risk Assessment
RIVM	Dutch National Institute for Public Health and the Environment
SAGE	Center for Sustainability and the Global Environment at the University of Wisconsin, USA
SDS	Safety Data Sheet (REACH regulation)
SO2	Sulphur dioxide
TAC	Total Allowable Catch
TMDLs	Total Maximum Daily loads
USGS	United States Geological Service
USLE	Universal Soil Loss Equation
vPvB	Very Persistent, Very Bioaccumulative
WFD	Water Framework Directive
WISE	Water Information System for Europe

1. Introduction

The study and monitoring of environmental thresholds is of increasing relevance for policy makers as human production and consumption activities put rising transformative pressure on the world's natural resources and ecosystems. Many of these natural systems can withstand disruption only up to a certain threshold (or "tipping point") beyond which ecological discontinuities with socially, economically and environmentally unacceptable and possibly irreversible consequences are likely to occur.[1] To avoid such consequences, it is important to identify where such thresholds might exist and what the actual threshold values are. The scientific study of environmental thresholds, their understanding, modelling and prediction should also be translated to and integrated into early warning systems that enable policymakers to understand the challenges and respond effectively.

The identification and definition of specific thresholds depends on the temporal and spatial scale adopted. The most appropriate temporal and spatial scales to address environmental thresholds can vary, depending on the ecological system involved and on the dynamics of the environmental services it provides.

Among the numerous environmental indicators that have been proposed and are being used today, only relatively few monitor threshold phenomena and most indicator efforts do not establish specific target levels nor do they alert to danger zones that identify whether thresholds are being approached or if environmental sustainability has been achieved.

Thresholds are especially important for policy makers when they lead to abrupt changes in the ecological services provided by the ecological system involved (Myers, 1996; Pimentel et al., 1997). Therefore, identifying and monitoring environmental thresholds or tipping points is highly relevant to EU environmental and sustainable development policy. Specifically, thresholds and danger zones can contribute to debates on the limits to growth. In its Communication on *GDP and beyond - Measuring progress in a changing world* the Commission states that:

> 'The EU Sustainable Development Strategy sets as a key objective to respect the limits of the planet's natural resources. These include nature's limited capacity to provide renewable resources and absorb pollutants. Scientists are seeking to identify related physical environmental threshold values and highlight the potential long-term or irreversible consequences of crossing them. For policymaking it is important to know the 'danger zones' before the actual tipping points are reached, thereby identifying alert levels. The cooperation of research and official statistics will be stepped up in order to identify – and regularly update – such threshold values for key pollutants and renewable resources in order to inform policy debate and support target setting and policy assessment.' (European Commission, 2009)

In addition, the International Commission on Measurement of Economic Performance and Social Progress recommends that threshold phenomena be included in the physical indicators for environmental pressures:

> 'Recommendation 12: The environmental aspects of sustainability deserve a separate follow-up based on a well-chosen set of physical indicators. In particular there is a need for a clear indicator of our

1 Thresholds are difficult to define, a problem explained extensively in the book *Road to Sustainability: GDP and Future Generations* (Pulselli, 2008). Luck (2005: 299) defines a threshold as 'a point or zone where there is a dramatic change in the state of matter or a system'. In a typical threshold response a minor change in the independent variable (e.g., habitat cover) results in a dramatic change in the dependent variable (e.g. species richness).

> proximity to dangerous levels of environmental damage (such as associated with climate change or the depletion of fishing stocks).' (Stiglitz et al., 2009).

This study, *Establishing Environmental Sustainability Thresholds and Indicators,* seeks to support EU policy efforts by making practical progress on a few selected key thresholds of immediate interest, identifying and testing ways in which thresholds can be defined in quantitative terms and monitored effectively through indicators.

The study focuses on environmental phenomena that are relevant to EU policy-makers. The project team decided to exclude climate change and biodiversity from this study. Climate change was removed from the initial list of threshold themes because it is analysed in substantial breadth and detail elsewhere and biodiversity was determined to be too complex and far-reaching an area to be discussed satisfactorily within the time and budget of this project.

The study aims to identify a small set of initial thresholds (including possible alert levels and danger zones[2]) and specific indicators useful for monitoring unsustainable trends in the EU that could lead to tipping-point or break-down phenomena.

The study aims to fulfil the following three-fold objectives as identified in the Study Request (Study Request, 2009, p. 4):

i. **Identify threshold areas**. The study "identif[ies] areas where there is likelihood of unsustainable trend[s] related to environmental issues (including renewable resources) that show threshold phenomena."

ii. **Select thresholds and establish indicators**. From among these threshold areas, "[four] thresholds [are] chosen for which a set of indicators will be established, able to alert EU decision-makers when the prevailing trends lead to an increased risk of entering danger zones and/or crossing some critical thresholds. The thresholds at stake can be directly linked to a state of the environment (e.g. biodiversity level), a pressure (e.g. emissions) and/or to an underlying driving force (e.g. social or economical) made on this state or pressure."

iii. **Ensure policy relevance.** These thresholds and indicators "should help in planning a better response by environmental policies and instruments at [the] EU level".

This final report provides a comprehensive overview of the study, its methodology and results. It gives an overview of the state of the art of environmental threshold research based on a broad-based literature review that draws from over 100 articles, reports, and research studies done on the subject.

The report is structured as follows. Section 2 explains the research methods employed in this study. Section 3 provides a detailed description of (i) empirical evidence and trends of dangerous thresholds and danger zones (including scales at which thresholds are or are likely to be reached) (ii) drivers, (iii) pressures, (iv) impacts, and (v) EU policy relevance for seven selected threshold areas: health, fisheries, water quality (eutrophication), water quantity, land use/land use change, soil degradation, and non-renewable resource use. Section 4 looks at how thresholds in four out of the seven areas described in section 3 (water quality, water quantity, soil degradation, and non-renewable resource

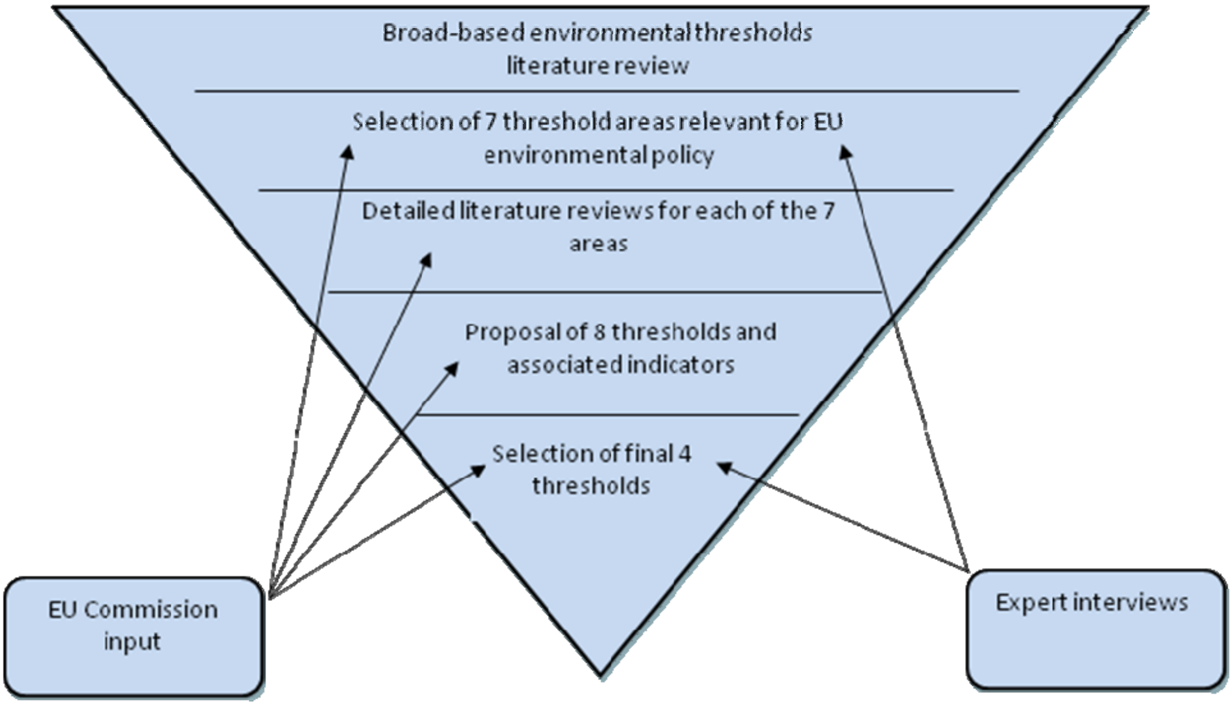
2 As stated in the Study Request, "alert level" is the critical value beyond which there is no safe distance from dangerous thresholds. Furthermore, a "danger zone" is a range of values outside the safe operating zone, which indicate a high probability and subsequently a high risk to reach the threshold levels.

use) can be measured and how they relate to other thresholds (including to each other, where applicable). It reviews appropriate pressure and state indicators (including their data availability and uncertainty), and suggests threshold indicators for each of the four selected threshold areas. The section also reviews the availability of data and the advantages and disadvantages of the different threshold indicators. Finally, an interpretation is provided for each indicator with respect to how closely it addresses the corresponding threshold phenomenon and how it can be used and interpreted. The concluding chapter summarises the main lessons from the study and provides an overview of the threshold indicators suggested in each of the four areas of in-depth investigation. It also discusses the advantages and limitations of the study's approach and suggests ways of moving forward in the research, monitoring and communication of environmental thresholds and indicators.

2. Methodology

Figure 1 illustrates the approach taken to identify specific thresholds that are highly relevant to current and anticipated future EU policy making (including monitoring and evaluation) and that are supported by sufficient scientific and empirical evidence within the boundaries of the EU.

Figure 1 Schematic depiction of the selection, consultation, and study process used in the project



2.1. Literature Review

The first step in the project was a broad literature review of the status of environmental thresholds research globally and with relevance to the EU. Seven areas that best fit the EU needs and priorities were identified: health, fisheries, water quality (with a focus on eutrophication), freshwater quantity, land use/land use change, soil degradation, and non-renewable resources.

The team identified and examined a broad range of scientific literature and EU-commissioned studies dealing with environmental threshold phenomena. The literature review built on the existing database of references used for the Yale/Columbia Environmental Performance Index (EPI, http://epi.yale.edu), the literature database of the Resilience Alliance (www.resalliance.org), and citation indices of the main scientific environmental and ecological literature. It also drew on the literature and findings of EU commissioned studies in this thematic area, such as the FP6 Thresholds Project (www.thresholds-eu.org), and the work of environmental and policy think-tanks. More than 100 articles, reports, books, and online sources were identified. Literature searches were conducted using keywords such as "threshold", "tipping point", "regime shift", "system modelling", "network theory", and "ecosystem equilibrium".

2.2. Selection of policy-relevant threshold areas

Based on the project proposal, initial literature reviews by Ecologic Institute and SERI, and the first two project teleconferences with European Commission staff, the project team was asked to examine seven thematic areas for thresholds and indicators:

1) Human health with focus on exposure to toxic substances in the environment,
2) Sustainable fisheries management,
3) Land use/land use change
4) Soil degradation,
5) Freshwater quality with focus on eutrophication,
6) Non-renewable natural resources,
7) Freshwater resources.

The importance of climate change and associated risks of irreversible changes was acknowledged, but the Commission asked the project team not to study this issue due to the extensive work on climate-change thresholds that has already been done recently. The issue of biodiversity is also very important but the project team determined that finding quantitative thresholds in this area was too difficult an undertaking with the available project budget; the project team thus excluded this area in its research proposal.

Within each of these seven areas detailed literature reviews and expert interviews[3] were conducted, and eight thresholds were presented to the EU Commission for review. Four out of the eight thresholds were discarded, because they were either linked too closely to climate change or biodiversity, which are not specifically covered by this project, or they were not truly environmental thresholds but affected human health through other pathways. One threshold was added to a selected threshold area due to its particular relevance for EU monitoring and policy.[4]

2.3. Establishing threshold indicators

The team first established a common framework which was planned to be used across all threshold themes in order to derive specific threshold indicators. This framework consists of three components:

1. **Pressure indicators:** describe human activities that have a negative impact on the environment, such as surface water abstraction or emission of air pollutants (see for example EUROSTAT, 2004).

2. **State indicators:** describe the state of environmental media, such as soil, water and air, which might cause long-term, on-going impacts. Examples for state indicators are available water quantities or concentrations of air pollutants in a city.

3. **Threshold indicators:** these indicators relate pressure and state indicators. They are "distance-to-target" type of indicators. In the literature, these indicators often include terms

[3] For a list of experts consulted please see Annex 1 and Annex 2.

[4] Although this threshold has strong links to biodiversity and habitat protection, it was selected for its superior relevance for EU environmental policy in the selected threshold area.

such as “index” or “ratio”, for example annual uptake of water resources / maximum annual renewable uptake of water resources, in %[5], or maximum atmospheric concentrations for specific air pollutants.

Following the identification of indicators for all three components for the selected four threshold areas, at least one threshold indicator is proposed. However, in some cases, where the literature already suggests well-established threshold indicators which do not relate pressure to state indicators, these conventional indicators are used. This was the case for water quality and soil erosion.

In order to select potentially applicable threshold indicators the following demands should ideally be met by the component indicators:

- the indicator should be applicable at the relevant threshold level (regional / national / EU)
- it should be encompassing with regard to environmental impacts / pressure
- it should be based on statistical data or research data (e.g. from modelling) and (potentially) be available in EU data collecting institutions, such as Eurostat, EEA and JRC.

2.4. DPSIR framework

In order to put the different threshold indicators into context, we used the DPSIR (driving force – pressure– state – impact – response) framework, developed by the EEA (Smeets and Weterings, 1999). This causal framework is a widely used tool to describe interactions between society and the environment, such as the environmental impact of human activities, in order to assess appropriate political measures and behaviours. Table 1 explains what is meant by the main terms of the framework.

Table 1 Main terms of the DPSIR framework

Term	Explanation
Driving force	refers to the driving forces of changes caused by human activities; they put pressure on systems indirectly and can be of demographic, economic, social, political, scientific, technological, or spiritual nature (e.g. the demand for energy, economic growth, the demand for food and housing, population growth).
Pressure	refers to pressures and stress points that impact systems and manifest themselves as changed environmental conditions (e.g. greenhouse gas emissions, contaminated sites, noise)
State	refers to the quantitative and qualitative condition of a system (e.g. lake water quality, average global temperature, number of species in a forest).
Impact	refers to the specific effect of a pressure on ecosystems’ functioning and thus also on humans and their quality of life (e.g. health problems, species extinction, eutrophication).
Response	refers to political and societal reactions (e.g. taxes, laws, migration) that reduce the driving forces and the pressures or make adaptation to the changed condition and its impact possible.

[5] In the water literature, terms such as “water scarcity index” or “water resource vulnerability index” are used for this ratio.

Source: Jäger (2008: 54)

The DPSIR framework aims to provide information for each element of the DPSIR chain, demonstrate their interconnectedness, and estimate the effectiveness of responses. It connects causes (driving forces and pressures) to states, activities (policy measures and decisions), and the impact on humans. It is important to note that the DPSIR framework is not able to demonstrate the complexity of all interconnections and thus should not be the only model used as a problem-solving aid. However, it serves the purpose of this study well, which is to put the different threshold indicators into context and to help find appropriate policy responses.

3. Selected environmental threshold areas and their relevance for EU policies

3.1 State of the art in thresholds research: general findings

Research into the existence of environmental thresholds or tipping points beyond which serious and/or irreversible – and usually negative or undesired – changes in environmental systems occur is not new and has drawn considerable interest over time[6]. Due to the inherent complexities in modelling ecological and environmental systems the subject has for a long time been more the focus of theoretical debate rather than empirical modelling. Early models were either simplistic or focused on a very narrowly defined aspect of an ecosystem. While simple models are still used, they are often calibrated by better data and supported by extensive simulation studies and statistical methods (Bennett et al., 2008).

Empirical observation of collapsed ecosystems, species, and environmental services has continued to inspire researchers to formulate and test threshold hypotheses. The global threat of catastrophic climate change has further reinvigorated the search for measurable indicators that can signal whether critical thresholds are being approached (IPCC, 2007a, b). While advances in computational power and the theory of ecosystem modelling have translated to more realistic models, focus has also expanded to explicitly study the anthropogenic drivers of threshold behaviour with the goal to implement controls for monitoring and avoiding reaching those thresholds.

Summary of expert interview with Federico Pulselli, Ecodynamics Group, University of Siena, Italy from 1 July 2010.

The concept of threshold in environmental and sustainability science refers to a relatively modern problem termed by Herman Daly as “full world economics”, i.e., a world where population and economic growth is pushing against many of the environment’s limits to provide goods and services and assimilate human waste products. Thresholds remain difficult to define, a problem explained extensively in the book by Pulselli et al. (Pulselli, 2008) titled *Road to Sustainability: GDP and Future Generations*. Threshold indicators can be systemic or analytical. Systemic threshold indicators refer to behaviours or processes intrinsic to human society or ecosystems and are of high significance. Examples include the Ecological Footprint, a widely known and used metric that provides systemic information on the status of carrying capacity for the whole world. Domestic Material Consumption (DMC, considered in this study) is another systemic measure that is connected to people’s behaviour, which needs to be understood in order to live within earth’s carrying capacity. Analytical threshold indicators are those that capture non-linear changes in physiological, ecological, or physic-chemical processes such as the necessity for a certain concentration of a chemical agent to trigger a chemical reaction. Other approaches include the emergy theory, the study of the differences in the quality of energy that occurs during energy transformations, and the Index of Sustainable Economic Welfare

[6] Humans have observed and studied nature since the beginning to identify changes that affected aspects critical for survival or economic activity, such as seasons, rainfall patterns, and other changes. Tipping points in mathematics were identified early on and are the subject of Catastrophe Theory (or Bifurcation Theory) and include the Fold catastrophe, in which the stability of the system given by the equation V=x3+ax depends on the value for a: for negative a, the system has a smooth transition to the extrema but at a=0 the system becomes unstable and for a>0 there is no stable solution anymore. The value a=0 is called a bifurcation point, or tipping point.

(ISEW), which is also known as the Genuine Progress Indicator. In a 2007 paper by Niccolucci, Pulselli and Tiezzi (Niccolucci et al., 2007) the interesting finding was made that, for Austria and the USA, at the time point at which the Ecological Footprint started exceeding the countries' biocapacity, the ISEW also started to stagnate or decline. This may be a coincidence but further analyses for a number of nations highlighted that environmental health is a crucial component of quality of life. At the same time an important aspect of indicators emerges, namely that accuracy is sometimes not critically needed to signal or visualize an important unbalance or development.

Translating such findings into policy remains challenging for at least two reasons: firstly, environmental and political cycles are often at odds, thereby reducing interest of politicians to embrace an ambitious environmental agenda when the fruits of which will only be harvested after the end of their tenure. Secondly, the language of science is not Euros or Dollars, which everybody understands, but complicated and multidimensional. Furthermore, environmental trends are by and large negative and therefore do not make for good publicity. On the other hand, the trends of environmental or ecological economic indicators can also be used to corroborate political choices made by those politicians who are interested in environmental problems and sustainability. It is nonetheless possible and necessary for scientists to think about how their science can inform policy-making.

Further readings:

Pulselli F.M., Bastianoni S., Marchettini N., Tiezzi, E. "The road to sustainability: GDP and future generations". WIT Press, Southampton, UK, 2008, 197 pp. ISBN 978-1-84564-140-5.

Pulselli F.M., Ciampalini F., Tiezzi E., Zappia C. "The Index of Sustainable Economic Welfare (ISEW) for a local authority: a case study in Italy". Ecological Economics, Vol. 60 (1), 2006, 271-281.

Niccolucci V., Pulselli F.M., Tiezzi, E. "Strengthening the Threshold Hypothesis: economic and biophysical limits to growth". Ecological Economics, Vol. 60 (4), 2007, 667-672.

The following sections will present an overview of seven thematic areas in which threshold phenomena are likely to impact the European Union: human health (3.2); sustainable fisheries management (3.3); freshwater quality (3.4); freshwater resources (3.5); land use/land use change (3.6); soil degradation (3.7); non-renewable natural resources (3.8). Each section summarizes the findings of a literature review which investigated the empirical evidence, scale and trends for the threshold, alert levels or danger zones, drivers, pressures and impacts as well as the relevance of the theme for EU policy. Following this broad literature review, a more in-depth investigation will follow in chapter 4, focussing on selected thresholds, danger zones and indicators.

3.2 Health

Protecting human health is the focus of officials within public health, food, drug, and medical administrations, as well as occupational and environmental health and safety agencies. Together, they employ a wide variety of methods from (environmental) toxicology, pharmacodynamics and -kinetics, epidemiology, statistics, and other fields to study the effects of toxic substances on human health.

The number of chemicals and chemical substances newly developed and used in industry, pharmacology, agriculture, the military and other sectors has grown exponentially since the beginning of the 20th century and now ranges in the tens of thousands. For the majority of these substances and compounds the full range of their effects on human health and the environment has never been fully assessed. There are many examples of chemicals that were banned only after they have entered public or occupational use.[7]

The comprehensive testing and establishment of adequate limits (thresholds) for the exposure of humans and the environment to toxic substances is of growing importance at national, regional, and global levels. It is noted that toxic substances also occur naturally in the environment and are mobilised by human activity or it is human activity that creates the conditions for human exposure to them, for example heavy metals such as lead, cadmium, mercury, copper, cobalt, and others, some organisms produce toxins[8], and radioactive compounds such as uranium and radon gas.

In this study we focus on toxic substances that are developed by humans, and therefore within the scope of the European REACH regulation (EC 1907/2006, REACH=Registration, Evaluation, Authorisation, and restriction of Chemicals). REACH replaces, synthesises, and harmonizes previous EU legislation on chemicals, reflecting the historical patchwork approach within which testing, registration, and use of chemicals with potentially detrimental effects on human health and/or the environment were handled. To illustrate the magnitude of chemical development and use in Europe: in 1981 – the cut-off date in previous risk assessment legislation – there were more than 100,000 chemicals on the European market, most of them had an inadequate information basis on which to base health and environmental risk assessments. At present, the Chemical Substances Index lists over 275,000 regulated chemical substances, albeit not all of which may be available in the EU.

3.2.1. Empirical evidence in the EU

Exposure to toxic substances carries the risk of adverse health effects that can be mild and temporary to permanent organ damage or even death depending on the toxicity of the substance, the length of exposure, and the exposure pathway. For the aforementioned reason of the large number of toxic substances, it is impossible to provide a comprehensive review or discussion of possible thresholds or upper limits on exposure for all existing chemicals in the environment. We, therefore, refer to the European Community Regulation on Chemicals and their Safe Use (REACH, EC 1907/2006) for further information on the toxicity of existing and new chemicals and substances and applicable restrictions on their use. However, REACH is the main means within the EU by which chemical substances are tested, registered and regulated and hence we use to its methods and results for determining thresholds for a small selection of toxic chemicals.

3.2.1.1 The REACH approach

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[7] An example is the synthetic pesticide DDT (dichlorodiphenyltrichloroethane) used to control, inter alia, malaria. DDT was banned in the US in 1972 after having been linked to cancer and deaths of wildlife, especially birds. This was followed by its international ban for agricultural use under the Stockholm Convention on Persistent Organic Pollutants in 2001 (entered into force in 2004). The Stockholm Convention singled out 12 chemicals, referred to as the Dirty Dozen, which were assessed for their adverse environmental and health impacts and outlawed nine of the 12, limited the use of DDT to only disease vector control (e.g., malaria) and reduce the unintentional production and release of dioxins and furans.

[8] An example is the protein *botulinum toxin* produced by the bacterium *Clostridium botulinum*, which is among the most potent neurotoxins known.

REACH applies a mass approach (tonnage-trigger) to identify which testing and information requirements apply. Although tonnage does not correlate strongly with toxicity, it was chosen as an indicator of the exposure potential. Good Laboratory Practice (GLP) rules then apply to generate high-quality and comparable risk assessments from toxicological and eco-toxicological analyses. A priority classification linked to information and testing requirements is based on three weight classes as shown in Table 2 (European Commission, 2007b).

Table 2 Summary of information requirements in REACH regulation as it pertains to different tonnages of substances in circulation and known or potential harmful effects on humans and the environment

1-10 tonnes	**10-100 tonnes**	**>100 tonnes**
Information corresponding to Annex VII for potentially carcinogenic, mutagenic, or toxic to reproduction (CMR category 1 or 2), persistent, bioaccumulative and toxic (PBT) or very persistent and very bioaccumulative (vPvB) and substances potentially dangerous to health or the environment and are used in dispersive uses.	Information corresponding to Annexes VII and VIII must be submitted in addition to all available information in the hands of the applicant.	Information in accordance with Annexes VII and VIII as well as all available information on the effects of the chemical. In addition, materials in line with Annex IX and for substances >1000 tonnes, Annex X, with testing results (or proposed testing protocols)
Applications for other substances must contain physicochemical information and any available (eco)toxicological data.		

Thresholds for safe use of and/or exposure to chemicals in tonnages of 10 or more are contained in the Chemical Safety Report (CSR) including exposure scenarios for the identified, specific uses of the chemical. The CSR's are the main standardized form for data assessment under REACH, allowing for the joint consideration of hazard and exposure data to ultimately judge the risk of a substance and determine safety values (analogous to threshold values in our study). The risk assessment can be simplified to yielding three types of results:

(1) Non-hazardous and low exposure, which equals low risk

(2) Non-hazardous and high exposure, which requires a hazard assessment, and

(3) Hazardous and low exposure, which requires a risk assessment.

The conclusions of a risk assessment is to compare the estimated exposure with the estimated effects and is expressed as a PEC / PNEC, based on the ratio of predicted environmental concentration (PEC) and predicted no effect level (PNEC). Human health elements to the risk assessment are less clear-cut in their conclusions, but the principles remain the same with a comparison between the predicted level of exposure and the known or estimated degree of hazard. The Derived No-Effect Level (DNEL) is estimated from toxicity data with the application of safety factors.

In an attempt to quantify 'safe' levels for human exposure, it is necessary to calculate a Derived No-Effect Level (DNEL) that is based on safety factors being applied to toxicity data endpoints such as the lowest observed adverse effect level (LOAEL) or no observed adverse effect level (NOAEL). The DNEL effectively follows the same principle as the PNEC for environmental effects.

REACH provisions will be phased in over a period of 11 years with CMR and PBT/vPvB substances (see Table 3) being prioritized such that the expected number of phase-in substances registered with ECHA over this time period is approximately 30,000.

Information sharing along the supply chain is facilitated by the Safety Data Sheet (SDS) for all dangerous substances (91/155/EEC amended by REACH).

Another safeguard in addition to the required information for registration and testing is the explicit authorization requirement for substances of very high concern to health and the environment and which cover CMR category 1 and 2, PBT, vPvB, and substances identified from scientific evidence as probable to have serious effects on humans or the environment equivalent to those in the previously listed categories, e.g., endocrine disruptors. Table 3 lists the substances identified by ECHA to belong to these categories. ECHA can also place restrictions and conditions on specific substances to further improve adequate safety from intolerable exposure risk by essentially setting conditional thresholds on mass or concentration (sometimes setting that threshold to zero). For an existing list of restrictions on existing chemicals and substances, the reader can refer to Table 3 and Table 4 which provide a small selection of examples (European Commission, 2006d).

Table 3 Examples of restrictions in place under the REACH regulation due to the particular health and environmental risks posed by the restricted chemicals or substances

Chemical/substance restricted	Conditions of restriction
Benzene	1. Not permitted in toys or parts thereof as placed on the market where the concentration of benzene in the free state is in excess of 5mg/kg. 2. Shall not be used in concentrations equal to, or greater than, 0.1% by mass in substances or preparation placed on the market (excluding motor fuels covered by Directive 98/70/EC, substances and preparations for use industrial processes not allowing for the emission of benzene in quantities in excess of those laid down in existing legislation, waste covered by Council Directive 91/689/EEC of 12 December 1991 on hazardous waste and Directive 2006/12/EC.
Toluene (CAS No 108-88-3)	Used in adhesives and paint. Maximum concentration allowed is 5% weight.
Chromium, hexavalent (Cr6+) compounds	Used in electronic equipment, for surface treatment and as pigment. Maximum concentration value of 0,1% by weight in homogeneous materials. Exemption for hexavalent chromium as an anti-corrosion of the carbon steel cooling system in absorption refrigerators. Pigments, such as zinc chromate, strontium chromate, and lead chromate. The latter is prohibited (see Lead and

	lead compounds on the prohibited list).
Polychlorinated Biphenyls (PCB)	Tolerated in concentrations <0.1%, prohibited in greater concentrations

3.2.1.2 Our Approach

Since we cannot mirror the extensive coverage provided by REACH, we aimed to include examples from the leading groups of chemicals and substances that have demonstrated or are likely to show toxicity. These are heavy metals (lead, cadmium, chromium, etc.), persistent organic pollutants (DDT, PCBs, which can cause formation of dioxins, etc.), and pesticides (organophosphates, organochlorines, carbamites, etc.). Prior to the REACH directive, JRC-EC conducted risk assessments (RA) for priority chemicals with the goal to protect human health and the environment. Approximately 140 RAs were completed but the process was slow and not always consistent, thereby giving rise to REACH and, with the creation of ECHA, all registered chemicals will undergo RAs as part of the Chemical Safety Reports, including target values for the protection of human and environmental health. These RA target values constitute thresholds in line with the scope of this study but cannot be discussed in detail in this study because they are too numerous. For some chemicals or compounds, however, the empirical evidence indicates no safe threshold (e.g., lead) or its exact determination is difficult because studies involving humans are often impossible to conduct.

Scientific data and knowledge about the exposure-effect pathways continue to accumulate and exposure thresholds or safety values have repeatedly been revised or amended for several substances, such as dioxin, lead, and others. The fact that the toxic substance affects the individual, often in local environments, via specific exposure pathways, and over long time periods (e.g. lead-based paint in a home or arsenic-contaminated drinking water), makes the generic and easy detection, monitoring, and regulation of toxics challenging.

We highlight this fact for three examples: dioxin, lead, and hexavalent Chromium. All three are of relevance in the EU from a historical perspective (e.g. lead was a long-time additive to gasoline and dioxin and hexavalent Chromium originates in certain industrial combustion and production processes) and monitoring and evidence gathering continues to protect human and animal health. A summary of the rationale for using these three substances is given in Table 4.

Table 4 Selected substances and rationale for their inclusion in our selection

Substance	**Rationale**
Dioxin	Simplified name for polychlorinated dibenzodioxins (PCDDs), which belong to family of halogenated organic compounds found naturally in the environment (volcanic activity, forest fires) but mostly originate from combustion, chlorine bleaching, and manufacturing. Dioxins bioaccumulate in fatty tissue in humans and animals and are teratogens[9], mutagens, and carcinogens – even at very low concentrations.
Lead	A poisonous metal that can damage nervous connections, can cause blood and brain disorders. Especially at risk are children due to their developing nervous system. Lead is a potent neurotoxin that accumulates in soft tissues and bone over time. It occurs naturally in

[9] Causing malformations in human fetuses.

	the environment and is emitted in combustion and smelting processes.
Chromium VI	Compounds containing chromium in +6 oxidized state. Cr VI is used for the production of stainless steel, textile dyes, wood preservation, leather tanning, and as anti-corrosion coatings. It is a carcinogen and exhibits genotoxic properties

Thresholds for toxic substances usually specify the maximum amount (possibly over a specified amount of time) that a person can be exposed to a toxic substance without endangering their health. Due to the diversity of people and scientific uncertainty (studies on humans are extremely limited or observational), such exposure limits include a margin of safety that is wider the more toxic the substance is known to be. lead, dioxin, and Chromium VI. summarises existing thresholds for lead, dioxin, and Chromium VI.

Table 5 Selected toxins and thresholds for their safe exposure or consumption

Substance	**Threshold**
Dioxin	No apparent thresholds, i.e., health effects were found at every tested or observed exposure concentration, but for policy-making purposes: maximum daily allowable dioxin concentrations of 1pg/kg/day in Germany, UK, 4pg/kg/day in NLD, 0-5 pg/kg/day in Scandinavia, 10pg/kg/day in Canada; see also 2006 Maximum thresholds on dioxin and dioxin-like PCBs (EC 1881/2006)[10]
Lead	Many studies suggest that no threshold exists for lead and that organ-specific concentrations as low as 7 microgram/dl blood have been shown to impact heart and blood vessels and can lead to hypertension (UNEP Chemicals Division). A US Centers for Disease Control (CDC) value of 10 microgram/dl is widely accepted but a 2000 report by the CDC found links to childrens' learning and behaviour. The health-based WHO guideline value is 0.1 mg/litre (WHO, 1993).
Chromium VI	0.05mg/liter of total chromium for drinking water (WHO guideline value for drinking water, 1953)

3.2.2. Scale and trends

Toxic substances, including the three examples lead, dioxin, and Chromium VI, essentially affect the health of the individual (person or animal) through its specific toxicological pathway. Dioxin can also be transmitted to foetuses through breast milk and because it bioaccumulates in fatty tissue it can rise in concentration along the food chain.

The geographical scale of dispersion of toxic substances depends on their origin and application. Dioxin and lead, for example, originate in combustion processes and can be transmitted through the air over tens and hundreds of kilometres. Pesticides are applied by farmers to fields using ground- and air-based machinery. It is possible for pesticide clouds to be transported by air currents over substantial distances but the main range of exposure is through the increasing globalization of agricultural markets that bring foods with pesticide residues to virtually all parts of the world. Chromium VI

[10] See http://ec.europa.eu/food/food/chemicalsafety/contaminants/dioxins_en.htm for the regulation and http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/06/54&format=HTML&aged=0&language=EN&guiLanguage=fr for more information.

exposure most directly affects workers in the factory but it can contaminate water resources used for drinking, bathing, and irrigation purposes and thereby affect communities around the factory and far away.

Trends in exposure levels of the population vary. In Europe, leaded gasoline has been nearly phased out and contributed to a substantial decline in blood lead values in children and adults. Chromium VI and dioxin are recognised carcinogens and therefore tightly controlled by emission and use regulations. However, comparable and comprehensive national data are difficult to obtain and it is thus difficult to satisfactorily determine the current status and trend in exposure risk from these toxic substances.

3.2.3. Alert levels or danger zones

As pointed out earlier, for many chemicals and chemical substances toxicological evidence is incomplete or even lacking. The EU Chemicals Directive REACH (EC/1907/2006) addresses the Registration, Evaluation, Authorisation and Restriction of Chemical substances and entered into force in 2007.

The aim of REACH is to 'improve the protection of human health and the environment through the better and earlier identification of the intrinsic properties of chemical substances. At the same time, innovative capability and competitiveness of the EU chemicals industry should be enhanced. The benefits of the REACH system will come gradually, as more and more substances are phased into REACH.' (http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm).

Comprehensive evaluation of chemicals and substances will inform scientists, policy-makers, and the public about safe exposure levels for certain occupational and population groups as well as exposure pathways. This information is also useful to determine danger zones, albeit the use of upper limits is more typical.

3.2.4. Drivers

Toxic substances are released into the environment as often unintended by-products of combustion and industrial production processes or are mobilised from the environment by human activities. New chemicals are developed daily to support industrial, pharmaceutical, and other activities. Workers are often the first to be exposed since they are in most direct contact with many industrially used chemicals and substances. Ensuring the safety of workers, the general population, and the environment can be challenging, costly, and requires a functioning institutional and enforcement infrastructure. As a result, the underlying socio-economic drivers of the development, release, and exposure to toxic substances are (a) innovation and economic growth pressures, (b) lack of safety standards and their enforcement, and (c) insufficient testing and toxicological assessments of the risks.

3.2.5. Pressures

Toxic substances act on exposed individuals, animals, or plants. In toxicology the terminology used differs substantially from that used in the environmental indicator community. But roughly, one can translate the concept of "pressure" to the severity and duration of exposure to a toxic substance, which can be measured at the individual or the population level. The latter is usually of concern to epidemiologists and public health officials, who are, for example, concerned with the effects of poor air and water quality. For lead, the exposure pressures is measured in terms of blood lead concentration, dioxin in concentration per kg body weight and day, and Chromium VI is expressed as concentration in air or drinking water.

3.2.6. Impacts

Toxic substances affect humans via three pathways: inhalation, ingestion and dermal contact and/or sub-coetaneous penetration. Once inside or in contact with the body, the exact pathway leading to adverse health outcomes depends on the toxic substance. The specific pathway is summarized in the following for our examples lead, dioxin, and Chromium VI.

Lead is a poisonous metal. The main sources of lead poisoning are the ingestion of food or water contaminated with lead, and may include (especially for children) the accidental ingestion of contaminated soil, dust, or lead based paint. Inhalation and ingestion of lead has essentially the same health effects and may involve almost every organ. It can cause lead-poisoning, including nerve damage, blood and brain disorders. Children are at particular risk because their bodies and nervous systems are still developing and they absorb more lead compared to their body weight than adults. Pregnant women are also vulnerable and may incur miscarriage and developmental abnormalities in the fetus. For males, lead exposure may result in reduced fertility. Aside from nervous system damage, long-term exposure to lead has also been linked to muscle weakness in the extremities, hypertension, and anemia. Exposure to high lead levels may be fatal. In Europe, lead poses a problem mainly through emissions from industrial processes and leaded gasoline (although now banned in Europe). Lead based paints are also banned in the EU but may still be present under coats of new paints in older buildings and may pose a threat if they are exposed again.

Dioxin is a persistent organic pollutant, that can be generated through the degeneration of PCBs. Dioxins are not intentionally produced and have no known use. They are by-products of industrial processes including bleaching paper pulp, and chemical and pesticide manufacture, combustion such as burning of household trash, forest fires, and waste incineration. The defoliant Agent Orange used by the US Military during WWII also contained dioxins. Dioxins also occur naturally in the air, soil, water, and sediments and can be found in foods such as meat, dairy, fish, and shellfish. The highest levels of dioxins are usually found in soil, sediment, and in the fatty tissues of animals. Dioxin builds up in fatty tissue (bioaccumulates) and is highly toxic even in very small concentrations. Dioxins are listed as teratogens, mutagens, and carcinogens. TCDD, the most toxic of the dibenzodioxins, is classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC). Exposure to high levels of dioxins in humans causes a range of health effects, including:

- an elevated risk of sarcoma associated with low-level exposure (4.2 fg/m3) to dioxins from incineration plants
- increased risk of tumours at all sites at high exposure levels
- Developmental abnormalities in the enamel of children's teeth
- Central and peripheral nervous system pathology
- Thyroid disorders
- Damage to the immune systems
- Endometriosis

- Diabetes

There is evidence that dioxins may change the sex-ratio in populations toward females. An important risk for humans lies in the bioaccumulative property of dioxins, which means that their concentration in fatty tissues increases along the food chains.

Hexavalent Chromium or Chromium VI refers to chromium in the +6 oxidation state. It is used for the production of stainless steel, textile dyes, wood preservation, leather tanning, and as anti-corrosion coatings. The main exposure pathway is via inhalation where it functions as a carcinogen. Primarily at risk of exposure are workers who handle chromate-containing products and steel welders. In the EU the use of hexavalent chromium in electronic equipment is largely prohibited by the Restriction of Hazardous Substances Directive (2002/95/EC). To the general public Chromium VI poses a threat through the consumption of contaminated drinking water (Finley et al., 1997) and soils (Lan et al., 2007). Chronic inhalation of hexavalent chromium compounds increases risk of lung cancer and negative impacts on kidneys and intestines. Consumption of contaminated water can cause cancer and other health problems.

3.2.7. Data availability

Data availability varies greatly from one chemical and substance to the other. Lead, dioxin, and Chromium VI by now have well-established bodies of scientific evaluation and are supported by numerous empirical studies. The same is not true for thousands of other chemicals and although some substances are known to be toxic, their use is not necessarily restricted or well-controlled in many – mostly developing – countries, for example, with respect to the safe use of pesticides and heavy metals. The REACH directive mandates a comprehensive testing protocol of old and newly developed chemicals and chemical substances in the EU. In the US the Food and Drug Administration and other agencies are concerned with the approval and testing of chemicals and substances. An international naming convention, the CAS, ensures a unified nomenclature for the identification and description of chemicals and substances.

3.2.8. EU Policy relevance

Toxic substances pose a continued – if not growing – risk to Europe's citizens and its environment due to the accelerating pace of development of new compounds and rise in high productivity, chemical intensive agriculture. The REACH directive sets and enforces testing protocols to increase product safety for workers, consumers, and the environment. Nonetheless are people in the EU today exposed to more chemicals than ever before: a study by British deodorant manufacturer Bionsen, for example, found that British women wear on average more than 515 chemicals on their bodies, mostly from perfume, crèmes, deodorants, and make-up[11]. In addition, labeling standards and requirements in the EU, US, and elsewhere are often insufficient and allow manufacturers to 'hide' ingredients, additives, and other substances, for example, in laundry detergent. Therefore, threshold studies for toxic and other chemicals are relevant for EU policy to ensure public health and environmental safety.

[11] http://www.smh.com.au/lifestyle/wellbeing/women-wear-500-chemicals-daily-20091120-ipoo.html

3.3 Fisheries

3.3.1. Background

The determination of safe fishing levels, i.e., levels at which the survival of the species and its future harvesting potentials are preserved, for commercial and leisure fisheries is of worldwide concern in a time where most commercial fisheries are overfished and fishing efforts necessary to maintain catch volumes have risen substantially.

3.3.2. Theoretical and empirical evidence and trends in the EU

The determination of safe fishing quotas for commercial and leisure fisheries is at the heart of the EU Common Fishery Policy (CFP) reformed in 2002 but with first initiatives dating back to the 1970s. With growing populations, technological innovation, and the perceived health benefits of fish came growing pressures on existing fish stocks and their capacity to maintain their reproductive capacity.

Environmental and ecological economics has generated an extensive body of research on how to determine 'safe' fishing levels when the goal is to preserve the resource indefinitely. The most widely used concept is that of the maximum sustainable yield (MSY), which defines the fishing effort that can be expended without reducing future harvesting potentials. Based on the MSY, regulators may use an additional margin of safety when determining Total Allowable Catch (TAC) to account for the uncertainty involved in estimating fish stocks, reproduction rates, and harvest volumes.

Some ecologists and other scientists have questioned the utility of the MSY and TAC by arguing, for example, that there is no surplus production of fish because of intricate ecological equilibrium relationships within its surrounding ecosystem, therefore, any extractions would destroy this ecosystem; even under strict observance and enforcement of MSYs and TACs some fisheries have nevertheless experienced declining productivity (e.g., in New Zealand and in North America). For example, OECD studies found that 16 of 22 TAC-managed fisheries experienced decline or collapse while the system was in use (OECD, 1995, 2000). Lack of enforcement of TACs is one reason (Morgan, 2001). Another is the so-called "race-to-fish" that takes place under TAC rules because only a limited number of fish is allowed to be taken from the fishery and, therefore, all participants fish as much as possible until the TAC is reached. In Canada this perverse incentive associated with TACs led to an entire year's TAC being caught in just a few days using, among other things, dangerous fishing practices followed by flooding the markets with fish and thereby ruining prices and price stability for fishermen (Kura et al., 2004).

Illegal fishing, destructive fishing methods (e.g., bottom trawling), and by-catch have also been cited as rendering MSYs and TACs essentially meaningless considering the sometimes considerable ecological damages caused by fisheries labelled as sustainable.

To avoid the "race-to-fish", individual quota systems issue permits to take a share of the total allowable catch to the participants in the fishery. When quota share can be bought, sold, leased, or otherwise traded, the system is called an individual transferable quota (ITQ) (Kura et al., 2004).

However, the need for enforcement of TACs and ITQs remains and is even higher in the case of ITQs. Fisheries may still experience decline if the quotas are erroneously set too high, as the stock can then be seriously overexploited (e.g., Newfoundland cod fishery).

3.3.2.1 Danger Zones

In addition to fishing quotas and their enforcement it is important to consider danger zones in sustainable fisheries management. Using MSYs and TACs, danger zones could be defined as a margin of safety below these threshold levels that would avoid diminishing the regenerative capacity of the fish stock should the MSY be exceeded. If MSYs are derived from stochastic models of biomass stock of fish abundance, then the level of uncertainty can be estimated and used to define the margin of safety (e.g., setting the margin of safety proportional to the estimated variance of the MSY).

A novel and more promising approach proposed by scientists but which has been slow in adoption and implementation is called Ecosystem-based Fisheries Management (EBFM). EBFM is based on a more holistic approach to fishery management that takes into account the entire ecosystem and its intricate dependencies and balances as opposed to applying a single species management strategy (Pikitch et al., 2004). EBFM takes into account a species' habitat, food, predators, and other relevant characteristics (Ecosystem Principles Advisory Panel, 1998). While the paradigm-shift from single-species management to ecosystem-based approaches is gaining track among scientists, bureaucrats, and policy-makers (including the CFP), few actual steps and resources have yet been invested in implementing them (Francis et al., 2007).

Instead, the European Union uses the TAC system by country and the most important commercial fish species. TACs are proposed by the Commission on the basis of scientific advice on the state of the stocks and decided on by the Council of Fisheries Ministers.[12] For most fish stocks the TACs are set annually, except for deep sea species for which they are agreed on biannually. However, the EU now makes increasing use of multi-annual plans. The TACs are shared between EU countries under a system of 'relative stability', which keeps national quotas stable in relation to each other, even when the total quantity of fish that can be caught varies with the productivity of the fish stocks. Nonetheless, many fish stocks in EU and global waters continue to decline and the CFP has been criticized for not attaining sustainable fishing levels. Thus the use of TACs and their calculation method must be viewed with caution.

3.3.3. Drivers

Although relatively small in relation to overall GDP for most countries, the fishing sector in the EU is a multi-billion Euro sector that enjoys EU-wide and domestic protection for various economic and other reasons. The considerable differences in fish catch by country also mean that some countries such as Spain exert disproportionally large influence on EU decisions about fisheries management.

Fisheries are capital and labour intensive and therefore vulnerable to heavy market fluctuations, which countries try to minimize or absorb using a variety of instruments that have market distorting side effects. Similar to agriculture, domestic fish and related production is a relevant contribution to food security and self-reliance. Fishermen and the industries connected to them used to have influential lobbies arguing on their behalf for domestic subsidies, bail-outs (e.g., the ship-building industry), and other forms of support.

At the social level, the protection of domestic fishing industries and the goal to preserve fishing communities and their distinct way of life in the face of diminishing stocks have resulted in a range of subsidies with varying effects on fishing stocks. Support to retire fishing boats and to retrain fishermen

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[12] Detailed information on current and past TAC quotas is available from http://www.eafpa.org/TAC.htm and http://ec.europa.eu/fisheries/cfp/fishing_rules/tacs/index_en.htm.

meant an initial reduction in the size of the fleet, which was quickly annihilated by increases in the size of the boats and improvements in technology to detect and catch fish as well as engine power.

3.3.4. Pressures

Technological advances and supply-side developments have put increasing pressure on fish stocks, including

- the size of fishing fleets in terms of the number of boats, their capacity and power, the number of fishermen employed,
- the capacity of the fish-processing industry
- the use of ever-advancing technology in all aspects of the fishing industry, ranging from more powerful and efficient engines to sophisticated sonar and radar technology to detect fish stocks, nets and other means to capture entire schools, their on-board processing and refrigeration.

The current capitalization of the global fishing industry exceeds the demand to maintain sustainable production by five to ten times.

The causal chain leading to overfishing includes several anthropogenic pressures and their rank order differs by region and country. Population growth and the associated increase in the need for protein and other nutrients is certainly one important contributor but of less relevance within the EU due to its slow population growth rate. Nonetheless, most fish stocks in EU waters are overfished and have a long history of being fished at excess rates, one reason being the “public good” status of many marine fish stocks that promotes a race to catch as much fish as possible as fast as possible[13]. European fishing fleets suffer from substantial overcapacity, which is economically inefficient. EU Member States also protected and continue to support (although to a lesser amount) their domestic fishing industries with perverse subsidies. Too many boats with too advanced technology, fishing methods, and power chase fewer and fewer fish. The Common Fisheries Policy enacted in 2002 aims to correct the most egregious of these subsidies, reduce overcapacity, and make ecological sustainability the overarching priority followed by economic and social considerations.

3.3.5 Data availability

Data on fish catch, fleet size, harvesting efforts, and the industries downstream are available from the FAO and Eurostat. FAO is the only intergovernmental organization formally mandated by its constitution to undertake the worldwide collection, compilation, analysis and diffusion of data and information in fisheries and aquaculture. Since its inception, the FAO Fisheries and Aquaculture Department has built up statistical databases that are publicly accessible. The data is provided by FAO Members and verified wherever possible. The main databases include

- Global production by species
- Global fisheries commodities and trade
- Global aquaculture production by species

[13] Cf. (Hardin, 1968)

- Global capture production by species
- Global number of fishers
- Global Tuna catches by stock[14]
- Consumption of fish and related products
- Regional capture statistics

FAO datasets often date back 50 years. However, the reliability of the analysis based on the data, and the quality of the conclusions to which it gives rise, depend on the reliability and quality of the data itself. FAO cooperates with the UN and member countries in international efforts directed towards the development of standard concepts, definitions, classifications and methodologies for the collection and collation of fishery statistics, most importantly through the Coordinating Working Party on Fisheries Statistics.

Eurostat collects and disseminates fisheries statistics for the EU Member States and until recently 'mirrored' several FAO series. It cooperates with the DG MARE, which is tasked with the implementation of the CFP, on data collection, harmonization, and dissemination issues. Eurostat continuously adjusts its data processing, analytical, and dissemination tools to new developments in the fisheries sector.

3.3.6 Uncertainty

The uncertainty in MSYs and TACs data depends on the amount and quality of data available but also indirectly on the enforcement of the specified fishing quotas. Within the EU TACs are set on the basis of the best available scientific evidence, while maintaining the 'relative stability' system. The continuing decline of many fish stocks gives rise to question the adequacy of the current system, although it requires disentangling the considerable political nature of the debate with the accuracy of the science and available data.

3.3.7 EU Policy relevance

Sustainable fisheries management is of considerable importance within the EU, comparable perhaps to that of the Common Agricultural Policy – certainly afflicted by the same conflicts between interested parties, the long history of the issue in European politics and policy, and the broad range of environmental concerns involved.

The 6th EAP has targeted sustainable use of natural resources and the review of the CFP is an important opportunity to continue to improve fisheries management in the EU.

3.4 Water Quality with Focus on Eutrophication

3.4.1. Background

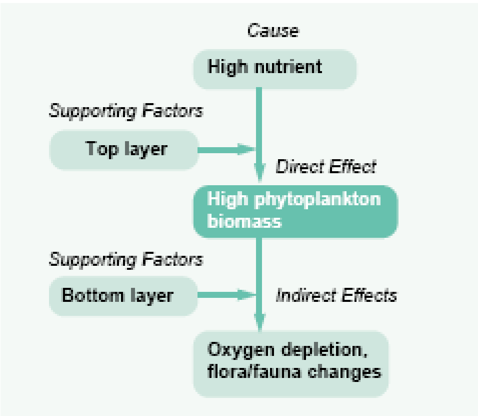
Water quality is not easily defined. Most narrowly, any deviation from the pristine status of a water body due to the influx or contamination with a substance or organism not normally found in it or occurring naturally in much smaller concentration can be understood as a degradation of water quality. More frequently, however, water quality is defined in accordance with the type and intended use of the

[14] A special database reflecting the global importance of tuna.

water, including water for drinking, for cooling or industrial manufacturing, and for maintaining ecological balance. Therefore, one broadly distinguishes between ecological water quality and water quality for human uses since the chemical, physical, and biological criteria for 'acceptable water quality' differ considerably, although many of the parameters used in monitoring programs are the same.

Eutrophication is one of the most pervasive water quality problems in Europe and around the world. The causal pathway from anthropogenic discharges of nutrients to the eutrophication of lakes and rivers (and ultimately of coastal zones, oceans and seas), and ultimately marine ecosystems and their resulting ecological regime shifts are well understood and documented (Carpenter and Lathrop, 2008). Eutrophication was first recognized as a serious and widespread problem for water managers in the 1960s and 1970s when, after World War II, laundry detergent manufactures started adding complex phosphates to laundry detergents because of their superior cleaning properties compared to conventional soaps. The resulting increase in the use of phosphate-containing detergents in Northern America and Europe coupled with efforts to increase agricultural productivity following the war led to an increase in P concentration in many freshwater lakes and rivers, a visible sign of which was the white foam wherever waters were mixed by wind or topography. The causal effect chain for eutrophication is summarised in Figure 2.

Figure 2 Causal effect chain for eutrophication



Source: WHO Europe and European Commission (2002)

Eutrophication describes the complex ecosystem responses to the influx of phosphorus (P) and nitrogen (N) from human activities, which leads to a shift in the steady state equilibrium between biologically available P and N which are used in the production of new biomass and which are released again by microbial action and animal metabolisms. Small increases in biologically available P and N can increase biomass productivity, including fish yields, however, over-stimulation of, mostly, algal growth can severely degrade water quality, reduce productivity of fish and other aerobic species, and threaten human health. This happens because algae grow – the fastest growing photosynthetic organisms – start to accumulate forming aggregates that sink to the bottom of the waterbody where bacteria aerobically decompose them. Dead plant material accumulates and increases the turbidity of the water body, further impeding light to penetrate to the deeper layers of the water body. This depletes oxygen and the bottom waters become hypoxic or even anoxic causing stressful and fatal conditions for fish, shellfish and other aquatic organisms. Some algae also excrete large amounts of toxins, which impair respiratory, nervous, digestive, and reproductive functions and can lead to large-scale fish kills. Biodiversity is further reduced by the elimination of habitat and food through the fouling of seagrasses and the destruction of wetlands as a result of phytoplankton growth

3.4.2. Empirical evidence and trends in the EU

Nutrients are released virtually everywhere where humans lived: in urban areas from sewage discharge and treatment, fertilizers used on lawns and for gardening, as well as road transport and power plants; in rural areas from agriculture and untreated sewage. Streams and rivers carry the phosphorus and nitrogen hundreds of miles through landscapes and ultimately to the ocean causing eutrophication along the way and in coastal areas. Therefore, although discharge and run-off takes place locally, eutrophication is a large-scale, regional problem.

Trends in the eutrophication of freshwater bodies differ globally, and it is occurring most rapidly in South and East Asia due to strong population growth and industrialization. Within the European Union, legislation and regulatory action starting in the 1960s and unilateral actions by Member States have resulted in initial reductions in phosphorus and nitrogen loads but have more recently seen a levelling off. The initial successes in reducing phosphorus loads can largely be attributed to more widespread and more effective waste water treatment and the banning of phosphates in domestically used laundry detergents. During the same period nitrogen levels fell only slightly and remained constant contributing to the failure of 19 of 31 countries included in the report[15] to meet groundwater maximum allowable concentrations of 50mg/l in 2005 (EEA, 2007). Eleven percent of monitored groundwater bodies even showed increasing nitrogen pollution. Nitrogen originates from both waste water and agriculture, the latter being a leading non-point source of nitrogen pollution that has proven difficult to control.

Nutrient pollution in the form of phosphorus and nitrogen does not only affect vital groundwater resources: more than 40% of all surface waters are at risk of failing to achieve the objectives of the EU Water Framework Directive set for 2015. The EEA’s nutrient surplus calculations for the EU15 – and which are hence not necessarily applicable to the EU27 – estimates that in Europe an average nitrogen surplus is 55kg per hectare annually (EEA, 2006). Some countries, such as the Netherlands, Belgium, Luxembourg, and Germany, have even higher nutrient balances of more than 100 kg N/ha/year. Nitrogen surplus is strongly correlated with agricultural intensity.

Eutrophication exhibits strong threshold patterns, and these are already utilised and reflected in the science, the terminology and monitoring protocols throughout the EU and around the world. Thresholds for the absorptive capacity of nutrients of a waterbody are dependent on the size, depth, temperature of the freshwater body, its hydrology, sediment characteristics, climatic conditions, and many other factors. Thus, it is not meaningful to specify a one-size-fits-all threshold value for phosphorus or nitrogen pollution.

In the US the main paradigm uses the concept of *Total Maximum Daily loads (TMDLs)*, which define the maximum influx of the pollutant (e.g., total phosphate or nitrogen) per day that carries a specified low risk of altering the ecology of the water body and thereby triggering a so-called regime shift. Examples of the implementation of TMDLs are the US Clean Water Act of 1972, which resulted in substantial financial support for farmers and water managers to reduce pollution and which has had measurable success. TMDLs are calculated starting with an assessment of the loading of nutrients

[15] The 4th Assessment of Europe’s Environment covered a total of 52 countries.

(notably P and N) to a watershed from all point and non-point sources and performing dynamic mass balance modelling to link the response of the water column in terms of productivity, nutrient concentrations to that load. The next step involves determining nutrient concentrations that are acceptable and working the analysis in the opposite direction and re-doing the mass balance modelling and estimating the total load that will generate the new lower target concentrations or productivity. The difference between current loads and target loads must then be allocated to different loading sources, which unavoidably implies political and economic decisions (Eisenreich, pers. communication).

Prior to the adoption of the Water Framework Directive (WFD), Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources provided a legislative tool to address deteriorating water quality within the EU. It is one of the earliest pieces of EU legislation aimed at controlling pollution and improving water quality in 39.6% of EU territory subject to the directive's implementation plans. And it is proving to be effective: between 2004-2007, nitrate concentrations in surface water remained stable or fell at 70% of monitored sites. Quality at 66% of groundwater monitoring points is stable or improving.

The 2000 WFD aims to synthesize and advance Europe's water management and protection laws and regulations. The EU paradigm for water quality is to achieve and maintain 'good status' for biological and chemical quality and is applied to freshwaters, transitional waters, rivers, lakes and coastal waters. It is a river basin approach that is currently being updated to include marine waters to ensure continuity from lakes to rivers to the coast to the open sea. The goal of 'good status' enshrined in the WFD includes the set deadline of 2015 to achieve it, and involved tremendous scientific effort to decide on the boundary between 'good' and 'not good' (ecological and chemical) status over the last 10 years. These boundaries represent thresholds and are the scope of the data generation and modelling under the WFD (Eisenreich, pers. communication).

The basis for benchmarking "good status" are waters classified as "high" in the five-class WFD, which means they are characterized by no or very low human pressures. The remaining four classes are "good", "moderate", "poor", and "bad". The classes are type-specific for different types of rivers, lakes or coastal waters so as to take into account the broad diversity of ecological regions in Europe. To operationalise the classification, a large-scale intercalibration exercise was (and continues to be) carried out with the participation of more than 500 scientists and experts and with the goal to harmonize the assessment criteria for high-good and good-moderate boundaries of the classification across Member States (WFD, 2010).

For the ecological status, no absolute standards are set for the whole EU due to ecological variability. However, for every type of water body national classification schemes for the quality elements, phytoplankton, macrophytes, macrofauna and fish are set. Member States are developing proposals for standards on how to define ecological status in accordance with the intercalibration exercise that is part of the Water Framework Directive and aimed at ensuring comparability of biological monitoring results across Member States[16].

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[16] The intercalibration exercise is required by the WFD for the consistent and comparable classification of waterbodies according to their ecological status. It consists of the formation of an intercalibration network and guidance principles for the operation of the intercalibration exercise. The intercalibration exercise itself involves the selection of intercalibration sites, data collection, assessment of ecological status at these selected sites, comparison and anlaysis of the reasons for deviations in status across sites, and setting the class boundary values for ecological status. More information can be found in Common Implementation Strategy

The chemical status of the water is tested on the basis of 41 dangerous chemical substances, including 33 priority substances and 8 other substances, specified by the EU Commission. The environmental quality standards for these priority substances are described in the directive COM(2006)-397 of 2006 (under revision). So-called Ecological Quality Standards (EQS) are described, which differ for inland surface waters (rivers and lakes) and other surface waters (transitional, coastal and territorial waters) and consist of (a) annual average concentrations and (b) maximum allowable concentrations (MAC), for protection against long-term and for short-term, direct and acute ecotoxic effects, respectively. Directive COM(2006)-397 applies to:

1. 33 priority substances for which EQS were set;
2. Among the priority substances, 2 substances have been identified as priority hazardous substances which are subject to phase-out or cessation of emissions, discharges and losses;
3. 8 substances which are not included in the list of priority substances but for which earlier established common standards proved to be useful (a.o. pesticides)

Maximum Allowable Concentratios (MACs) were developed under the WFD as an environmental quality standard to limit the quantity of certain chemical substances that pose a significant risk to the environment and to health in surface water (2008/105/EC). Albeit not expressly mentioned for eutrophying compounds, MACs may also serve as an indiator for such processes.

The WFD established two types of standards: (1) the average value or concentration of the substance calculated over a one-year period for ensuring the long-term quality of the aquatic environment and (2) the maximum allowable concentration of the specific substance to limit short-term pollution peaks. Standards are further differentiated by inland surface water (rivers and lakes) and other surface water. Directive 2008/105/EC on environmental quality standards in the field of water policy, inter alia, amends the WFD and continues to use the concept of MACs.

Box 1: Summary of expert interview with Thorsten Blenckner, Stockholm Resilience Centre, Stockholm University from 21 May 2010.

Aquatic ecosystems are dynamic systems that can only be compared in terms of their water quality status if they share similar conditions and characteristics. They may nonetheless have historically different baseline levels. Scientists therefore use approaches informed by topology and biology to examine water quality across different watersheds. One surprising finding was that drivers such as temperature interplay in a stochastic manner to influence threshold levels and scientific understanding of these stochastic relationships is still limited. What is evident though is that for most aquatic systems conditions are not monitored or sampled frequently enough, thereby creating time series data that can mask important events (e.g., short episodes of high nutrient concentrations). In addition, the WFD in Europe does not specify explicitly how often sampling should be conducted. Monitoring station density is also a budgetary issue that the right balance has to be found between cost effectiveness and production of sufficiently fine-grained and frequent information on the status of water quality. More recently, some Member States have therefore begun to look into systems for automated sampling (e.g., every hour or day) and data transmission to a computer system. In such

for the Water Framework Directive (2000/60/EC), Guidance document no 6 Towards a guidance on establishment of the intercalibration network and the process of the intercalibration exercise, produced by Working Group 2.5 – Intercalibration, European Communities, 2003. ISBN 92-894-5126-2.

systems extreme events would trigger an even higher sampling frequency thereby providing scientists and analysis with a wealth of information into the cause and progress of the event.

With respect to the types of threshold indicators used, there are TMDLs applied [at state level across the United States], for example, in New York State, and cyanobacteria counts used to indicate algal blooms in Sweden and Finland. The ultimate choice depends on the water system, local conditions, and budgets.

Data availability EU-wide is still not sufficient but improving. There is the WFD's WISE system [hosted by the EEA] but national agencies also maintain their own – and sometimes more comprehensive – water quality monitoring databases, the systems of which are difficult to combine as they do not align spatially and/or temporally and are based on different database systems.

Note: statements in brackets are additions by the authors and not the interviewee.

3.4.3. Alert levels or danger zones

Eutrophication is a cumulative process that exhibits tipping point patterns. Therefore, the accumulation of the underlying pressures, namely nitrogen and phosphorus compounds and the reactions they trigger in the aquatic ecosystem, can be used to define alert levels or danger zones. The WFD uses the "good status" paradigm to define five water quality classes and the boundary standards separating the "high" level from the "good" level can be used as benchmarks and thresholds. Alert levels or danger zones could be defined using the boundary standards for the "good" to "moderate" water quality classes. The TMDL approach can utilize danger zones in the form of safety zones around the TMDL values. In fact, by federal regulation, the TDML budget must also include a "margin of safety" (MOS). Useful for policy-making are ecological, physical, or chemical, indicators[17] that are linked to the visible signs of eutrophication such as algae blooms, seagrass densities, and phytoplankton biomass indices. These can be used for decision-making. While they still allow public health and water management officials to effectively warn the public, fishermen, and others, the eutrophication process itself is often already advanced and can be mitigated or corrected only slowly. Actual values for all three approaches to establishing alert levels depend on both policy decisions and local ecological conditions.

There are at present not many examples of water management systems or public information campaigns using alert levels for eutrophication processes. According to UNEP[18], Australia is a leader in developing and using alert systems to inform public health officials, water managers, and the public about the status and trend of algal blooms, which occur frequently in the country during the summer months. For example, the New South Wales government's Algal Management and Alert Service in Australia defines three levels: Green, Amber, and Red, depending on the amount and type of algae present in the waterbody.[19] Another Australian system that was also recommended by the World Health Organisation's European Office and the European Commission in its pamphlet to local authorities on eutrophication and health (2002) uses cyanobacteria concentration as the primary index

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[17] Examples include the light penetration factor, dissolved oxygen concentration, and salinity.

[18] UNEP Division of Technology, Industry and Economics (2000). Planning and Management of Lakes and Reservoirs: An Integrated Approach to Eutrophication. UNEP International Environmental Technology Centre Osaka/Shiga.

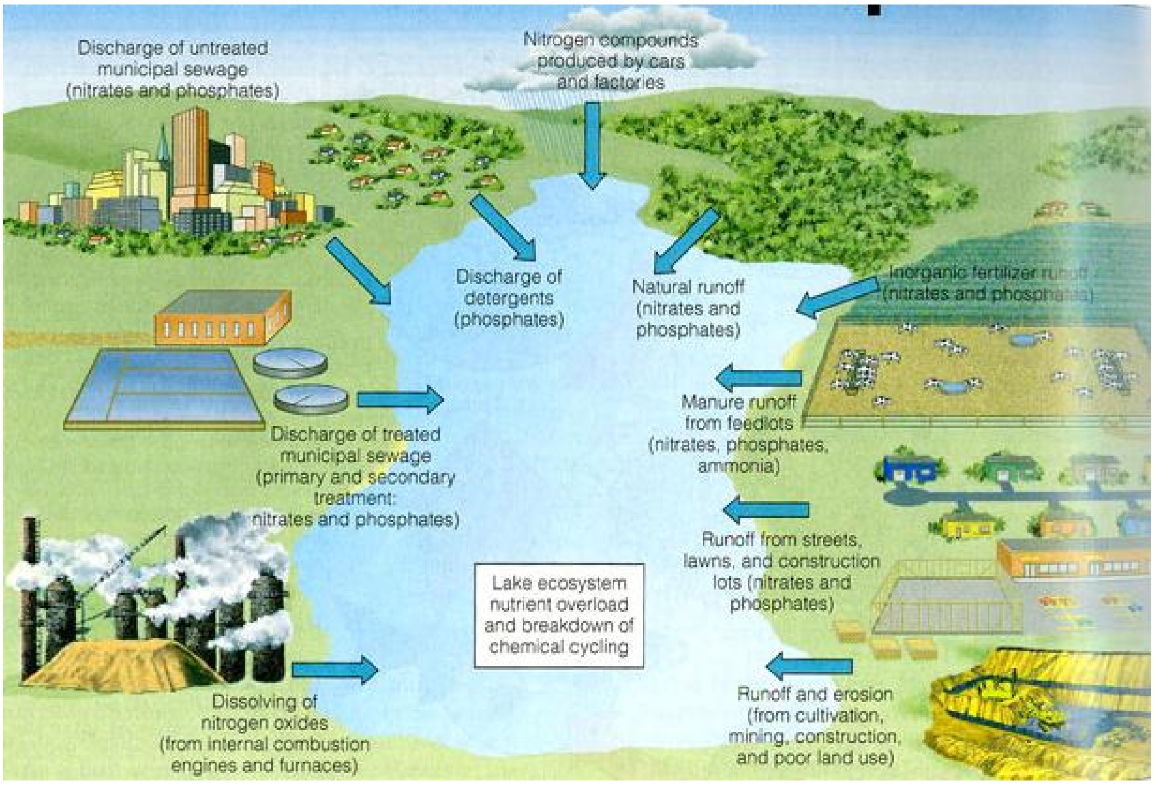
[19] http://www.water.nsw.gov.au/default.aspx?ArticleID=187#def

and defines a vigilance level and two alert levels. The vigilance level is triggered when one colony or five filaments of a cyanobacterium are found in 1ml water. Monitoring should be done at least weekly. Alert level 1 comes into effect if the cyanobacteria concentration rises to 2,000 cyanobacterial cells per ml or 0.2 mm3/l biovolume or 1 µg/l chlorophyll-a are detected. Toxicity of the raw water needs to be assessed, and public health officials and possibly the public should be informed about the present threat of an algae bloom. Finally, Alert level 2 enters force when 100,000 cells per ml or 10-mm3/l biovolume or 50 µg/l chlorophyll-a are detected. Presence of toxins is also confirmed. Reaching Alert level 2 means that a toxic bloom with high biomass and possibly also localized scums is established requiring corrective measures such as water treatment. In the U.S. the National Oceanic and Atmospheric Administration (NOAA) has worked with scientists to develop an integrated harmful algal bloom (HAB) alert system for the Great Lakes. The system was tested and found to effectively detect, assess, and predict harmful algal blooms using a combination of detection methods. There is no EU-wide coordinated or harmonised system for detecting harmful eutrophication events, however, the WFD approach to eutrophication implies benchmark values that can be used to define threshold and danger zones on the basis of the WFDs ecological river basin management approach. The Water Information System in Europe (WISE) that was implemented under the WFD gives information on the status of water bodies in Europe over time, at different geographical and political scales as well as compliance information on the status of the implementation of the WFD. Other water related directives are slowly integrated into WISE system as well.

3.4.4. Drivers

The main drivers of eutrophication are high productivity, intensive agriculture through the use of organic and synthetic fertilisers, untreated or insufficiently treated municipal and domestic sewage, power plant and industrial emissions of nitrous oxides, as well as transport-related emissions of nitrogen oxides (cf. Figure 3).

Figure 3 Main sources of eutrophication



Source: adapted from http://library.thinkquest.org/04oct/01590/pollution/culturaleutroph.jpg

3.4.5. Pressures

The main anthropogenic sources of nutrients are intensive agriculture (phosphorus and nitrates from livestock and fertilizers), laundry and dishwashing detergents containing phosphates, untreated or insufficiently treated sewage, domestic fertiliser run-off from lawns and gardening, and nitrous oxide emissions from fossil fuel power plants.

Eutrophication pressures arise from excessive influx of nutrients into aquatic systems such as lakes, rivers, creeks, and groundwater. Due to the growth and accompanying economic development of the world's population and further exacerbated by the distances that nutrients can travel in aquatic environments and the interconnectedness of soil, water, and air, very few watersheds remain untouched by the problem. At the local level, eutrophication pressures are measured either as a load, i.e., a flux of nutrients into a system, or as a concentration, i.e., the status of a system. Each ecosystem has different capacity to absorb nutrients, which is expressed in a nutrient balance. If influx exceeds absorption and outgoing flows, this balance is in surplus. Therefore, pressure indicators such as TDMLs can be used to effectively monitor nutrient balances in waterbodies.

3.4.6. Impacts

Water quality is of significant importance within the EU both from an environmental health and ecological perspective. Threats to water quality arise from industry, transportation, energy production and transformation, agriculture, and households. Within the EU[20] the primary threats to water quality, according to the fourth assessment report on Europe's Environment (EEA, 2007), include excessive influx of essential nutrients, mainly in the form of phosphorus (P) and nitrogen (N)[21], which can cause eutrophication with long-lasting negative effects on ecosystem productivity, aesthetic value, and human health.

Eutrophication can ultimately lead to a tipping point, which causes the complete collapse of the water body and its near-shore ecosystem. The damage is not only ecological but also economic, including the loss of fish and other harvested species, the decline in leisure, aesthetic, and recreational value. Human health may also suffer as a result of the toxic chemicals released by algae that contaminate drinking and bathing water.

Eutrophication also has implications for a wide range of other ecological and environmental processes, many of which support economic and other human activities. Important links include the availability of water resources for industrial production, cooling, as bathing water, the production of fish and shellfish for commercial and recreational purposes, the tourism and aesthetic enjoyment of healthy aquatic ecosystems.

3.4.7. EU Policy relevance

Eutrophication is a widespread and persistent problem in Europe and has been the subject of several pieces of legislation and regulatory action which have had measurable but not complete success. Water quality is managed under the umbrella of several pieces of legislation: the Surface Water Directive (75/440/EEC) of 1975, the Urban Waste Water Treatment Directive (91/271/EEC) of 1991, which requires to designate sensitive areas (which includes freshwater bodies, estuaries and coastal waters that are eutrophic or which may become eutrophic if protective action is not taken), the Nitrate Directive (91/676/EEC) of 1991, which requires the designation of *nitrate vulnerable zones (NVZs)*, the Drinking Water Directive (98/83/EC) of 1998, the Water Framework Directive (2000/60/EC) of 2000, the Groundwater Directive (2006/118/EC) of 2006, and the Freshwater Fish Directive (2006/454/EC) of 2006 (see Table 6).

Despite significant reductions in phosphorus concentrations in European waters over the past two decades, concentrations have levelled out and more recently remained stagnant. They remain at comparatively high levels in the new EU Member States (Archibald et al., 2009).

Table 6 Directives demonstrating relevance of eutrophication at EU level

Directive	**The legislation addresses**
Surface Water Directive (75/440/EEC)	Concerns surface water used or intended for the abstraction of drinking water after appropriate treatment and supplied by public

[20] Note that political boundaries generally do not coincide with watershed boundaries. However, since waterbodies are connected through an intricate network of surface and underground water flows and precipitation, it is not meaningful to only consider the political boundaries of the EU27. The mismatch between socio-political and hydrological boundaries for water management (both resources and quality) generates additional challenges for monitoring and management but its detailed discussion is beyond the scope of the analysis.

[21] The third critical nutrient is potassium but it does not constitute a major contributor to eutrophication.

	distribution networks. Sets minimum quality requirements to be met by surface fresh water and classifies it on the basis of its characteristics into three categories with different limit values. A standard method of treatment is defined for each category.
Urban Waste Water Treatment Directive (91/271/EEC)	Protect the environment from urban waste water discharges and discharges from certain industrial sectors concerning the collection, treatment and discharge of: • Domestic waste water • Mixture of waste water • Waste water from certain industrial sectors
Nitrate Directive (91/676/EEC)	Protect waters against pollution caused by nitrates from agricultural sources.
Drinking Water Directive (98/83/EC)	Protect the health of consumers of tap water. • Sets quality standards for drinking water quality at the tap (microbiological, chemical and organoleptic parameters) • Regular monitoring of drinking water quality and information to consumers about drinking water quality
Water Framework Directive (2000/60/EC)	Integrated management and protection of water resources and quality at hydrological watershed level and definition of five ecological status classes using an intercalibration approach and measures to define acceptable water quality thresholds for each status class.
Groundwater Directive (2006/118/EC)	Aaddress the requirements of Article 17(1) and (2) of the Water Framework Directive to prevent and control groundwater pollution by establishing criteria for measuring good groundwater status and criteria for the identification and reversal of significant upward trends and starting points for their reversal
Freshwater Fish Directive (2006/454/EC)	Protect and improve the quality of rivers and lakes to encourage healthy fish populations by setting water quality standards and monitoring requirements.

The EU employs a range of economic and other instruments to reduce eutrophication. The WFD serves as a framework that synthesizes, aligns, and harmonizes previous EU water legislation to achieve the overarching objective of “good water status” in all of Europe’s surface waters and groundwater. Under Article 11 of the WFD, from 2006-2012, member states need to develop the Program of Measures (POMs) for each River Basin District (RBD). The POM, which must be operational by 2012, may include wide-ranging actions such as:

- measures to manage specific pressures arising from: forestry, agriculture, urban development, etc;
- control regimes or environmental permitting systems;
- water demand management measures;
- economic instruments such as incentives, taxes on fertilizers, etc;
- river restoration strategies, etc.

Table 7 lists common economic instruments used to manage water resources and quality and that will find application by Member States in the POMs.

Table 7 Types of economic instruments available and used in the EU to protect and improve water resources

Type of Instrument		Main Purpose	
Market-based instruments using existing markets	Taxes and charges	Water tariffs	To collect financial resources for a functioning water service and efficient water use.
		Environmental taxes	To internalize negative environmental impacts and correct behaviour
		Environmental charges	To internalize negative environmental impacts and correct behaviour. To collect financial resources to support environmentally friendly practices and projects
	Subsidies	Subsidies on products	To increase attractiveness of green products and production processes that have limited environmental impact/footprint
		Subsidies on practices	To promote use of practices that limit negative environmental impacts on water resources or deliver positive environmental externalities
Market-based instruments creating new markets	Markets for environmental goods	Tradable permit for pollution	Ensure optimal allocation of pollution among producers
		Tradable permit for abstraction	Ensure optimal allocation of water resources across sectors (incl. the environment)
		Compensation mechanisms	Ensure payment for environmental degradation and its allocation to action for rehabilitation
Market and Non-market based instruments	Voluntary agreements		To establish a contractual arrangement between parties to promote good practices that reduce pressures on water resources, also referred to as payments for environmental services. Includes unilateral agreements and public voluntary schemes
Other instruments	Insurance, finance and full-cost recovery mechanisms		Other instruments not covered above

3.5 Water Quantity

3.5.1. Empirical evidence and trends in the EU

Empirical evidence shows that the quantity of freshwater in Europe has become increasingly problematic (EEA, 2009). Over the past thirty years, droughts have dramatically increased in number and intensity in the EU. The number of areas and people affected by droughts grew by almost 20% between 1976 and 2006 (European Commission, 2007a). In the OECD in general, water is mostly being used in sustainable ways at the national level. However, most OECD countries still face at least seasonal or local water quantity problems and several have extensive arid or semi-arid regions where water is a constraint to sustainable development and to the sustainability of agriculture (OECD, 2004). In the EU, water scarcity is also manifested through increasing external water resources dependency (even EU countries that do not have an image of being water-scarce, such as the UK, Belgium, the Netherlands, Germany and Denmark, have a high virtual water import dependency) (Hoekstra, 2006).

Water scarcity and droughts are localised and temporal phenomena as water availability can vary during one year and between different regions within a country (Yang et al., 2003). While Europe is by large considered as having ample water resources, water scarcity is an increasingly frequent phenomenon in some countries and regions. The long-term imbalance resulting from water demand in excess of available water resources is no longer uncommon. Especially countries in the Mediterranean as well as regions with intensive agricultural production often face temporal water scarcity. But even some rivers in the UK are at long-term risk of drying out (WWF, 2010). The European Commission expects further deterioration of the water situation in Europe if temperatures keep rising. Thus, water is no longer the problem of a few regions, but now concerns all 500 million Europeans.

Outside the EU, limits have already been reached or breached in several river basins that are now "closed" because people have used all the water, leaving just an inadequate trickle for the ecosystem (e.g. important breadbaskets around the Colorado River in the United States, the Indus River in southern Asia, the Yellow River in China, the Jordan River in the Middle East, and the Murray Darling River in Australia) (Molden et al., 2007). In the more arid regions of the world, water scarcity has become the single greatest threat to food security, human health and natural ecosystems (Seckler et al., 1999). Therefore, it is important to monitor thresholds and danger zones in the use of freshwater.

In the literature there are various ways of measuring water stress or water scarcity, but there is little consensus on the actual thresholds. A number of indicators have been suggested for monitoring the availability of water (see Table 8).

Table 8 Water resources indicators and applicable scales

Indicator	Reference	Spatial scale
Water Exploitation Index	EEA	country (EU27, Iceland, Macedonia, Norway, Switzerland, Turkey)
Water Footprint	Hoekstra (2006)	country
Water reservoir supply index	Shiau (2003)	water basin level
Falkenmark water stress indicator	Falkenmark et al. (1989)	country
Water resources vulnerability index	Raskin et al. (1997)	country
Water poverty index	Sullivan et al. (2003)	country, region
Indicator of water scarcity	Heap et al. (1998)	country, region
Water availability index (WAI)	Meigh et al. (1999)	region

However, very few suggestions have been made on actual threshold values, and there is no consensus among scientists on the exact threshold that leads to water scarcity. So far, there are only rough estimates. The EEA uses the Water Exploitation Index (WEI) to define water scarcity. The WEI divides the total water abstraction by the long term annual average (LTAA) resource. The warning threshold, which distinguishes a non-stressed from a water scarce region, is around 20%, with severe scarcity occurring where the WEI exceeds 40%. Note, however, that the WEI does not reflect the diverse situations that occur at regional or large river basin level. Regional analysis is therefore required to get a more specified picture of the situation in terms of water scarcity.

Looking at river basins, Molden et al. (2007) define physical water scarcity as a situation where more than 75% of water resources are withdrawn for agriculture, industry and domestic purposes. A water basin that is physically water scarce does not have enough water to meet environmental flows. The 75% is a rough but robust estimate which still has some room for refinement.

Considering the very diverse results from the literature (thresholds set for abstractions representing 20% of long term average resources in the context of WEI and at a level of 75% in the Molden's study), our analysis suggests that a good indicator for danger zones and thresholds in the area of freshwater use should provide a warning before reaching dangerous levels of withdrawals of renewable or non-renewable freshwater, which would endanger the continuous provision of water for nutrition, feeding, production and ecosystem maintenance purposes. Section 4.2 further investigates what threshold indicators can be used to monitor sustainable freshwater use.

3.5.2. Drivers

Monitoring danger zones and thresholds of freshwater resource availabilities requires not only quantitative data on water abstraction but also a good understanding of the main driving forces behind it. Addressing them can help achieve a more sustainable management of water in the EU.

Water demand is driven by various economic and human activities, including the demand from households, industry, agriculture, energy sector, urban amenities, tourism, etc. The quantity of freshwater used per capita is directly related to individual and industrial water consumption patterns (EUROSTAT, 2004).

Increased water use that contributes to water scarcity is mainly driven by population growth, higher incomes, and changing lifestyles which in turn lead to an increased global demand for food and feed, biofuels and other industrial uses of crops and biomass (thus increasing demand for water in agriculture), increased demand for services that require more water (toilets, washing machines, golf courses), as well as pollution and climate change linked to economic activities (Rosegrant et al., 2002; WRI and Rabobank, 2008; Yang et al., 2003). An important economic driver behind this increasing demand is the price of water which is often only a small fraction of what it actually costs to extract water, deliver it to users, and treat it after its use. A more political cause of water problems is inadequate institutions (policies, laws, and organizations that influence how water is managed) (Molden et al., 2007).

The main sectoral drivers for the increased water consumption that contributes directly to water scarcity are an increasing abstraction for energy production, agriculture, public water supply and industry (Rosegrant et al., 2002; Yang et al., 2003). On average in the EU, energy production accounts for 44% of total water abstraction, primarily serving as cooling water; 24% of abstracted water is used in agriculture; 21% for public water supply and 11% for industrial purposes. However, these averages conceal strong regional and temporal differences as water demand can strongly vary by region and season (EEA, 2009). In southern Europe, for example, agriculture accounts for more than half of total national abstraction, rising to more than 80% in some regions[22], while in Western Europe more than half of water abstracted goes to energy production as cooling water.

In Mediterranean countries, seasonal tourism regularly inflates the population, adding extra pressure to already scarce water resources. Available per capita figures on water abstraction for those countries with a large tourist industry are well above the EU average, as they are calculated using the normal population of the country, and do not include the massive influx of tourists each year (EUROSTAT, 2004).

Energy production, agriculture and industrial production also differ significantly in their 'consumptive' use of water. Almost all cooling water used in energy production is restored to a waterbody, while the consumption of water through crop growth and evaporation typically means that only about a third of water abstracted for agriculture is returned (EEA, 2009).

3.5.3. Pressures

The main pressure on sustainable water quantities is human water consumption. Water is only a renewable resource for as long as the consumption rate does not exceed the long term replacement rate.

3.5.4. Impacts

When water resources are limited and renewal rates are low, strong demand for freshwater can cause the collapse of aquifers, so that they can no longer be replenished. Overexploitation also affects the natural flow of rivers, the water cycle as a whole and the ecosystems and ecosystem services that depend on it (EUROSTAT, 2004; WWF, 2010). Prolonged periods of dry conditions can also pose dangers for human activities, in particular related to agriculture (Rosegrant et al., 2002). Some of these effects may be irreversible.

It is generally expected that climate change will worsen local problems of water scarcity and flooding as climate change is altering the hydrological cycle, affecting the temporal and spatial distribution of rainfall, leading to more prolonged droughts in some parts and increased flooding in other parts (WRI and Rabobank, 2008). Flooding and water shortages tend to reinforce one another further through erosion, the loss of water holding capacity and the decrease in storage capacity due to the accumulation of silt in reservoirs (WRI and Rabobank, 2008).

The impacts of water shortages and flooding are further worsened by the fact that water quality and water quantity are strongly linked. The amount of water that can be supplied to households, industries and farms is reduced where water pollution is worsening (WRI and Rabobank, 2008). Decreasing water quality is directly linked to the loss of ecosystems and the extinction of whole species.

Water quantity and quality are also linked to fisheries, soil degradation, land use change, and to the consumption of non-renewable materials. While excessive water withdrawals from surface waters endanger fish habitats, decreasing levels of groundwater bodies due to, for instance, irrigated or intensive agriculture lead to a drying out of soils resulting in increased susceptibility to soil erosion. Moreover, the use and pollution of water resources, for example, for mineral extraction activities have

[22] The demand from agriculture is strongly linked to the needs for irrigation which may vary widely from country to country and from one year to another, depending on the weather conditions.

a direct impact on water availability. As a consequence, multiple pressures on the existing water resources lead to a strong competition among different uses, especially in countries which face water scarcity.

3.5.5. EU Policy relevance

Freshwater resources are a priority area of the 6th Environment Action Programme of the European Community, which calls for rates of extraction to be sustainable over the long term. The 3rd Thematic Strategy on the Sustainable Use of Natural Resources used in Europe (COM 670 (250)) aims at 'ensuring that the consumption of resources and their associated impacts do not exceed the carrying capacity of the environment and breaking the linkages between economic growth and resource use' (European Commission, 2005b).

The sustainable availability and supply of freshwater resources have been a concern for the European Commission as evidenced by a number of policy documents and directives. In 2007, the European Commission addressed the challenge in a Communication on water scarcity and droughts in the European Union (COM (2007) 414 final). The Communication identified seven main policy options to address water scarcity and drought issues (European Commission, 2007a):

(1) Putting the right price tag on water
(2) Allocating water and water-related funding more efficiently
(3) Improving drought risk management
(4) Considering additional water supply infrastructures
(5) Fostering water efficient technologies and practices
(6) Fostering the emergence of a water-saving culture in Europe
(7) Improve knowledge and data collection

At the policy level, the most prominent example is the *Water Framework Directive* (91/676/EEC). While the WFD generally focuses on water quality issues, water scarce countries in the EU focus mainly on water quantity aspects.

The EU *Floods Directive* (2007/60/EC) on the assessment and management of flood risks requires Member States to assess if all water courses and coast lines are at risk from flooding, to map the flood extent and assets and humans at risk in these areas and to take adequate and coordinated measures to reduce this flood risk.

The *Eco-design Directive* (European Parliament, 2009), which was established as a framework for the setting of eco-design requirements for energy-related products, also aims to foster water performance technologies and practices.

The importance of water efficiency is also reflected in the *Construction Products Directive* (89/106/EEC). A further implementation of this directive may enable appropriate standards related to water efficiency to be introduced for construction products (European Commission, 1988).

The Joint Research Centre is also planning to develop and manage a European level Drought Information (+ platform and Observatory).

3.6 Land use/Land use Change

3.6.1. Background

Land Use and Land cover change (LULCC) is a general term for the transformation of the terrestrial surface of the Earth through human activity (Erle and Pontius, 2007). These activities began with the evolution of man but have increased dramatically in speed and extent since the industrial revolution. The resulting changes in ecosystems are observable globally and at all spatial scales. The processes involved in increasing pressures on limited land resources, and their ability to regenerate, are complex and deeply rooted. Researchers and experts warn that many soils and landscapes are reaching their absorptive and regenerative limits, including two primary services provided by land, namely the availability of fertile, productive agricultural land and species habitat (Foley et al., 2005). Land delivers many ecosystem services, including the provision of food and water, the regulation of climate, support of nutrient cycles, and through its cultural, recreational and spiritual values. However, across the globe critical ecosystem functions provided by land are lost at an alarming rate[23]. Land is not an unlimited resource and increased pressure on and competition for land resources in Europe also affects global land use patterns through the diversion of land uses to areas beyond its borders.

The search for thresholds in land use and land use change management is proven to be challenging because it is primarily a political and societal problem, in the sense that a decision has to be made or a consensus has to be found about the amount and type of land use changes that are acceptable vis-à-vis their negative environmental (and possibly economic and societal) impacts (Verheijen, Jones, pers. communication). In addition, the problems of soil sealing, land abandonment and marginalization, the expansion of urban areas as well as increasing landscape fragmentation are usually discussed in the context of soil degradation and biodiversity loss (Davidson, 1998; Gardner et al., 1991; Jaeger, 2000; Nagendra et al., 2004). Each of these is explained briefly in the following paragraphs.

Soil sealing: The Joint Research Centre's Land Management and Natural Hazards Unit defines soil sealing as the loss of soil resources due to the covering of land with impervious materials for housing, roads or other construction work. The term is also used to describe a change in the nature of the soil leading to impermeability (e.g. compaction by agricultural machinery). Sealed areas are lost to uses such as agriculture or forestry while the ecological soil functions are severely impaired or even prevented (e.g. soil working as a buffer and filter system or as a carbon sink). In addition, surrounding soils may be influenced by change in water flow patterns or the fragmentation of habitats. Current studies suggest that soil sealing is nearly irreversible (JRC, 2010).

Land marginalization: agricultural land marginalization is a process involving economic, social, demographic, political, and environmental causes under which certain lands cease to be economically viable under the present land use system (Geist, 2006). Although it can be found everywhere, it is most prevalent in remote areas and under harsh climatic conditions.

Land abandonment: This is the process of withdrawal of land from production and often follows land marginalization (Geist, 2006). Agricultural land abandonment is not a new but a recurring phenomenon in the EU due to agricultural policies, agricultural market prices, and changing demographic factors. The ecological problem of land abandonment is that anthropogenically modified

[23] With negative impacts on species diversity of such magnitude that scientists and other experts including the UNEP Global Environmental Outlook speak of the imminent threat of a 6th mass extinction of species.

landscapes over time developed their own unique biodiversity and their abandoning threatens the present species equilibrium and diversity, usually with the effect of reducing them.

Landscape fragmentation: refers to the alteration of land resulting in the spatial separation of units from a previous state of greater continuity (Hogan and Draggan, 2010). It occurs naturally (e.g., landslides, volcanic eruptions, landscape changes on geologic time scales) but is most relevant for environmental policy making as a result of human activities such as road and rail construction, urbanization, agricultural, deforestation, and other changes to landscapes. The conversion of forest land or pastures to arable, built-up, and other land use types impacts the size and connectedness of the remaining forests and other land types with potentially detrimental effects on their ecological and species diversity equilibrium and resilience. Ecologists, foresters, urban planners, social scientists, and others study the impacts of fragmentation on species survival, ecosystem productivity, and liveability of cities.

The many different processes and underlying causes for land use change and resulting impacts on soils, biodiversity, water and nutrient cycles have led to a high degree of specialization in the field, which is further exacerbated by the extensive need of specific and spatially explicit data. As a result, different technical languages evolved, which also contribute to a reduced level of exchange, knowledge transfer and harmonisation of methodologies. We now discuss the policy-driven approaches to land use and land use change while noting that thresholds relating to the effects of unsustainable land use practices are discussed in more detail later.

3.6.2. Empirical evidence and trends in the EU

The policy nature of managing land use and land use change means that we discuss this topic jointly with its EU policy relevance. The problem of direct and indirect land use change has to a certain extent been acknowledged by European authorities but remains controversial[24] (Gay, 2010 and ADEME, 2010). Along the same line, the lack of rules on soil protection across the EU MS, while proposals for a common approach are being critically debated in the Council, has been characterised by a European Commission representative as “probably the single biggest impediment to biodiversity protection at EU level today"[25].

In order to preserve and reduce land use impacts on the environment, land use planning and management involves various sectors and various decision making levels. The European Spatial Development Perspective (ESDP), launched in 1999 with the strategic aim to coordinate spatial planning and to better integrate the various forces affecting natural resource use to achieve a balanced and sustainable spatial development strategy, helped spawn the European cohesion policy, and knowledge and wiser management of natural resources. Recently the Territorial Agenda of the EU has addressed integrated spatial development seeking for regional cohesion, sustainable economic growth

[24] A recent IFPRI report, to inform the EU Commissions' work on environmental impacts of biofuels and indirect land use change identified a sustainability threshold of 5,6% of first generation biofuels as a share in the overall EU renewable energy target of 10% for road transport fuels by 2020.(Gay et al, 2010) Several scenarios of land use changes induced by increased demand for first generation biofuels were assessed in a life cycle analysis published in April 2010 by the French energy agency ADEME, Pessimistic scenarios of direct and indirect land use change show that the benefits of biofuels are significantly reduced or cancelled out.. (ADEME, 2010)

[25] ENDS Europe DAILY, Thursday 8 April 2010, Europe 'needs sub-targets to protect biodiversity'

and more jobs using, inter alia, the European Spatial Planning Network (ESPON),, adopted by the European Commission in 2007. ESPON's aim is to support sound spatial policy development by providing (a) high quality, comparable data and analyses as well as (b) revealing territorial capital and opportunities for integrated, sustainable planning.

The literature review shows that substantial EU financing has been provided to the subject of land use and spatial planning (ETC-LUSI, PRELUDE); and soil threats and indicators of soil degradation (MEDALUS, ENVASSO, IRISE). Land use is often analysed under other topics, such as climate change adaptation, river basin management (under the WFD), Integrated Coastal Zone Management policy and urban environment policy. Threshold phenomena of different land use practices and rates of land use change are discussed as part of biodiversity studies, soil degradation, and climate-related research (e.g., conversion of land for the production of biofuels). Within this context, soil erosion thresholds are well documented and indicators of desertification, soil degradation threats and Mediterranean forest resilience have been proposed as well.

With respect to environmental thresholds, land use and land use change is related to threshold research through its effects on soil quality and habitat integrity (mainly landscape fragmentation). Soil erosion thresholds are discussed separately in Section 4.3 but for landscape fragmentation a number of indicators have been proposed (Jaeger, 2000; Moser et al., 2007) that measure to what extent a landscape has been divided into smaller patches. The effective mesh size, for example, is a metric that estimates the probability that two randomly chosen points in a landscape are not separated by a barrier (road, rail, river, etc.). Regardless of the choice of metric, specification of a cut-off point, or threshold value for landscape fragmentation, below which a high likelihood for irreversible change or damage to the landscape, biodiversity, or other characteristics of interest exists, is scientifically challenging. Similarly thresholds for soil sealing, land abandonment, and land marginalization are primarily based on policy decisions and/or societal choices.

Examples for the implantation of land use and land use change thresholds include the landscape fragmentation indicator, effective mesh size, used in the Swiss Sustainable Development Strategy (Monet), in Baden-Wurttemberg, Bavaria, Hesse, Thuringia, Saxony, Schleswig-Holstein, and South Tyrol (Italy). In 2004, the German Conference of the Ministers of the Environment decided to calculate this indicator for all German states. It is also used by the EEA and in Canada. The program "Fragstats"[26] at the University of Massachusetts in Amherst, USA, was designed to analyze the structure of landscapes quantitatively, it also includes the "effective mesh size" metric as well as "landscape division" and "splitting index" developed by Jaeger (2000). In addition "Fragstats" can deal with other fragmentation issues like habitat fragmentation.

In Europe, the "Infra Eco Network Europe" (IENE)[27] is a community of experts and institutions on the European level that is concerned with the problem of habitat fragmentation and dissection caused by transportation infrastructure. The network brings the experts together to foster the exchange of knowledge and practical experience among the European countries.

Land use and land use change is also a result of changes in global demand for land resources (see 3.6.3), which includes two examples of thresholds related to sustainable biocapacity and their use for agriculture and biofuel production. However, their in-depth analysis is beyond the scope of this project:

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[26] The link to the Fragstats project is http://www.umass.edu/landeco/research/fragstats/fragstats.html

[27] http://www.iene.info

- Planetary boundary for land system change: < 15% of ice-free land surface under cropland. Source: Rockström et al., 2009.

- Threshold of sustainable share of biofuels in transport fuels: First generation land-using biofuels threshold: consumption above 5,6% as a share in the overall EU renewable energy target of 10% for road transport fuels by 2020 can rapidly increase and erode the environmental sustainability of biofuels through ILUC emissions. Source: Al-Riffai et al., 2010.

3.6.3. Drivers

Lambin et al. (2007) distinguish two categories of reasons for land cover and land use change:

- proximate (direct or local) and

- underlying (indirect or root).

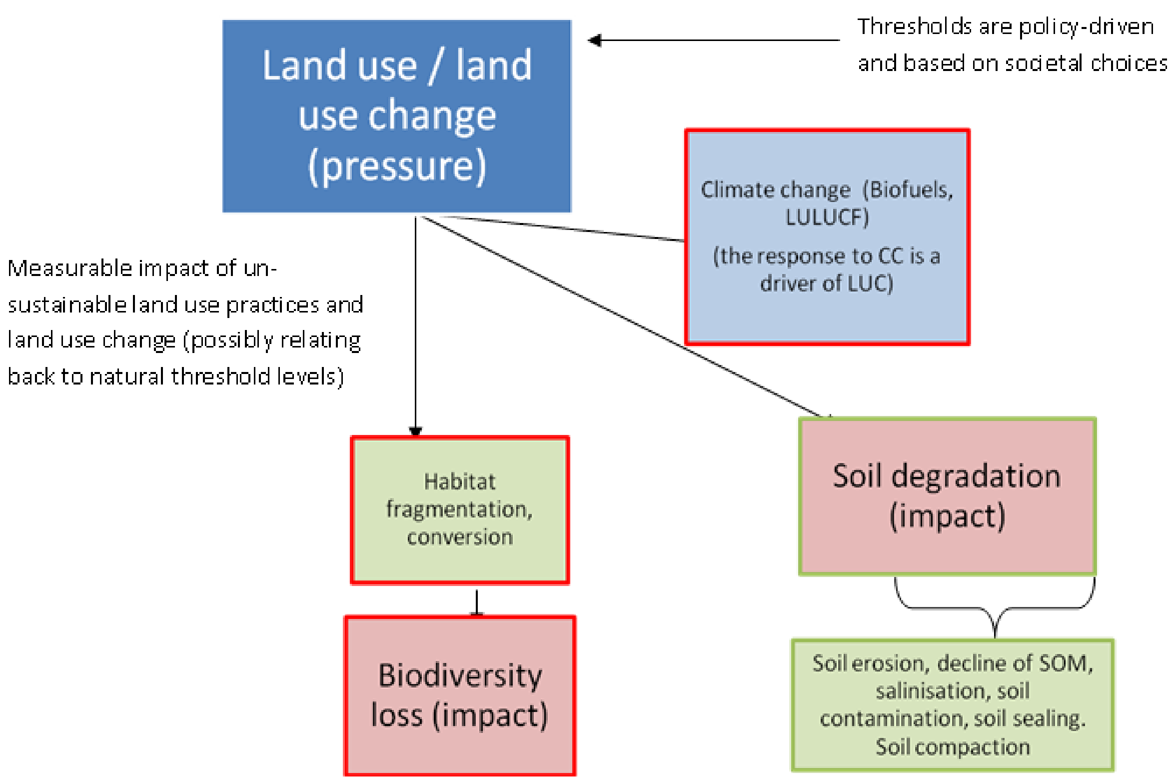
The authors state that '[...] proximate causes explain how and why local land cover and ecosystem processes are modified directly by humans while underlying causes explain the broader context and fundamental forces underpinning these local actions. In general, proximate causes operate at the local level (individual farms, households, or communities) and underlying causes originate from regional (districts, provinces, or country) or even global levels, though complex interplays between these levels of organization are common. As a result, underlying causes also tend to be complex, formed by interactions of social, political, economic, demographic, technological, cultural, and biophysical variables. Some local-scale factors are endogenous to decision-makers and are therefore under local control. However, underlying causes are usually exogenous to the local communities managing land and are thus uncontrollable by these communities. In general, underlying causes tend to operate more diffusely (i.e., from a distance), often by altering one or more proximate causes.'

Measurable underlying causes (drivers) of land use and land cover change include economic and technological factors (prices, taxes, subsidies on land use inputs, etc.), demographic (population growth/decline, changes in fertility and mortality, availability of labour, migration, urbanization, etc.), institutional (political, legal, and other institutions affecting decision-making and setting the agenda), cultural (attitudes and belief systems, collective and personal traditions and memories, shared and individual histories, etc.) and globalisation (amplifies or attenuates other drivers) (Lambin et al., 2007). Locally these factors manifest themselves as demographic change, growth in mobility, urban sprawl, and increased demand for "green space", which act together to contribute to the already significant alteration, fragmentation, and degradation of landscapes in Europe as well as contribute to air and water pollution, the depletion of natural resources, and the conversion of forests, pastures, and other land types to built-up land. Urban sprawl causes soil sealing, which may result in the unnecessary loss of soil organic matter and soil erosion (see Section 3.7.5 on soil degradation). Many of Europe's coastal zones face intensive urbanisation, tourism and leisure activities that lead to the deterioration of their environmental, socio-economic and cultural resources; Tourism has a very high spatial and seasonal impact and its flows affect the whole of Europe. Mountainous and upland areas face abandonment by traditional uses and are replaced by tourism-related uses. As land resources lie at the centre of dietary, energetic, climatic, recreational and environmental interests, the impact of land degradation and conversion or fragmentation of natural ecosystems will impact on a whole range of aspects of human well-being.

One of the main economic instruments that has influenced or controlled land use patterns is land pricing. Land pricing has been cited as both a sign of market failure that leads to destructive and unsustainable land use and land use change as well as a policy instrument to correct and influence land use patterns (EEA, 2010 and REFINA project cited therein). Although the processes, regulations, perceptions, and individual as well as institutional behaviors that influence land prices are complex, the hypothesis is that urban areas with very high land prices favor sprawl by "outpricing" local residents and newcomers to more affordable peripheral and rural areas. Sprawl is further exacerbated through other market and policy failures such as subsidies for fuel, residential and commercial infrastructure (roads, sewer systems, lighting, etc.), and land zoning, which all may increase urban expansion. If done correctly, municipalities and states or provinces can use zoning laws, land pricing mechanisms, taxes, and payments for ecosystems to correct some of the market failures and to more adequately reflect the land value.

Land use and land cover change are at the same time the results of underlying and proximate causes and drivers of further degradation of soils. Graphically, this is visualized in Figure 4.

Figure 4 Schematic depiction of the role of land use and land use change as a driver of soil degradation



3.6.4 Data availability

Data on land use and land use change differs from land cover data in that it informs about the use of the land and not about the type of landscapes, such as forests, meadows, desert, etc. Indeed, different land types may be put to similar uses such as the production of wood/wood products. The EEA's Corine Land Cover data sets contain detailed land cover information for EEA and other countries while Eurostat's LUCAS gathers information on land cover and land use through regular surveys of Member States.

Natural scientists have developed broad and fine-grained land use categories that focus on their ecological characteristics, while social scientists have further elaborated on the aspects such as property rights. Many different national classification systems are supplemented by a dozen regional and international systems such as the EUROSTAT Regio land use classification shown in Table 9 and the far more detailed system from the EU's remote sensing programme (using a matrix of 6x4 levels).

Table 9 EUROSTAT Regio land use categories

Land use type Level I	Land use type Level II
Forest (Wooded area)	
Agriarea (Utilized agricultural area)	
Garden (Kitchen gardens)	
Grasland (Permanent grassland)	
Permcrop (Permanent crops)	Vineyard
Permcrop (Permanent crops)	Olive plantations
Arabland (Arable land)	Green fodder on arable land

Land cover data are obtained from land or aerial surveys and increasingly from remote sensing /or satellite images.. Land use data combine this information with surveys on land use and/or socio-economic and demographic variables. Within the EU, land use data are available at national level for Member States as well as from FAO and EUROSTAT. Examples of data sources include:

- FAOSTAT for national aggregated crop statistics
- FAO Aquastat for irrigation data
- NASA cultivation data
- USGS Global Ecosystem data
- UNEP-WCMC Protected Areas
- SAGE and RIVM historical land use change data
- GLIPHA sub-national livestock data

We refer to a FAO paper by George and Nachtergaele (2002) hat gives a comprehensive overview of land use and cover data sources and also discusses the strengths and weaknesses of the methods used to collect them. Furthermore, it is challenging to develop statistics on land use change since this requires a spatially explicit (i.e., geo-spatially referenced) matrix approach to identify to what uses a certain area of, for example, forest land has been converted. Therefore, land use change data are generally not as well developed as land cover statistics.

3.6.5. Uncertainty

Depending on the data source and resolution, land use and land use change data can be highly accurate. However, data collection is generally expensive and land use patterns may change dramatically in some instances or vary cyclically such as crop rotation in agriculture. The frequency with which land use surveys are conducted may also not be high enough to capture cyclical changes. In addition, the local environmental effects of even small land use change can be substantial, for example, the loss of wetlands due to agricultural expansion, which may exacerbate run-off, erosion, and increase the extent and severity of floods. Therefore, land use and land use change data must be spatially explicit with sufficient resolution, and accuracy to realize their full potential for environmental management and planning. However, many uncertainties and assumptions arise in the data collection, including measurement errors, misclassification, and reporting errors.

3.7 Soil degradation

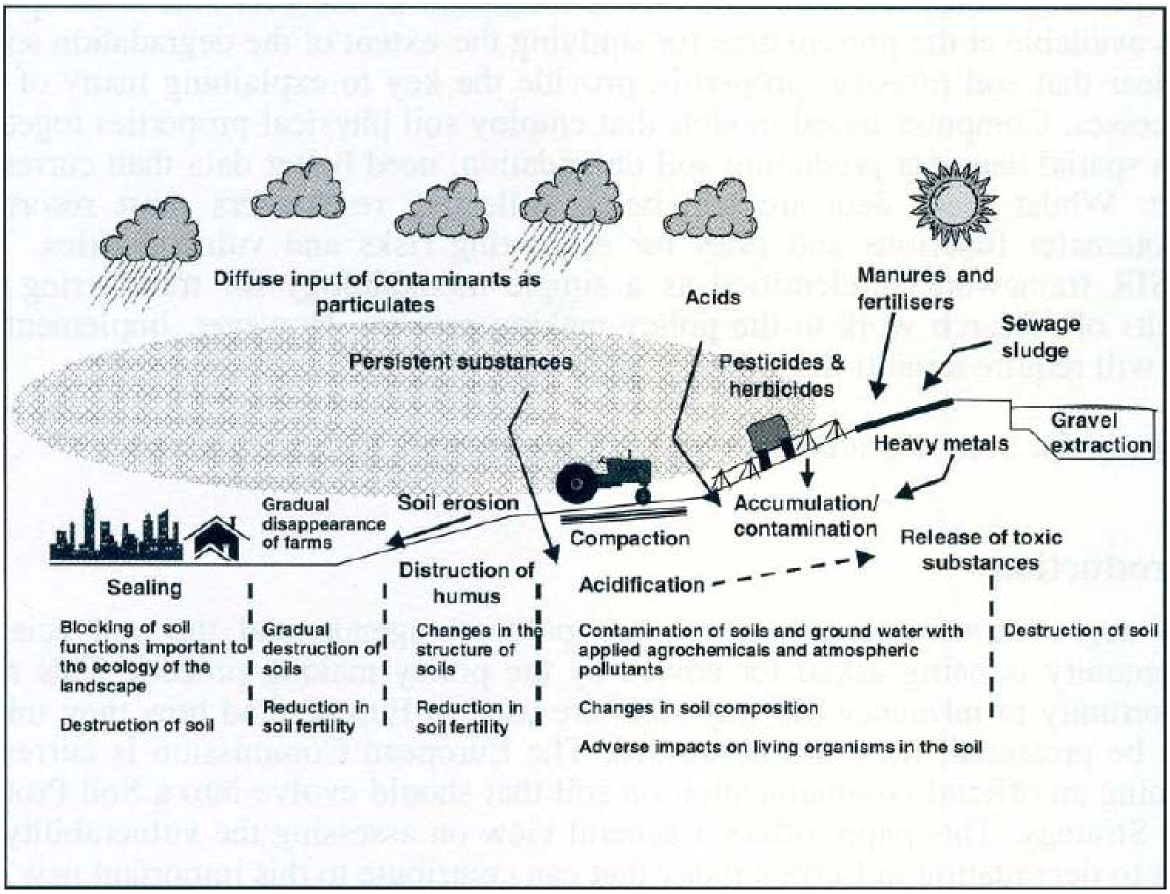
In the following sections, based on a literature review, the main characteristic elements of soil degradation processes are summarised using the DPSIR approach and illustrated by fitting examples of soil threats. As soil degradation encompasses many varying processes the focus will lie on the process of soil erosion, which will serve as the main example of soil degradation. This is justified by the scope and aim of this study due to the following reasons: (1) soil erosion is among the most widespread and severe threats to soils in Europe, (2) accelerated erosion is to a significant extent related to human activities, especially to agriculture, (3) there has been productive and recent scientific debate and research on the issue of thresholds in this area and at European level.

3.7.1. Background

The threats to soils in Europe have not changed nor have their driving forces diminished since they were described in an EEA report on soil degradation and sustainable development in 2000 (EEA, 2000). Due to the increasing need to feed an expanding world population, to the more recent challenge of increased demand for biomass in the context of climate change mitigation and also to the expansion of built-up areas ‘the limits of the resilience and multi-functional capacities of soil are being tested’ (EEA, 2000). Given that geological soil formation processes are extremely slow, soil is often considered as a non- renewable resource (European Commission, 2006b).

Agriculture physically, biologically and chemically affects soils especially through the intensification and industrialisation of practices, and through unsustainable management practices including land levelling, excessive irrigation and overgrazing. Soils are disappearing or are being translocated through erosion and soil sealing. In addition, as soils are being degraded in some areas and are lost for production the pressure on available productive soils rises. Soil resilience, i.e., their ability to absorb and recover from pressures or sudden shocks, and soil functions (e.g. cleaning and filtering) are affected as soil biodiversity suffers from pollution (industry or agriculture related), soil salinisation, loss of soil organic matter or change in physical soil properties (EEA, 2000). Figure 5 gives a visual summary of human induced soil threats and their impacts.

Figure 5 Human impacts on soil causing degradation



Source: Jones (2002)

Natural soil erosion processes occur over geological time scales and are crucial for soil formation (Jones et al., 2004). Accelerated soil erosion, e.g., when the natural rate is increased by human activity, is regarded as the major and most widespread form of soil degradation (Van-Camp et al., 2004). It is defined as:

> ‘The wearing away of the land surface by physical forces such as rainfall, flowing water, wind, ice, temperature change, gravity or other natural or anthropogenic agents that abrade, detach and remove soil or geological material from one point on the earth's surface to be deposited elsewhere.’ (ENVASSO glossary of key terms, based on Soil Science Society of America, 2001)

The dominant agents of **soil erosion** in Europe are water, wind and tillage/ translocation[28]:

- **Soil erosion by water** is estimated as the most extensive erosion type in Europe and results from excess surface runoff. The scope of water erosion is influenced by the type of soil, slope and land cover (De Ploey, 1989 cited in Verheijen et al., 2009). Soil erosion by water can be observed as rill and inter-rill erosion and gully formation. Through the removal of surface soil

[28] In their overview of erosion processes, Jones et al. (2004) also include coastal erosion, erosion caused by floods and landslides and subsurface erosion by groundwater.

(including organic matter and nutrients) from the soil mass, effective soil functioning is affected (Fullen and Brandsma, 1995 cited in Verheijen et al., 2009).

- **Soil erosion by wind** occurs through the simultaneous effect of high wind velocity, loose surface particles and insufficient surface protection (Verheijen et al., 2009). The severity of this type of erosion is also influenced by soil type (texture, organic matter content, moisture content), land use and cover.

- **Disturbance or translocation erosion** in this overview includes both 'tillage operations' and soil removed by harvesting root crops (such as potatoes and sugar beet) and erosion caused by slope engineering or land levelling[29]. The perception of the significance of soil movement and loss by tillage, root crop harvesting and land levelling, thus caused by mechanised and industrialised agricultural practice, has increased over the last 15 years. Some researchers have even observed a shift from water to tillage as the major cause of erosion on arable land (Van Oost et al., 2005 cited in Verheijen et al., 2009), although spatial patterns of both types of soil translocation differ.

- Finally, the effects of **various erosion types are combined** and often exacerbate each other by deteriorating in turn the resilience of the soil system (e.g. runoff of top soil will affect soil cover and thus the soil will be more sensitive to further erosion). Tillage erosion can overlap with water erosion processes, for instance an increase in water erosion can be observed due to changes in soil management (ploughing vertical to slope instead of parallel to it, changes in crop rotation with less soil cover etc.).

Soil erosion operates at varying spatial and temporal scales. This is related to the natural factors that determine the severity of erosion (local characteristics) and to the particularities the process of erosion. Soil erosion is characterised by a slow rate of development punctuated by severe erosion events (e.g. caused by a storm, flood, drought) that can be sporadic in time and space. This makes it a process that is challenging to detect and predict but also difficult to measure or monitor. In consequence, the necessary site data should be widespread and gathered over a long duration but currently measurements are fragmented and not standardised across the EU (Gobin et al., 2004).
The effects of soil erosion can be observed at varying scales as well: at local level (e.g. raindrop impact), at field level (creation of rills and gullies) and at regional level (off-site impacts of erosion due for example to increased sediments in water bodies).

As Frank Verheijen[30] points out, 'the complexity of erosion processes in terms of their scale represents a major challenge for erosion monitoring, measuring and modelling. As it complicates comparisons and extrapolation or upscaling, more knowledge is also needed on the connections and correlations that exist between these scales' (pers. communication).

The temporal and spatial scale challenges for soil erosion monitoring are:

- **Temporal scale variation in erosion processes:** ranging from small spatial scale processes such as raindrop impact occurring in fractions of seconds up to catchment scale processes usually being monitored over much longer time scales (i.e. seasons, years, decades or even geological timescales). Sediment delivery ratios are also time-dependent, ranging from

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[29] Erosion by trampling and burrowing animals can also be included in this category (Jones et al., 2004).

[30] Dr. Verheijen is currently postdoctoral researcher at the Joint Research Centre (JRC). He is one of the authors of a 2009 article on "Tolerable versus actual soil erosion rates in Europe", published in Earth Science Reviews.

effectively no sediment delivered at the exact moment of detachment to sediment delivery ratios at the catchment scale approaching 100 % over geological timescales (Van Rompaey et al., 2005 in Verheijen et al., 2009).

- **Spatial scale variations in erosion process:** the mean value of erosion per unit area might change at different spatial scales, all other factors being equal. For example, at smaller spatial scales (e.g. individual aggregate), better control of variables, ease of replication and understanding of erosion mechanisms can be gained. However, such fragmentation or deconstruction of processes may exclude many of the factors affecting the true rates of erosion (e.g. slope topography) as observed at a larger spatial scale (Van Noordwijk et al., 1998 in Verheijen et al., 2009).

3.7.2. Empirical evidence and trends in the EU

The main threats to soil as recognised in the European Community's Thematic Strategy for Soil Protection in 2006 (European Commission, 2006b) are soil erosion, decline in soil organic matter, soil contamination, soil sealing, soil compaction, decline in soil biodiversity, soil salinisation, floods and landslides, which combined can lead to desertification. The geographical distribution and severity of soil threats varies across Europe because natural factors such as climate, soil type and topography have a critical influence on the type and impact of soil threats. However, generally speaking and in comparison to other European regions, Mediterranean regions are most affected by a combination of soil threats such as soil erosion, decline in soil organic matter, soil salinisation, landslides and desertification. The following table gives a brief overview of indications on trends (e.g. land area affected) and geographical distribution of the major soil threats.

Table 10 Trends and geographical areas most concerned by soil threats

Soil threat	Trend and Geographical area most concerned
Soil erosion	Soil erosion above tolerable thresholds is mostly associated with agricultural land use. Soil erosion by water is the most widespread form of erosion across Europe. It is most severe in Mediterranean environments, but also affects significant parts of north-western and central Europe. 'Soil erosion by wind can be the dominant type of soil erosion particularly on the North European Plain and in the Mediterranean.' Soil erosion by tillage most severely affects Mediterranean regions because of their more vulnerable topography and soil erosion by crop harvesting can be observed in northern Europe. (Jones et al., 2004; Kirkby et al., 2004; Van Rompaey et al., 2003; Verheijen et al., 2009)
Decline in soil organic matter	'Soil organic matter decline is of particular concern in Mediterranean areas. The problem is, however, not restricted to Mediterranean regions and a recent study in the UK confirms that loss of soil organic matter can be relatively high even in temperate climates. Mineralisation of peat soils is a major cause of reduction of organic matter stocks in northern Europe.' (Huber et al., 2008)

Soil contamination	'Except for acidification, there is no widespread diffuse pollution of Europe's soil. However, contamination is high in restricted areas or hot spots (urban areas and industrial compounds), due to both diffuse and localised sources.' (EEA, 2000)
Soil sealing	'Urbanisation, suburbanisation and urban sprawl are the most important drivers of soil loss due to soil sealing. Over the past 20 years the extent of built-up areas in European countries has increased by 20% while the population has increased by only 6%. At present 75% of the European population live in urban areas and this is expected to increase to 80% on average by 2020, but to 90+% in several Member States' (EEA, 2006 in Huber et al., 2008).
Soil compaction	Soil compaction processes occur mainly due to the industrialisation of agriculture (heavy machinery). Based on a database of experimental results on subsoil compaction more than a third of European subsoils are classified as having high or very high susceptibility to subsoil compaction.(Jones et al., 2004)
Soil salinisation	'Salt-affected soils in Europe occur south of a line from Portugal to the Upper Volga including the Iberian Peninsula, the Carpathian Basin, the Ukraine, and the Caspian Lowland (Kibblewhite et al., 2008). The largest area of salt affected soils in Europe can be found in the semi-arid steppe and forest steppe regions of Russia, Ukraine, on the lowlands of the Danube in Slovakia, Romania, Hungary, Croatia and Serbia, and in Spain. The main climatic conditions favouring salinisation are arid, semi-arid and semi-humid' (Jones et al., 2004).
Landslides	'Natural events are occurring more frequently on areas with high relief and steep slopes, intense precipitation and harsh climate, such as the Alpine and the Mediterranean regions. However, damage to soil due to flooding is also occurring in lowlands' (EEA, 2000).
Desertification	'Desertification is a cross-cutting issue and the countries in Europe that are most affected are Spain, Portugal, southern France, Malta, Greece, Cyprus and southern Italy. Some small parts of other countries may meet the criteria of desertification largely through aridification, where the ground water level has been lowered by over-exploitation or intensive drainage has dried out the land and there are prolonged periods without rainfall' (Huber et al., 2008).

About one-third of the land used for agriculture at global level has been affected by soil degradation. Most of this damage has been caused by water and wind erosion (Braimoh and Vlek, 2008). According to Robert Jones[31], soil erosion rates in Europe have increased in the last 30 years due mainly to intensification of agriculture and exacerbated by other unsustainable land use practices (pers. communication*)*. With the impacts and evidence of climate change accumulating in recent years, specifically increases in the frequency of extreme weather events, seasonal shifts in heavy rainfall, and more indirectly increases in temperature and decreases in precipitation which impact the vulnerability of soils to erosion by wind for example, the problem of soil erosion is likely to increase.

[31] Dr. Jones is currently Principal Research Fellow in Soil Science at Cranfield University. He was one of the leading authors in the ENVASSO project, an FP6 research project on "'Environmental Assessment of Soil for Monitoring". He was senior scientist responsible (2000-2003) for the JRC's input to the Pan-European Soil Erosion Risk Assessment - PESERA project (EC FP5). From 2002-4, he was a Task Leader in the Technical Working Groups on Soil Erosion and Organic Matter, under the EU Soil Thematic Strategy (STS).

Geographical occurrence of different erosion types can be described as follows (Jones et al., 2004; Kirkby et al., 2004; Van Rompaey et al., 2003; Verheijen et al., 2009):

- **Soil erosion by water** is considered the most widespread form of erosion in Europe. The Mediterranean region is particularly prone to soil erosion by water due to its characteristic steep slopes with fragile shallow soil, long dry periods that are followed by extreme rainfall events. In parts of the Mediterranean region, erosion has reached a stage of irreversibility because there is no more soil left. By contrast, the area affected is less extensive in north-western and central Europe, for example, in parts of Belgium and England; however, it is still a serious problem and has an increasing tendency. Snowmelt erosion is especially problematic in parts of Northern Europe used for cereal production and particularly when snowmelt is accompanied by heavy rainfall. Snowmelt erosion has been regularly measured in the range of 1-9 t ha^{-1} y^{-1}.

- **Soil erosion by wind** is most extensive and severe in south-eastern parts of Europe, and moderate in the Czech Republic, parts of France, the UK and Hungary. Other regions affected include the North European Plain (Northern Germany, eastern Netherlands and Eastern England) and parts of Mediterranean Europe. However, soil erosion by wind is not an extensive problem in Europe compared to the arid and hyper-arid regions of the world.

- **Soil erosion by disturbance or translocation:**

    - **Soil erosion by tillage** is the result of ploughing either up and down a slope or around a contour resulting in a movement of soil up or down a slope. This type of erosion occurs most severely in topographies with many convexities (where erosion occurs) and concavities (where soil is deposited) (Jones et al, 2004). It is thus most intense in Mediterranean countries, for instance a survey in Tuscany has shown soil losses of 2 cm yr^{-1} and up to 4 cm yr^{-1}. (Borselli et al, 2002 as cited by Jones et al. 2004) This can lead to significant changes in soil properties and exacerbate wind and water erosion by exposing more erodible subsoil.

    - **Soil erosion caused by crop harvesting** is characteristic to northern Europe because of large areas growing root crops, in particular sugar beet, potatoes, carrots and chicory.

    - **Soil erosion caused by slope engineering and land levelling** is common in many parts of Europe where slope surfaces are adapted to mechanised agriculture. It is especially common in the Apennines and hilly pre-Alpine regions in Italy, in southern Spain, particularly Andalusia, as well as in Norway.

3.7.3. Irreversibility, alert levels and policy examples of thresholds

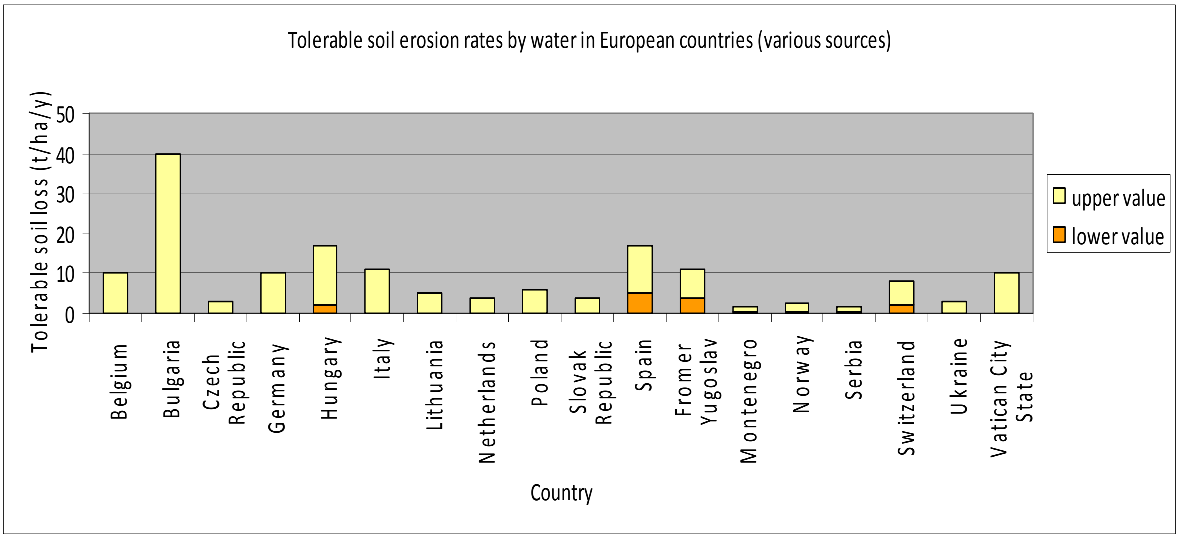
The multi-functionality of soil and its relevance to a wide range of human activities make soils especially vulnerable to depletion and degradation from many sides. The resilience of soils and of their functions (e.g. buffering capacity, filtering and absorption of contaminants) makes it difficult to detect damage at its early stages (EEA, 2000). As stated above and due to slow soil formation rates, soil should be perceived as a non-renewable resource and substantial damage to soils can be irreversible (Gobin et al., 2004; Jones et al., 2004).

The characteristics of **soil erosion** processes, slow and sometimes latent development combined with severe erosion events make it a process that is difficult to monitor. According to Frank Verheijen and Robert Jones, the concept of alert levels does not apply well to the process of soil erosion due to the temporal scale variations characterising it (see section 3.7.1 above). As Jones points out 'in reality an alert level would probably be reached very suddenly and in the middle of a severe erosion event (storm, flood etc.)' (pers. communication). There is currently no scientific evidence that could justify a particular alert value for soil erosion.

According to Verheijen et al. (2009) and to Robert Jones (pers. communication) two European countries are currently known to have established tolerable rates of erosion thresholds. In Switzerland, the tolerated soil erosion is either 1 t ha^{-1} yr^{-1} or 2 t ha^{-1} yr^{-1} depending on the vulnerability of the soil to erosion. In Norway, the threshold is set at 2 t ha^{-1} yr^{-1} (pers. communication with Robert Jones).

In the context of the RAMsoil (Risk Assessment Methodologies for Soil threats) research project, the objective of which was to collect and evaluate current risk assessments methodologies used in the EU Member States in order to provide scientific guidelines on possibilities for EU wide parameter harmonisation[32], existing tolerated levels of soil erosion by water were collected via expert questionnaires (see Figure 6).

Figure 6 Tolerance level used as threshold: differences between and within countries



Source: presentation of results of the project RAMsoil– accessed at http://www.ramsoil.eu/UK/Results/Presentations+final+meeting/ based on OECD (2008); Boardman and Poesen (2006); RAMSOIL questionnaires

3.7.4. Drivers and pressures for soil degradation

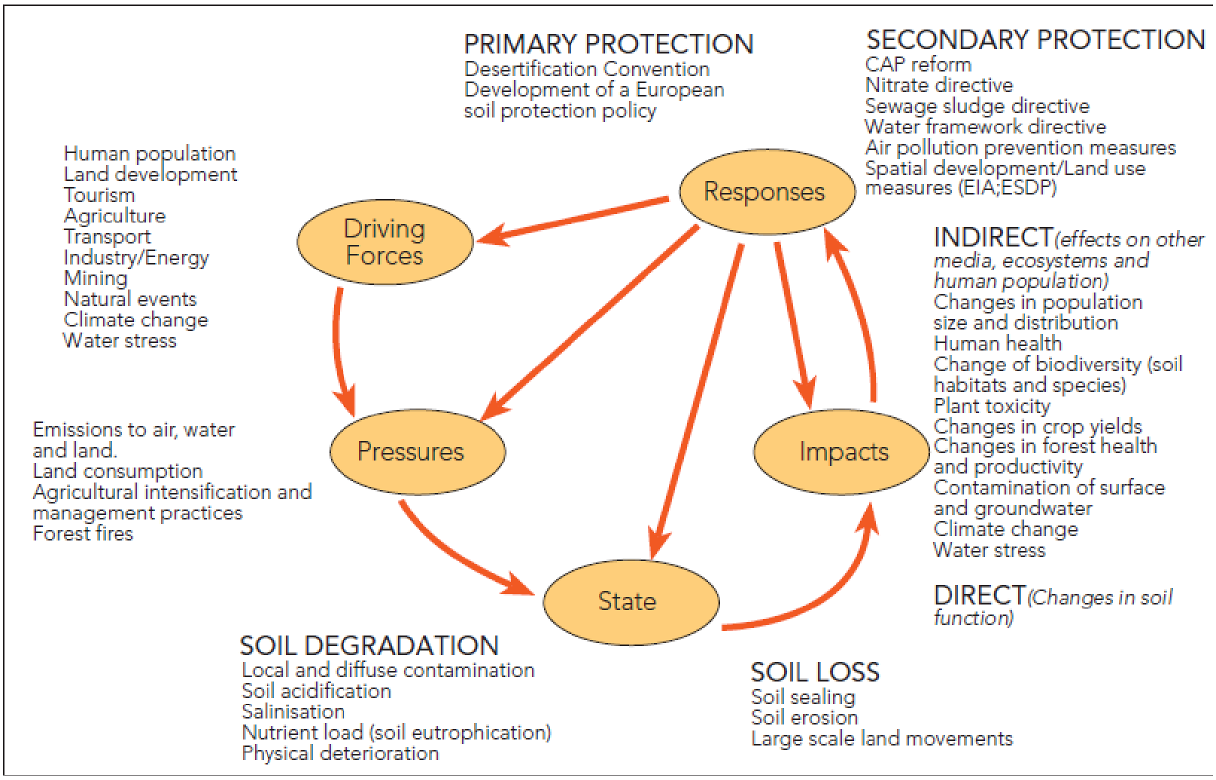
The driving forces of soil degradation can either be social and economic, i.e. related to human activities (human population, land development, tourism, agricultural production, transport, industry, mining) or ecological/ technical i.e. physical phenomena (climate change, natural events, water stress) (Blum, 2004). Blum also notes that a dimension of space and time has to be taken into account while identifying the driving forces of soil degradation. Depending on these dimensions the driving forces

[32] RAMsoil website, last accessed 30.06.2010: http://www.ramsoil.eu/UK/Background/.

can vary but are inter-connected: e.g. social and economic driving forces can both originate from the local level, at farm or household level (land tenure, family and farm structure) and from a more global level (property rights, global demography, price of energy, WTO regulations). These driving forces naturally occur at different temporal scales (Blum, 2004).

Figure 7 shows the DPSIR approach as applied to soil degradation:

Figure 7 DPSIR framework applied to soil degradation



Source: EEA, 2000

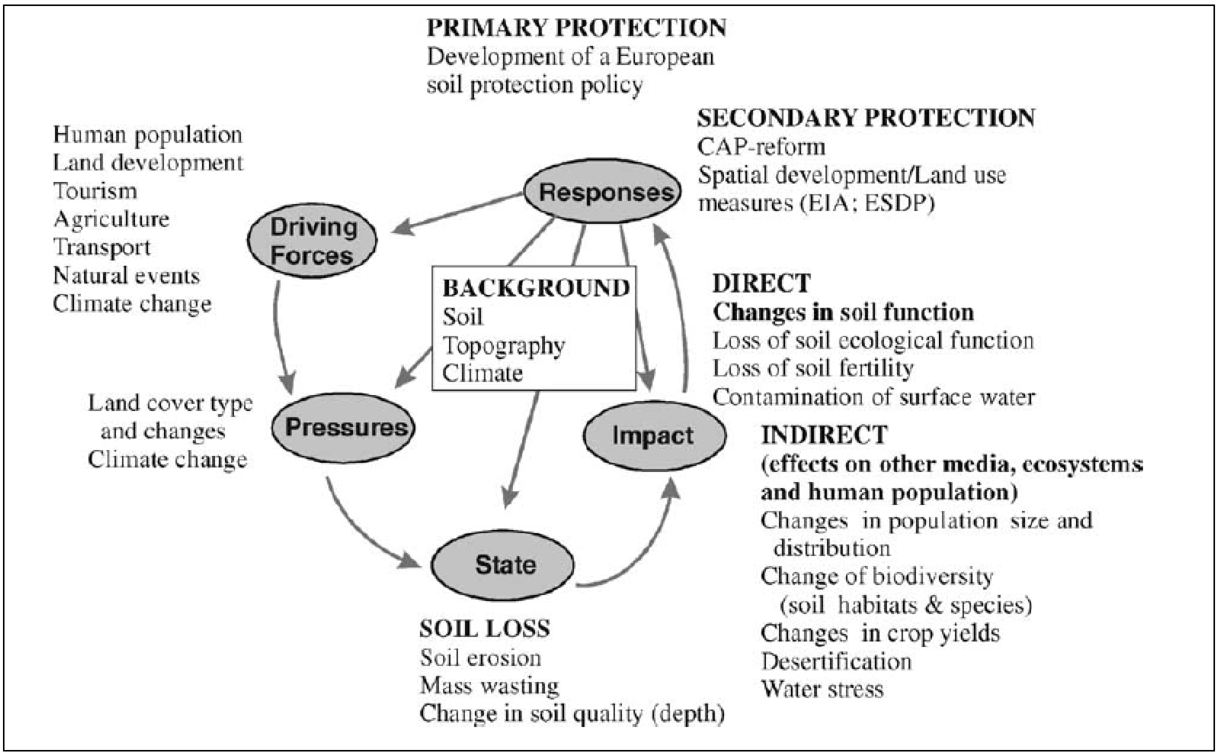
Drivers and pressures of soil erosion:

There are several natural and anthropogenic factors that drive soil erosion. The main driving forces of erosion related to human activity are the intensification of agriculture, the development of tourism in sensitive areas and urban development. Natural drivers affecting soil include inter alia droughts or climate change, to some extent also triggered by human activity. As stated by Jones et al. (2004) although these natural drivers are often the direct cause for erosion events 'the way in which land is managed can have a decisive influence on whether soil erosion remains at an acceptable level, or is increased to a rate leading to long-term and perhaps irreversible degradation of the soil'. Human activities thus have a critical role to play in the deterioration or conservation of the natural resilience of soils.

The main driving forces of soil erosion are the following (Esteve et al., 2004) (see also Figure 8 representing the DPSIR framework applied to soil erosion). To clarify linkages the pressures associated with the drivers are presented below for each category of driver.

- **Agriculture and Forestry:** inappropriate intensification of land use and management mainly determined by market prices, technological development, structural changes, and agricultural policies.
    - **Associated pressures:** Intensification and inappropriate practices in agriculture and forestry, changes in land structure include for example cultivation of steep slopes beyond their inherent 'capability', collapse of terrace structures through poor maintenance, over-grazing, ploughing practices, inappropriate irrigation methods on slopes, use of heavy machinery and frequent passes with cultivation equipment, building forest roads, continuous arable cropping (increasing the exposure of soils to erosion), harvesting roots and tubers, intensification of crops with low cover density and necessitating much tillage activity (e.g. maize), forestry on steep slopes, abandonment of land with little cover, disappearing of buffer strips and field margins with permanent vegetation, land abandonment, clear cutting of large forested areas.
- **Human population:** this includes drivers such as population growth and density, urban pressure, transport infrastructures and land development**.** These are mainly related to population dynamics and increasingly competing land uses.
    - **Associated pressures**: For example improper planning choices (soil uses not matching soil characteristics), urban pressure and development (exposing and removing bare soils and increase of soil compaction), indirect pressure by pushing agricultural activities to less productive and more vulnerable soils, development of transport infrastructure which creates an increase of pressure on land by making it more accessible, increase of water runoff, poor maintenance of drainage systems, mining activities.
- **Tourism:** this includes the use of land and soil for lodging- and transport-related infrastructure, intensified visits of fragile ecosystems by tourists, disposal of waste, and other tourism-related by-products.
    - **Associated pressures**: Increased pressure on fragile systems (e.g. sand dunes, mountain areas used for winter sport), demand for new leisure infrastructures (e.g. ports, coastal defences).
- **Natural events and climate change**
    - **Associated pressures**: storms, droughts, forest fires, flooding, sea level rise and climate change (some of these natural direct causes are actually indirectly due to human activities, e.g. climate change due to increased fuel consumption, deforestation or livestock farming).

Figure 8 The DPSIR framework applied to soil erosion



Source: Gobin et al. (2004)

3.7.5. Impacts

The impacts of soil degradation are manifold and vary in geographical scope. The main direct impacts are soil loss or consumption and change of physical or chemical properties of soils. Land consumption and soil sealing isolate the soil system from other ecological parts; this affects the water cycle, geochemical cycles, energy transfer, climate (at micro and meso scale), increases surface runoff and thus increases flood risk and reduces options for biodiversity and nature conservation or restoration. (Huber et al., 2008) The physical structure and properties of soil are for example affected by soil compaction. Compacted top soil is characterised by reduced rootability and permeability to water and oxygen. The compacted layer acts as a barrier above the subsoil and impedes its filtering and buffering function. Compacted soils crust, which increases runoff that exacerbates soil erosion. Soil salinisation is an example of a changed chemical status that harms biological processes and living organisms in soils, thus reducing productivity but also making soils more vulnerable to erosion and desertification (Huber et.al., 2008).

The impacts and costs associated with soil loss by erosion are both on-site (where soil loss occurs) and off-site (where the sediment is transported):

- **On-site effects** concern the degradation of soil functions and soil productivity caused by the loss of rooting medium, nutrients, seeds, seedlings, fertile topsoil and its organic matter, microbial communities (biodiversity). Further on-site impacts entail reduced water holding capacity, depletion of the soil's filter and buffer capacity, potential accumulation of pollutants by elevated concentrations of fertilisers and pesticides in local deposition areas. Consequently erosion can generate a loss of income and additional costs due to the reduced fertility and an increased need for fertilisers. The on-site impacts are usually assessed in terms of economic losses resulting from decline in crop yields or changes in soil productivity.

- **The off-site impacts** can have a larger geographical scope as an increased deposition of eroded sediments can restrict the capacity of water bodies to carry peak flows and can thus lead to flooding. Floods, caused by heavy rainfall and exacerbated by the effects of soil erosion are among the most important off-site impacts of soil erosion by causing damage to infrastructure (e.g. silitation of dams and destruction of roads). Water quality and aquatic biota are also affected by increased turbidity and transportation of contaminants (nitrates, phosphates and/or pesticides) into the water that lead to eutrophication of water bodies. Less studied impacts include changes in air quality due to the transport of particulate matter in the air and the emission of greenhouse gases into the atmosphere.

Given the broad extent of impacts, soil erosion also has an indirect impact on other areas, such as water, human health, climate change, nature and biodiversity protection, and food safety (Van-Camp et al., 2004, Verheijen et al., 2009). Soil erosion thus impacts other threshold areas. By contributing to the removal of soil material and the deterioration of the soil system, it directly affects the quality of the soil and the biological diversity that is stored or lives in soil. The effects of soil erosion also affect water quantity (loss of water holding capacity of soils) and water quality (turbidity through increased sediments in water).

Figure 9 Links of soil erosion to other threshold areas and thresholds

Threshold area	**Effects of erosion affecting another threshold area**
Soil biodiversity	loss of seeds, seedlings, microbial communities, impacts on aquatic biota
Water quality	increased sediments in water, turbidity and preferential transport of contaminants on eroded sediment surfaces
Water quantity	loss of water holding capacity of soils, leading to increased flooding risks also due to deposition of eroded sediments restricting the capacity of water channels to carry peak flows
soil degradation	Loss of organic matter in the superficial soil layer lost because of erosion, soil compaction influences water runoff processes and thus impact on erosion, increasing risk of desertification

Source: Verheijen et al. (2009)

3.7.6. EU Policy relevance

The 6th EAP recognises that “soil is a finite resource that is under environmental pressure” and sets as an objective to promote the sustainable use of soil, “with particular attention to preventing erosion, deterioration, contamination” (European Communities, 2002). It refers to the Thematic Strategy on Soil Protection as an instrument to implement this objective. The EU soil policy is an area of EU environmental policy that has in recent years been subject to increasing political attention. It was first addressed in 2002 in the Communication "Towards a Thematic Strategy for Soil Protection" (European Commission, 2002). This document identifies the main eight soil degradation processes to which soils in the EU are confronted: erosion, organic matter decline, contamination, salinisation, compaction, soil biodiversity loss, sealing, landslides and flooding. The current Thematic Strategy for Soil Protection (European Commission, 2006b) is accompanied by a proposal for a Soil Framework Directive (European Commission, 2006c) and an impact assessment (European Commission, 2006a). The Council has not yet reached a political agreement that would lead to the adoption of the Soil Framework Directive as a legally binding instrument. In the wider context of the debate on EU's post-2010 biodiversity strategy the lack of rules on soil protection across the EU Member States, while proposals for a common approach are being critically debated in the Council, has been characterised by a European Commission representative as “probably the single biggest impediment to biodiversity protection at EU level today"[33].

The proposal for the Soil Framework Directive (European Commission, 2006c) does not set threshold values and according to the subsidiarity and proportionality principles leaves the definition of risk reduction targets to the discretion of Member States. The draft proposal requires the identification of risk areas based on a common methodology, taking measures to prevent further soil degradation by reducing its risk, and the restoration of degraded soils in order to preserve soil functions. Actions should be taken at the most appropriate level, based on the establishment of risk reduction targets and programmes of measures to reach those targets.

In the meantime and given the important role played by the Common Agricultural Policy as a driver in the process of intensification of European agriculture and as a key attenuating factor through the promotion of soil conservation measures in the rural development policy or through the cross compliance mechanism (see Box 2 below), it is clear that this area of European policy is crucial to tackling the problem of soil erosion in European Member States. Failure to act will only lead to a worsening situation.

The literature review shows that substantive EU financed research has been undertaken on the subject of soil threats and indicators of soil degradation and desertification as well as collection of soil information in Europe (e.g. MEDALUS, IRISE, ENVASSO, DESIRE, DESERTSTOP) and specifically soil erosion in Europe[34]:

- Pan-European Soil Erosion Risk Assessment – PESERA project: provides data on pan European water soil erosion estimates in t/ha/yr. This model is based on physical data.
- Soil Erosion Risk Assessment in Europe: MESALES (Modèle d'Evaluation Spatiale de l'ALéa Erosion des Sols - Regional Modelling of Soil Erosion Risk). Prior to the PESERA project, Soil Erosion Risk Assessment data have been calculated by INRA - France.
- Soil Erosion Assessment in European Countries: erosion in Italy (USLE) aims to assess erosion risk at national level. The approach is based on the Universal Soil Loss Equation (USLE). The USLE model is an empirical model that has been developed for Agricultural soils in US.
- Soil Erosion in European Regions: Erosion in Alps (ClimChAlp): aims to develop a comprehensive assessment of soil erosion in the Alps.
- Risk Assessment Methodologies for Soil threats (RAMSOIL): collects and evaluates current risk assessment methodologies used for soil degradation and provide scientific guidelines on possibilities for EU wide parameter harmonisation.

[33] ENDS Europe DAILY, Thursday 8 April 2010, Europe 'needs sub-targets to protect biodiversity'

[34] http://eusoils.jrc.ec.europa.eu/Themes.html, http://eusoils.jrc.ec.europa.eu/library/themes/erosion/

- Tillage erosion: current state, future trends and prevention (TERON): data collection to assess the extent of tillage erosion and its effect on soil quality in Europe (current status), prediction of likely future effects of tillage erosion on soil quality and development of tools and guidelines for the prevention of tillage erosion.

- Wind erosion and loss of soil nutrients in semi-arid Spain (WELSONS): assessment of the role of land use in wind erosion, modelling and prediction of wind-induced erosion.

Box 2: Cross Compliance standards relevant to soil degradation

Cross compliance (GAEC[35]) EU standards relevant to soil degradation to be filled in according to existing national rules and indicators:

a. Soil erosion: Protect soil through appropriate measures
   i. - Minimum soil cover
   ii. - Minimum land management reflecting site-specific conditions
   iii. - Retain terraces
b. Soil organic matter: Maintain soil organic matter levels through appropriate practices
   iv. - Standards for crop rotations where applicable
   v. - Arable stubble management
c. Soil structure: Maintain soil structure through appropriate measures
   vi. - Appropriate machinery use
d. Minimum level of maintenance: Ensure a minimum level of maintenance and avoid the deterioration of habitats
   vii. - Minimum livestock stocking rates or/and appropriate regimes
   viii. - Protection of permanent pasture
   ix. - Retention of landscape features
   x. - Avoiding the encroachment of unwanted vegetation on agricultural land

3.8 Non-renewable resources

3.8.1. Background

Natural resources comprise both renewable and non-renewable materials. For renewable resources, several threshold concepts and indicators have already been developed; the most prominent example is the “Ecological Footprint”, which compares anthropogenic demand for biological capacity with the available biocapacity of the national and global ecosystems (WWF et al., 2008). This report focuses on the larger fraction of non-renewable resources, i.e. resources which cannot be produced, re-grown, regenerated, or reused on a scale which can sustain their consumption rate (e.g. fossil fuels, metal ores, phosphorus, uranium).

Analysing the use of non-renewable natural resources from the perspective of environmental thresholds is a challenging task. On the one hand, there are clear links between non-renewable resource use and a number of environmental impacts (and related thresholds). On the other hand, a linear link between the amount of resource use and negative environmental impacts (which may pass a threshold) can only be established for some non-renewable resources. The best example is the use of fossil fuels for combustion and the resulting impact on climate change. In many other cases, for

[35] Good Agricultural and Environmental Condition

example the use of metal ores, the causal chain is much more complex, i.e. there is no linear relationship between the amount of metal used and a certain threshold phenomenon related to the impacts of metal use. This is the case as technologies in production and consumption processes determine the quantity and quality of impacts and their effects on thresholds, i.e. whether air pollution abatement technologies are applied or whether hazardous waste is properly collected and treated. For many specific non-renewable resources and the resulting negative environmental impacts it is therefore difficult to establish environmental thresholds and express them in terms of quantities of non-renewable resource use.

A key threshold aspect of non-renewable resources use, resource scarcity and depletion, is generally regarded as an economic problem rather than an environmental problem (European Commission, 2005b). Therefore, aspects of resource scarcity and potential resource depletion are excluded from this study. Instead, this report concentrates on the relation between the consumption of non-renewable resources and one exemplary threshold-related impact: air emissions resulting from the extraction, processing and use of these non-renewable resources.

3.8.2. Material flow-based indicators

In recent years, indicators for the extraction and use of non-renewable resources, calculated from Material Flow Accounting and Analysis (MFA), have been established on the level of EUROSTAT and the OECD. An economy-wide MFA provides a comprehensive description of the material flows between the environment and the economy. The measurement unit of all MFA-based indicators is mass (tonnes). MFA-based indicators, such as resource consumption and resource productivity, today form part of major EU indicator sets, such as the EU Sustainable Development Indicators and the Eurostat Structural Indicators (for example, EUROSTAT, 2009b).

So far, officially published indicators for non-renewable resource use are calculated based of data on direct material flows. The most important indicators are Direct Material Input (DMI) and Domestic Material Consumption (DMC), both of which are given in terms of tonnes per year. DMI comprises all materials with economic value which are directly used in production and consumption activities. DMI equals the sum of domestic extraction and imports. DMC subtracts exports from DMI and thus measures the total quantity of materials used within an economic system. As DMC is the closest equivalent to aggregate income in the conventional system of national accounts it is currently the main indicator for material flows in the EU indicator sets.

EUROSTAT reports annual DMC data for all EU-27 countries. As a number of different materials are separately reported, it is possible to subtract all biotic materials from DMC, resulting in the non-renewable DMC. The threshold indicator as developed in chapter 4.4 builds on the non-renewable DMC data.

The DMC data in absolute terms differ widely between different EU countries, due to the large variety of country sizes and the size of their economies. For the illustrative purpose of this report, we therefore use the DMC (non-renewable) data in per capita terms.

The above mentioned existing MFA-based indicators are calculated based on direct material flows and do not include the indirect material flows associated with international trade (also called up-stream or hidden material flows, or ecological rucksacks). Therefore, using indicators such as DMI and DMC, a national economy can simply improve its performance by outsourcing resource-intensive extraction and processing of materials and instead import the processed raw materials and semi-manufactured products from abroad. This development is taking place in many European countries (see, for example, Bringezu and Bleischwitz, 2009). Therefore, more comprehensive MFA-based indicators are currently being developed, including Raw Material Input / Raw Material Consumption, which transforms imported and exported products into their so-called Raw Material Equivalents (OECD, 2007). According to this concept, for example, a car is not accounted by its own weight, but by the weight of the raw materials, which were necessary to produce that car along the production chain (metal ores, oil, etc.). EUROSTAT is currently running projects which develop methodologies and data for these types of MFA-based indicators for the EU; first data will be available by 2011(EUROSTAT, 2009a).

Recently, discussions have started regarding a global per-capita target for the use of non-renewable resources, given the large inequalities in per capita resource use between different countries and world regions (see, for example, Behrens et al., 2007; Krausmann et al., 2008). Ekins et al. (2009) suggest a target of six tonnes of annual per capita consumption of non-renewable resources by 2050, which would imply a significant absolute reduction from current consumption levels in European countries. However, this suggestion is not backed up by scientific evidence.

3.8.3. Empirical evidence and trends in the EU

On the global level, there is a clear trend of steadily increasing extraction and use of both renewable and non-renewable natural resources for the production of goods and services. In 2005, humans extracted and used about 60 billion tonnes of natural resources, about 50% more than 30 years before.[36] European levels of per capita resource consumption are among the highest in the world (see for example SERI et al., 2009).

Between 2000 and 2005, total DMC in the EU increased from around 8.5 to 8.8 billion tonnes. This increase was driven by increased consumption of minerals and fossil fuels, growing at average annual rates of 0.9% and 1.0%, respectively. In contrast, biomass consumption decreased by 0.1 % per year on average over the same period. Particularly strong increases in DMC between 2000 and 2005 were observed in several eastern European countries. Around 79% of DMC (in terms of mass) in 2005 was caused by non-renewable resources, of which minerals (metal ores, industrial minerals, construction minerals) made up 55% and fossil fuels 24% (EUROSTAT, 2009b).

3.8.4. Drivers

Reviewing a range of studies on the environmental impacts of resource use, Nielsen et al. (2004) find that the largest share of the main environmental pressures affecting the major environmental impact categories[37] originate from a limited number of human activities, including combustion processes, solvent use, agriculture, metal extraction and refining, dissipative uses of heavy metals, housing and infrastructure, marine activities, and the chemical industry. These core activities are often directly driven by second order drivers, largely in the form of market forces which ultimately reflect human demands. At the more general level, environmental impacts and resource use in Europe are largely driven by only three activity areas: housing (construction and temperature regulation), transportation, and food consumption (Moll and Acosta, 2006; van der Voet et al., 2005).

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[36] SERI Global Material Flows Database, 2008 Version, available at www.materialflows.net.

[37] Acidification, climate change (global warming), ecotoxicity, human toxicity, nutrient enrichment (eutrophication), Photochemical ozone formation (smog), and Stratospheric ozone depletion

Non-renewable natural resources are essential inputs for most human production processes. However, humanity's rapidly growing consumption of these resources is causing severe environmental damage, including land use changes and the production of toxic waste and emissions to air and water (SERI et al., 2009). Demand for these resources is driven by a range of different factors: higher income; change in lifestyles, such as larger living space per capita, higher share of individual mobility, increasing consumption of electronic goods, etc.), and population growth.

3.8.5. Pressures

Extraction, processing and use of non-renewable resources by humans are regarded as the environmental pressures, which are behind a large number of different environmental problems. At each step in the production-consumption chain, the pressures of non-renewable resource use generate different types of impacts (see chapter 3.8.6. below for details).

3.8.6. Impacts

The extraction of metals and minerals as well as their use (e.g. constructing buildings and infrastructure) lead to land use changes that cause a loss of habitat for species and thus reduce biodiversity. The use of fossil fuels for energy generation leads to GHG emissions which cause climate change. Transformation of non-renewable resources into products (such as chemicals or electronics) can lead to emissions to air and water as well as to the production of hazardous waste, with losses in environmental quality and risks to human health. For example, the use of non-renewable resources can lead to SO_2 and NO_x emissions into the air. Ceilings have been set in the EU for these emissions, due to their impact on human health, on acidification and eutrophication of water and soils, and damage to natural ecosystems, cultural heritage and crops. Often these are transboundary effects, as pollutants in the air can travel a considerable distance away from their source.

Some studies (see Moll and Acosta, 2006, for a study on Germany) identified the main areas of non-renewable resource use, which cause the major environmental problems. They found that the most relevant product groups are construction work, food, motor vehicles, basic metals, and electricity. The top product groups are characterised by both high resource requirements and high residual outputs (air emissions, wastes).

On the level of single materials, the environmental impact per kilogram of material differs substantially. Van der Voet et al. (2003) illustrate that non-renewable resources have the highest life-cycle wide per kilogram impact regarding land use change, global warming, aquatic ecotoxicity, and waste production. When multiplied with the absolute amounts, the following non-renewable resources are found most often in the high-impacting categories: iron and steel, aluminium, concrete and cement as well as some plastics.

On the aggregated, macro-economic level, correlations between overall levels of resource use and aggregated environmental impacts have been observed to some extent, in particular for short time frames in which the non-renewable resources used by a country do not change considerably (see section 4.1.1 for details).

3.8.6. EU Policy relevance

The use of natural resources for human production and consumption purposes and the related environmental and economic impacts are an increasingly important policy issue on the European level.

A number of recent EU policy documents (European Commission, 2008a, b) contain policy objectives related to resource use, such as increasing resource productivity and keeping human resource use within the ecological boundaries of the planet.

The *EU Sustainable Development Strategy* (EU SDS) aims at more efficient resource use, the prevention of waste, and increased re-use and recycling. So far, however, no quantitative goals or indicators have been put forward.

The *Thematic Strategy on the Sustainable Use of Natural Resources* (2005), which runs for 25 years, aims to ensure that the consumption of resources and the impact involved does not exceed the environment's capacity to regenerate. It is designed to help break the link between economic growth and resource use.

In the *Sustainable Consumption, Production and Industry Action Plan* (2008), the Commission proposes the implementation of a series of measures to improve the energy and environmental performance of products throughout their life cycle, and to stimulate demand and consumption of better quality products. It aims at increasing the acceptance of sustainable products and product technologies, for example by supporting eco innovation and the ecological potential of industries. The use of non-renewable resources still has room for more integration into this strategy.

Natural resources also play an increasingly important role in the EU's trade and industrial policy, especially with regard to access, supply and security issues. The trade strategy *Global Europe* (2006) describes access to resources and resource security as key factors for the success of Europe‘s export nations. In the field of industrial policy, the *Raw Materials Initiative* (2008) also aims at resource security. This strategy, which is focused on non-energy raw materials, has three main goals: an increase in the resource efficiency and recycling share of the EU, improved framework conditions for a sustainable supply from European sources, and the creation of equal access to the raw materials on the world markets.

A number of directives have been established which address specific environmental problems related to the use of non-renewable resources. For example, in order to reduce atmospheric pollution and the adverse environmental and health effects of acidifiying and eutrophying pollutants, the EU has set national emission ceilings. Directive 2001/81/EC of the European Parliament (2001) and of the Council on national emission ceilings for certain atmospheric pollutants, which was established as part of a wider strategy to combat acidification, sought to establish, for the first time, national emission ceilings, or critical loads[38] for four pollutants - sulphur dioxide (SO_2), nitrogen oxide (NO_x), volatile organic compounds (VOC) and ammonia (NH_3) - causing acidification, eutrophication and tropospheric ozone formation (also referred to as "bad ozone", present at low altitudes, in contrast to stratospheric ozone), regardless of the sources of pollution. The concentrations of these emissions are useful pressure indicators for the use of non-renewable resources (see section 4.4.2).

[38] A critical load is 'a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge' (Nilsson and Grennfelt (1988) cited in Hettelingh et al., 1995).

4. Thresholds and indicators in selected areas

4.1 Water Quality with Focus on Eutrophication

4.1.1. Existing thresholds and threshold indicators

As pointed out in Section 3.3.1, the Water Framework Directive uses the paradigm of "good status", which consists of "good ecological" and "good chemical status". For ecological status, including eutrophication, no absolute standards are set but the five status class, especially the "high" class can be effectively used as benchmarks and Member States are working on the definition of operational standards to classify water basins into the five status classes, including mean annual average and maximum allowable concentrations for long-term and peak pollution trends, respectively. These concepts are used to establish thresholds for each river basin based on an inventory of emissions, discharges and losses of the substances covered by the WFD. On the basis of the information provided by the Member States, the Commission evaluates whether the objectives for pollution reduction by 2018 have been reached. Table 11 shows the values for different types of water uses and pollution.

Table 11 Established thresholds, policy targets, and supporting legislation at EU level

Pollutant	Concentrations Thresholds	Policy Goal	Supporting Legislation
Nitrate	- 50 mg/l MAC (Drinking Water Directive 98/83/EC); - 25 mg/l guideline concentration (Surface Water for Drinking Directive (75/440/EEC); - 50 mg NO_3/l (annual average) for designating groundwater bodies or monitoring sites if annual average exceeds this value (Nitrates Directive 91/676/EEC)	Decrease nitrogen and nitrate concentrations in freshwater, especially drinking water, decrease nitrate use in agriculture	- Nitrates Directive (91/676/EEC), - Urban Waste Water Treatment Directive (91/271/EEC), - Integrated Pollution Prevention and Control Directive (96/61/EEC), - WFD (2000/60/EC), - Drinking Water Directive (98/83/EC)
Phosphorus	- 5000 - - P_2O_5 µg/l (Drinking Water Directive 98/83/EC)	Decrease phosphorus and phosphate concentrations in freshwater, improve waste water treatment, reduce input of phosphates in detergents	- WFD (2000/60/EC), - Surface Water Directive(75/440/EEC), - Freshwater Fish Directive (2006/44/EC) - Drinking Water Directive 98/83/EC

For the two main nutrients responsible for eutrophication, the thresholds generally define the average annual and maximum allowable concentrations (for peak pollution events) or loadings that would not result in ecological changes in the aquatic ecosystem or impede the usability of the water for designated purposes, e.g., as drinking water. Operationally, Maximum Allowable Concentrations (MACs) and Total Maximum Daily Loads (TMDLs) take into account local/watershed specific conditions. Recognizing the locally varying pressure on aquatic systems with respect to P and N loadings, the Nitrate Directive, for example, requires Member States to designate nitrate vulnerable zones (NVZ) with increased density of water monitoring points and for which action programme(s) for reducing nutrient loads of agricultural origin must be developed and implemented.

4.1.2 State indicators

The following table summarizes the state indicators of eutrophication in terms of actually observed concentrations of nitrogen and phosphorus.

Table 12 State indicators for eutrophication

Pollutant	**Threshold Value**
Nitrogen (N-based compounds)	Maximum allowable concentration for nitrogen varies by lake and stream segment
	TMDL for nitrogen varies by lake and stream segment
Phosphorus (and P-based compounds)	Maximum allowable concentration for phosphorus varies by lake and stream segment
	TMDL for phosphorus varies by lake and stream segment

4.1.3. Pressure indicators

The important information for water managers and other decision-makers is the relation of the maximum permissible amount of pollution or pollution flux that is in line with ecological, health, economic or other objectives and the actually observed pollution/pollution flux. The actual, or pressure indicator, is therefore often measured in the same unit as the threshold indicator. Table 13 lists the relevant pressure indicators for the threshold values shown in Table 12.

Table 13 Pressure indicators for eutrophication

Pollutant	Pressure Indicator
Nitrogen (and N-based compounds)	Observed maximum concentration of nitrogen at monitoring site
	Observed load of nitrogen at monitoring site
Phosphorus (and P-based compounds)	Observed maximum concentration of phosphorus at monitoring site
	Observed load of phosphorus at monitoring site

4.1.4. Data availability

1. At European level

At the national and sub-national level, water quality data are obtained from a network of monitoring stations near pollution sources or in background areas and equipped with sampling protocols for a set of relevant water quality parameters. The density of monitoring stations, sampling frequency, comparability of monitoring data, and accessibility of the information vary greatly across countries.

At the European level the main source of harmonised data on water quality is the Eurowaternet, which feeds into the Waterbase of the European Topic Centre on Water. The data are sub-samples of national data sets assembled for the purpose of providing comparable indicators of pressures, state, and impact of waters on a European scale.[39] The participation in Eurowaternet varies across Member States and national statistics are needed to complement the subset available through Waterbase for a more accurate, consistent, and reliable analysis of water quality. In-depth studies on local trends and status of water quality require increased sampling frequency and siting of monitoring stations according to a statistical experimental plan.

The EEA's Waterbase contains time series data by river monitoring station for nitrate, total oxidised nitrogen, and phosphorus, phosphate, orthophosphate (among others), by lake monitoring station for nitrate and total phosphorus (among others), and for groundwater monitoring stations for nitrate and phosphorus (among others).

EIONET, the European Environment Information and Observation Network, uses monitoring data collected from monitoring stations in accordance with the Eurowaternet type station classification for rivers and lakes or stations considered representative. The station types used are Flux, Impact, and Reference. Concentrations are calculated as annual mean concentrations. Observed values below the Limit Of Detection/Determination (LOD) are requested to be replaced by a value equal to half of the LOD before calculating the annual means.

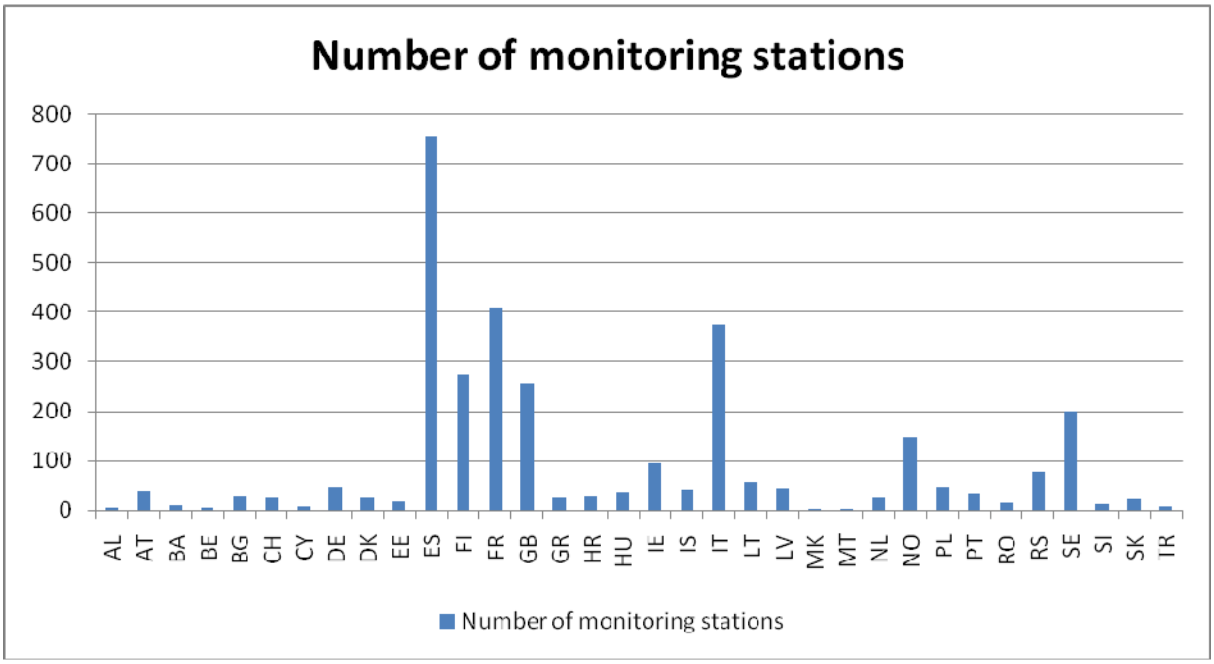
After the WFD entered into force, the Water Information System for Europe (WISE) was launched in 2007, which also provides access to selected data on, inter alia, water quality and other information related to water as specified in other directives. The underlying data are drawn from a variety of sources including Member States reports, EUROSTAT, and OECD. WISE also contains a data centre, which can be accessed by users to obtain more detailed maps, reports, or data for their own analytical and information purposes.

In general, the proposed threshold indicators based on either MAC or TMDLs have not been applied widely in the EU yet, with the exception of the MAC of 50 mg/l for Nitrate in the Drinking Water Directive. As per a 2007 report on the implementation of the Nitrate directive (EC, 2007c), it can be said that information on eutrophication has improved compared to the previous reporting period both in terms of the density of the monitoring stations as well as with respect to the comparability and reliability of the measurements. There are now 3201 monitoring stations for 33 countries in the EEA's Waterbase for WISE (cf. Figure 10), up from fewer than 1500 in 1995. Nonetheless, the total number of monitoring stations varies greatly from 2 in Malta to 754 in Spain. In any case, the size of the country and spatial distribution of the stations must be taken into account

[39] However, the data are not specifically intended to monitor compliance with European Directives or other legal instruments.

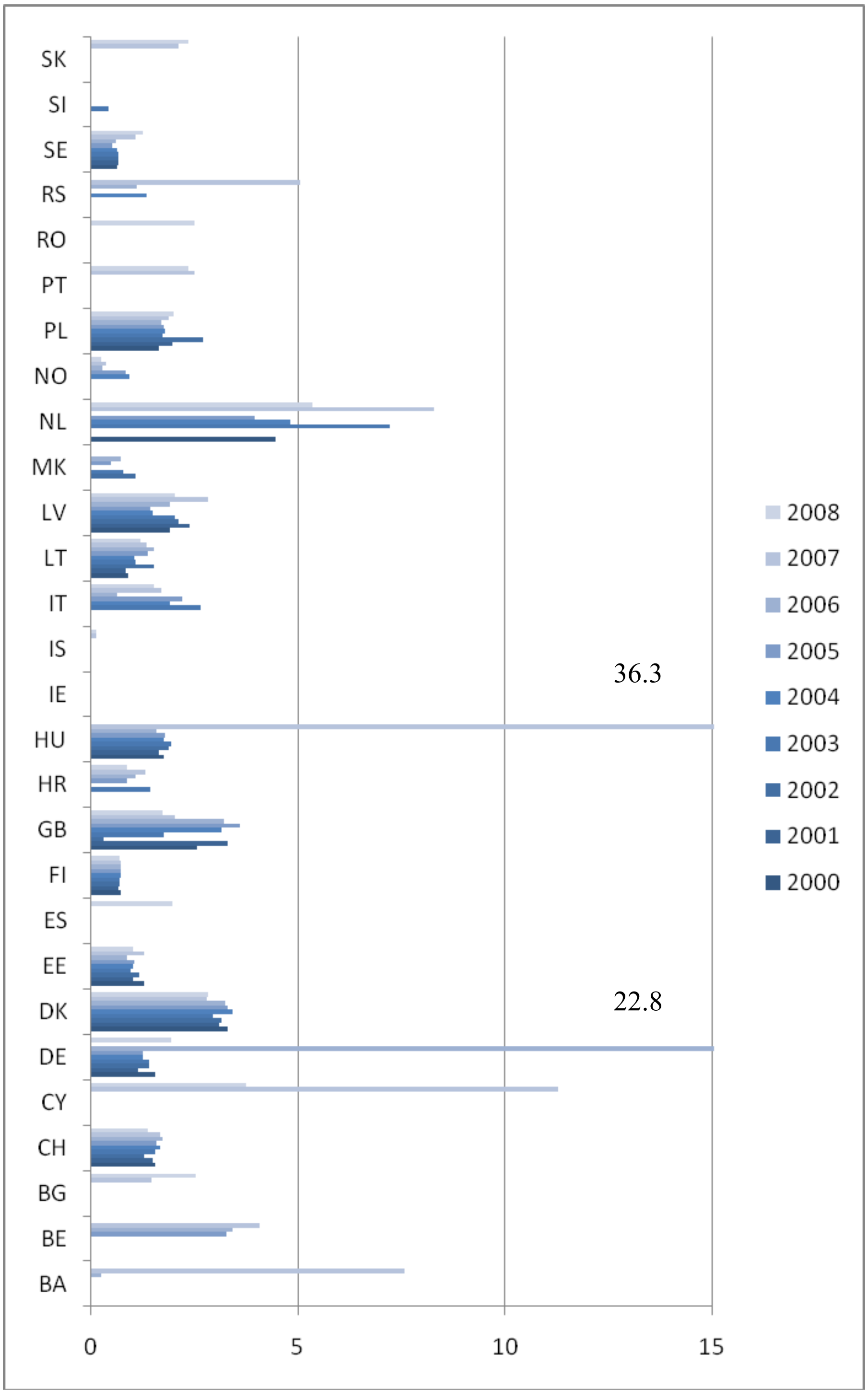
when attempting to determine if station density is high enough to allow an evaluation of how much of a country's territory is affected by high levels of eutrophication.

Figure 10: Number of monitoring stations by country in EEA Waterbase.



In addition, not all Member States have reported on the parameters used to assess eutrophication, including total nitrogen, total organic nitrogen, nitrates, and total phosphorus, orthophosphate. And only a few Member States provided the results of assessment of individual water bodies, river or lakes. Figure 11 shows the spatial annual average maximum (across all monitoring stations that reported in that year) by Member State and year for Nitrate for lakes. In this sample and level of aggregation, the maximum allowable concentration of 50mg/l was not crossed during the 2000-2008 reporting period but national averages can mask extreme values.

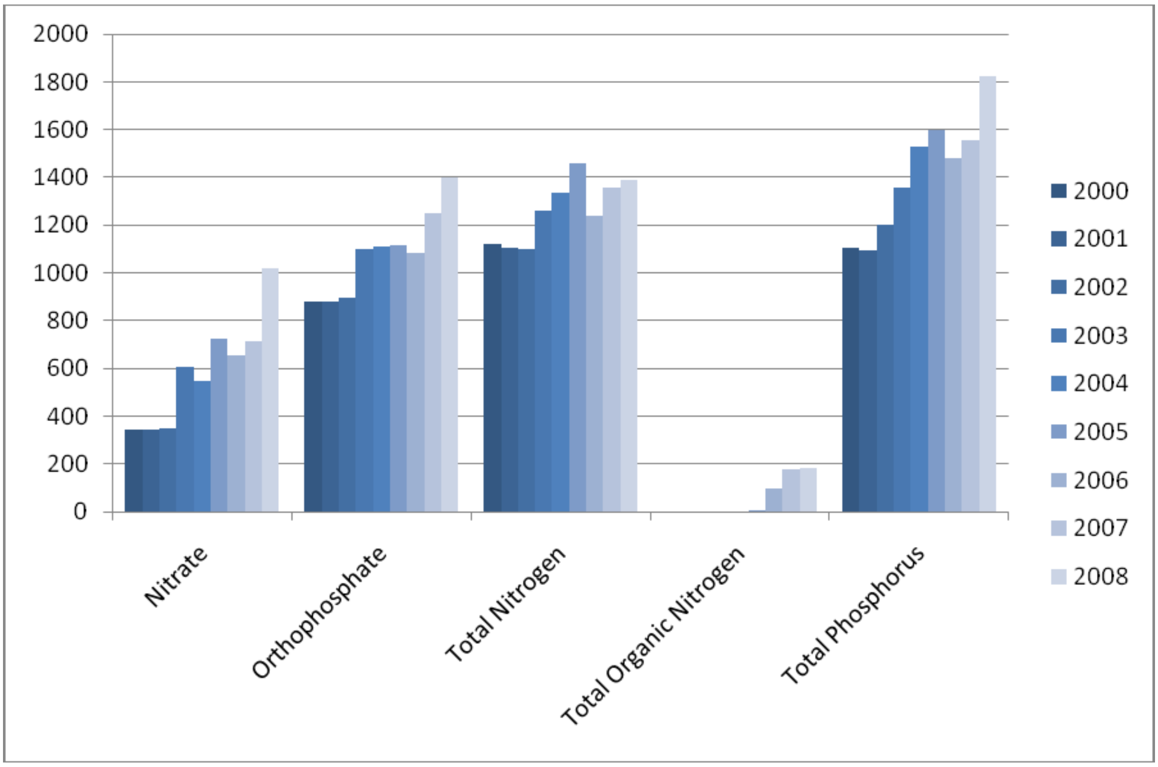
Figure 11 Average maximum Nitrate concentration (in mg/l) in lakes by country and year in Waterbase



Note: The maximum concentration attained in this sample is 36.3, i.e., well below the MAC.

Based on the spatial location information contained in Waterbase, it is possible to conduct watershed-specific analyses of eutrophication for selected rivers and lakes. Data availability for lakes is shown in Figure12.

Figure 12 Number of observations by parameter for lakes in EEA Waterbase

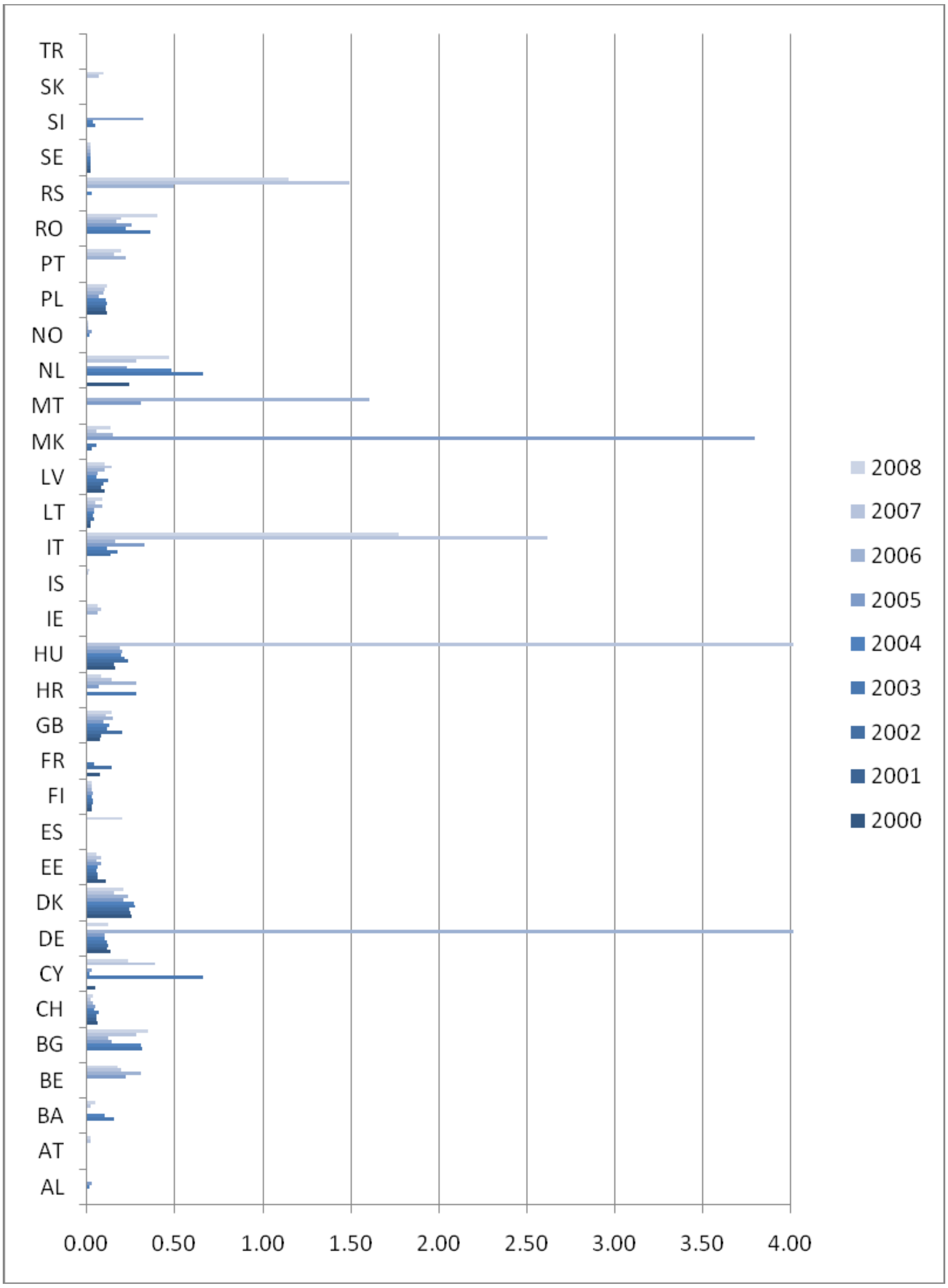


With respect to groundwater eutrophication, in the period 2000-2003, 17% of EU monitoring stations had **average** nitrate concentrations above 50 mg NO_3/l, 7% were in the range 40-50 mg NO_3/l and 15% were in the range 25-40 mg NO_3/l. Approximately 61% of the groundwater stations had a concentration below 25 mg NO_3/l.

For surface water eutrophication, the results were, for the same period 2000-2003, as follows: average annual nitrate concentrations below 10 mg NO_3/l were observed in 53% of the monitoring stations and equal or below 2 mg NO_3/l in 19% of monitoring stations notably in mountainous areas. In 2.5% of the monitoring stations nitrate concentration exceeded 50 mg NO_3/l and in 4% recorded values in the range 40 to 50 mg NO_3/l. Areas with high nitrate levels include the UK, France, and the Netherlands, followed by the Danish agricultural plains, Luxembourg, Belgium (Wallonia), Ireland, and areas of Spain, Italy, and Austria.

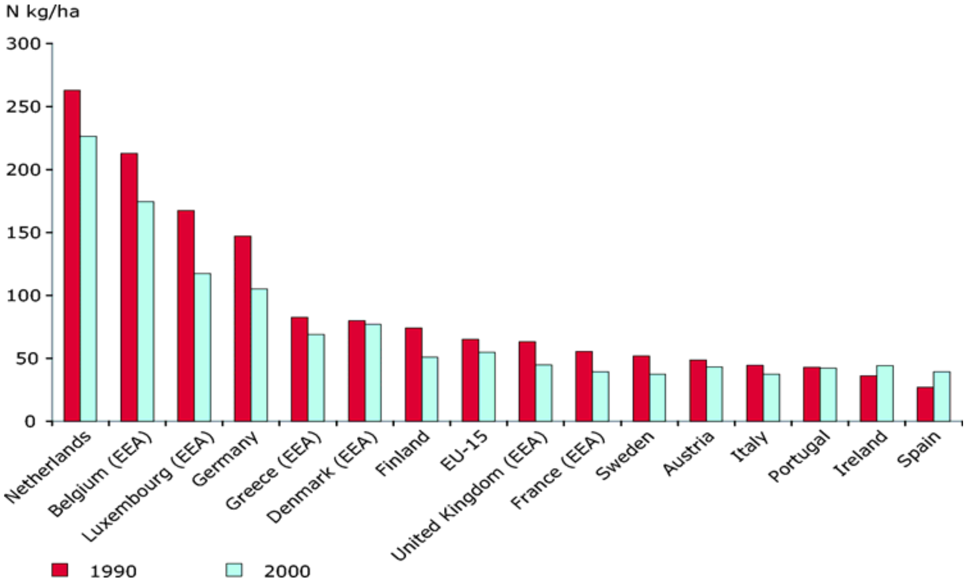
With respect to phosphorus, the situation is similar, aside from a few large outliers. Since no unified threshold concentration is available, no comparison can be made about the situation with respect to avoiding the threshold. The spatial coordinates available in Waterbase again permit more detailed analyses at watershed level, if sufficiently frequent and spatially dense measurements are available.

Figure 13 Average maximum total phosphorus concentration in lakes by country and year in Waterbase



The following graph does not show an individual watershed's eutrophication pattern relative to an established threshold but it does show the trend of nutrient loads in general in selected EU Member States. WISE can be used to extract local, time-specific monitoring data and relate it to scientific threshold values.

Figure 14 Gross nutrient balance at national level in 1990 and 2000



While data density and quality appear to be improving, there remains a persistent lack of sufficient and comparable data on eutrophication. We quote the assessment report (COM/2007/0120 final)[40]: "Discussion and evaluation of trophic status of waters are greatly hampered by the different methods and criteria that Member States have used for the assessment of eutrophication. As a result, no maps of the eutrophication in EU 15 surface waters have been prepared."

As part of the WFD's river basin approach and the associated river basin management plans, monitoring networks have to be established by end of 2006 by Member States and must include monitoring stations for allowing for surveillance, operational, and investigative monitoring:

The objective of monitoring is to establish a coherent and comprehensive overview of water status within each River Basins District and must permit the classification of all surface water bodies into one of the five classes ("high", "good", "moderate", "poor", and "bad"). To ensure that a reliable assessment of the status of all water bodies can be achieved, it is important that the appropriate parameters are chosen and measured at meaningful locations with sufficient frequency and with the most appropriate method. The member states are allowed to adjust their monitoring program to the condition and variability within their own waters. This means that local monitoring programs will differ in the type and quantity of information they generate, which is desirable for economic reasons and acceptable as long as the desired information on water quality status can be deduced with a reasonable degree of certainty.

2. Experience outside EU

Outside of the EU, the United States has by far the most extensive experience in implementing and monitoring eutrophication thresholds using the TMDL concept. In Missouri, for example (implementation of the Clean Water Act is under state authority), each nutrient is assigned an advisory

[40] Report from the Commission to the Council and the European Parliament on implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources for the period 2000-2003 {SEC(2007)339} in COM/2007/0120 final.

level and an action level value for Total Phosphorus (TP) and Total Nitrogen (TN) with the following policy responses:

a. Advisory levels: If a lake or reservoir has an overall geometric mean for TP or TN concentration between the advisory and the action level, the department may list the water as impaired if the weight of evidence from algal blooms or other nuisance conditions can be attributed to excessive nutrient loading.

b. Action levels: If a lake or reservoir has an overall geometric mean for TP or TN concentration equal or greater than the action level, the department will list the water body as impaired because of excessive nutrient loading.

By applying a localized, watershed based approach, this yields site-specific threshold values such as the ones illustrated in the following table.

Table 14 Example of site-specific threshold values for TMDLs in Missouri (TP: Total phosphorous, TN: Total Nitrate, Chl: Chlorophyll)

Lake Ecoregion	Lake	County	Site specific criteria (µg/L)		
			TP	TN	Chl
Plains	Bowling Green Lake	Pike	21	502	6.5
	Bowling Green Lake (old)	Pike	31	506	5.0
	Forest Lake	Adair	21	412	4.3
	Fox Valley Lake	Clark	17	581	6.3
	Hazel Creek Lake	Adair	27	616	6.9
	Lincoln Lake – Cuivre River State Park	Lincoln	16	413	4.3
	Marie, Lake	Mercer	14	444	3.6
	Nehai Tonkaia Lake	Chariton	15	418	2.7
	Viking, Lake	Daviess	25	509	7.8
	Waukomis Lake	Platte	25	553	11.0
	Weatherby Lake	Platte	16	363	5.1
Ozark Border	Goose Creek Lake	St Francois	12	383	3.2
	Wauwanoka, Lake	Jefferson	12	384	6.1
Ozark Highlands	Clearwater Lake	Wayne-Reynolds	13	220	2.6
	Council Bluff Lake	Iron	7	229	2.1
	Crane Lake	Iron	9	240	2.6

Source: Missouri Nutrient Rule, 7.031(4)

A further state level example of the kind of information that TMDL assessment can give, is the Virginia TMDL Assessment, which includes the following table on the numbers of impaired water segments.

Table 15 List of impaired water segments

Basin	Impaired Freshwater Segments	Impaired Shellfish Segments	Waters Impaired Due to Natural Conditions	Waters with Multiple Impairments	Total Non-CD Waters needing TMDLs
Bay/Coastal	43	68	5	3	119
Chowan	46	0	12	0	58
James	162	3	22	6	193
New	52	0	2	1	55
Potomac/Shenandoah	103	34	8	13	158
Rappahannock	20	42	13	7	82
Roanoke	79	0	7	7	93
Tennessee, Big Sandy	98	0	0	0	98
York	30	3	7	6	46
Total	633	150	76	43	902

Note: Numbers obtained from the Final 2004 305(b)303(d) Water Quality Assessment Integrated Report. Non-CD refers to non-consent decree waters, i.e., waters for which no TMDL implementation plans have been developed yet

Overall, the TMDL program in the US has led to the designation of more than 44,000 impaired waters nationwide and more than 40,000 TMDLs[41]. Upon designation as impaired, the Clean Water Act then provides for actions, including the development of water quality management plans, that must be taken to bring the waterbody in compliance with the Act's requirements. In that, the American approach is similar to that under the WFD, which also requires the development of management plans to ensure that good ecological status is achieved. The efforts and costs incurred in the TMDL program are substantial and EPA estimates range from \$900 million to \$4.5 billion, which may exceed the resources of some states to implement the law to the full extent[42]. The TMDL program in the US can therefore provide useful insights into the design of an economically feasible water quality monitoring program in the EU and it remains to be seen if the WFD implementation will be cost-effective.

4.1.5. Suggested threshold indicators

The threshold indicators proposed for monitoring threshold phenomena in water eutrophication are the ratio of the proposed pressure and state indicators, i.e., for nitrogen and phosphorus these are the ratio of observed to maximum allowable concentration and the ratio of observed to total daily maximum loads. Ratios larger than one indicate transgression of the threshold, values smaller but close to one indicate that human activities have moved the phenomenon into dangerous levels, and values much smaller than one indicate that the phenomenon is within a "green zone". It remains a scientific challenge how to determine the boundaries of the danger and green zones, respectively. Again, the

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[41] See, US EPA. Analysis of TMDL Implementation Rates in EPA Region 5. Final Report, December 1, 2009. Document EPA EPA841-R-09-005, US EPA.

[42] For more information, please see http://yosemite.epa.gov/opa/admpress.nsf/b1ab9f485b098972852562e7004dc686/2c012bb8d27b038085256aa0004e8480?OpenDocument.

WFD's riverbasin approach will allow the specification of such boundaries, albeit not without dispute. Table 16 - Table 18 summarise these indicators.

Table 16 Measuring the Ratio of observed to maximum allowable concentration of nitrogen

	Ratio of observed maximum to maximum allowable concentration	
	Observed maximum concentration of nitrogen	**Maximum Allowable Concentration of nitrogen**
Unit of measurement	mg/litre	mg/litre
Data source/s	National or sub-national water quality monitoring databases; EEA Waterbase; WISE; EIONET	WFD, WISE
Temporal coverage	WISE: varies by issue and indicator but for nitrogen concentrations time series data are available for 1990s onwards;	Maximum allowable concentrations are under development in several MS (e.g., UK TAG)
Geographical coverage	Varies by issue and indicator but for nitrogen concentration increasingly complete coverage for the EU27	Maximum allowable concentrations are under development in several MS (e.g., UK TAG)
Update of data	Sampling frequency varies across stations but is generally in the weekly-monthly ranges. Data are often aggregated to annual or seasonal averages for eutrophication assessment reports.	WFD water quality classes are being developed with the objective of "good status" is to be achieved by 2015, the first management cycle ends in 2021, and the second management cycle ends in 2027 with the aim to have achieved all objectives in the WFD. MS may update their standard setting in accordance with their management plans.
Access to data (free/fee)	Free access to pre-processed data (as maps, indicators, etc.) from WISE; raw data also available for free from EEA Waterbase and WISE data service (e.g., users can download the zipped Waterbase databases for lakes, rivers)	MACs or other types of thresholds for defining ecological status not comprehensively available yet but this information should be in the public sphere once it is agreed upon and implemented.
Links, references	Free WISE interactive data viewer: http://www.eea.europa.eu/themes/water Free WISE access to raw data from Waterbase: http://www.eea.europa.eu/data-and-maps/data/datac#5=all&c11=water&c17=&c0=5&b_start=0	Member States' information portals on the implementation of the WFD (examples): UK TAG: http://www.wfduk.org/ UK TAG Classification Scheme for Surface Waters: http://www.wfduk.org/management_info/News/sw_class_news WFD Implementation Ireland: http://www.wfdireland.ie/ German Working Group of the Federal States on water problems (LAWA) [in German]: http://www.lawa.de/

Table 17 Measuring the Ratio of observed to maximum allowable concentration of phosphorus.

	Ratio of observed maximum to maximum allowable concentration	
	Observed maximum concentration of phosphorus	**Maximum Allowable Concentration of phosphorus**
Unit of measurement	mg/litre	mg/litre
Data source/s	National or sub-national water quality monitoring databases; EEA Waterbase; WISE; EIONET	WFD, WISE
Temporal coverage	WISE: varies by issue and indicator but for phosphorus concentrations time series data are available for 1990s onwards	Maximum allowable concentrations are under development in several MS (e.g., UK TAG)
Geographical coverage	Varies by issue and indicator but for phosphorus concentration increasingly complete coverage for the EU27.	Maximum allowable concentrations are under development in several MS (e.g., UK TAG)
Update of data	Sampling frequency varies across stations but is generally in the weekly-monthly ranges. Data are often aggregated to annual or seasonal averages for eutrophication assessment reports.	WFD water quality classes are being developed with the objective of "good status" is to be achieved by 2015, the first management cycle ends in 2021, and the second management cycle ends in 2027 with the aim to have achieved all objectives in the WFD. MS may update their standard setting in accordance with their management plans.
Access to data (free/fee)	Free access to pre-processed data (as maps, indicators, etc.) from WISE; raw data also available freely from EEA Waterbase and WISE data service (e.g., users can download the zipped Waterbase databases for lakes, rivers)	MACs or other types of thresholds for defining ecological status not comprehensively available yet but this information should be in the public sphere once it is agreed upon and implemented.
Links, references	Free WISE interactive data viewer: http://www.eea.europa.eu/themes/water Free WISE access to raw data from Waterbase: http://www.eea.europa.eu/data-and-maps/data/datac#5=all&c11=water&c17=&c0=5&b_start=0	Member States' information portals on the implementation of the WFD (examples): UK TAG: http://www.wfduk.org/ UK TAG Classification Scheme for Surface Waters: http://www.wfduk.org/management_info/News/sw_class_news WFD Implementation Ireland: http://www.wfdireland.ie/ German Working Group of the Federal States on water problems (LAWA) [in German]: http://www.lawa.de/

Table 18 Measuring the Ratio of observed to total Maximum Daily Load in the US

	Ratio of observed to Total Maximum Daily Load for Nitrogen and Phosphorus*	
	Observed Load	**Total Maximum Daily Load**
Unit of measurement	kg/day	kg/day
Data source/s	US EPA as the clearinghouse but authority to collect the data rests with the States	US EPA as the clearinghouse but authority to develop TMDLs lies with the States
Temporal coverage	Monitoring data go back to 1970s but initial sampling frequency was lower (in addition to larger gaps in spatial coverage). Best coverage since 1990s.	Earliest approved TDML for 1992 but most coverage since 2002.
Geographical coverage	Nationwide by waterbody but sampling station density and frequency vary substantially with higher levels in dense population areas, industrial areas, and historically polluted areas that carry risk of exposure of general public or specific population segments.	TMDL implementations vary by State and many waterbodies still do not have a TMDL established. But the basic unit is the watershed and waterbody segment.
Update of data	Monitoring takes place in the range of daily-weekly and also monthly frequencies, overall assessments conducted annually (and biennially as required by US Clean Water Act) by aggregating the collected monitoring data	TMDLs are reviewed at least every three years as mandated by US federal law.
Access to data (free/fee)	Free access to EPA Query Tool. Free access to EPA STORET (STOrage and RETrieval of water quality, biological, and physical data)	Free access to EPA Query Tool. Free access to EPA STORET (STOrage and RETrieval of water quality, biological, and physical data)
Links, references	EPA Waters Query Tool: http://www.epa.gov/waters/tmdl/expert_query.html EPA STORET data warehouse: http://www.epa.gov/storet	US EPA Water Quality and TMDL Information (ATTAINS): http://www.epa.gov/waters/ir/

*The information presented in this table applies equally to nitrogen and phosphorus.

4.1.6. Advantages and disadvantages of the suggested threshold indicators

Table 19 Advantages and disadvantages of suggested threshold indicators for water quality

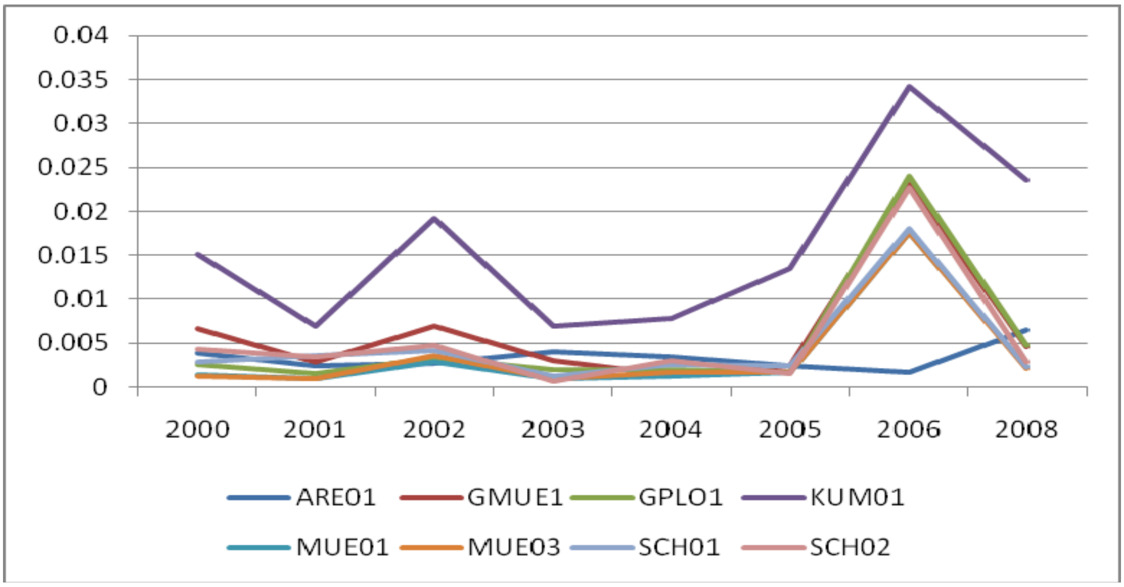
	Ratio of observed to maximum allowable concentration	**Ratio of observed to Total Maximum Daily Load**
Advantages	• Underlying concept easy to understand and communicate • Monitoring data increasingly available and mandated under WFD implementation plans (other directives, time scale of data from MS) • Consideration of local watershed and surrounding conditions • Compliance assessment and trend analysis (with potential evaluation of policy effectiveness) possible • Scientifically sound conceptual basis, although the separate specification of values for N and P may not reflect important N and P interactions	• Underlying concept easy to understand and communicate • Consideration of local watershed and surrounding conditions in specification of TMDL • Scientifically sound conceptual basis, although the separate TMDL for N and P may not reflect important N and P interactions • Loadings approach permits source allocation and hence more effective control of fluxes • Shorter time lags between actual discharge or run-off of nutrients and their measurement
Disadvantages	• Determination of MAC carries varying levels of uncertainty, assumptions, and validity over time • Monitoring of concentrations does not allow source apportionment and hence more effective control of major emitters • Time lags in ecological, sediment and hydrological processes delays the exposure-event chain such that detrimental practices may go unabated until their harmful effects are measured years later	• Determination of TMDLs carries varying levels of uncertainty, assumptions, and validity over time • Monitoring/estimation of actual loadings more challenging than that of concentrations and carries greater uncertainty • More data and methods intensive than monitoring concentrations

4.1.7. Interpretation of threshold indicators

The proposed threshold indicators for water quality can be interpreted in a straightforward manner. Ratios exceeding 1 indicate that current pressures on the aquatic system exceed the specified threshold. Ratios smaller than but close to 1 signal that the system is close to reaching a critical level at which non-linear and hard to reverse ecological regime shift might occur. In contrast, ratios much lower than 1 show that the system is in good condition (at least with respect to nutrient balances).

Using Nitrate concentrations for selected lakes in Germany for the period 2000-2008 from Waterbase, it is possible to calculate the ratios for the proposed threshold indicator for Nitrate. The results are shown in Figure 15. All ratios are well below one, implying a low risk of eutrophication.

Figure 15 Ratio of observed and maximum allowable Nitrate concentration in selected German lakes and monitoring stations in the period 2000-2008



Note: The codes shown refer to the following monitoring stations and lakes: ARE01=Arendsee, Saxony-Anhalt, GMUE1=Grosser Mueggelsee, Berlin, GPLO1=Grosser Ploenersee, Schleswig-Holstein, KUM01=Grosser Kummerower See, Mecklenburg-Western Pomerania, MUE01=Mueritz (Binnenmueritz), Mecklenburg-Western Pomerania, MUE03=Mueritz (Aussenmueritz), Mecklenburg-Western Pomerania, SCH01=Schweriner See (Innensee), Mecklenburg-Western Pomerania, SCHO2=Schweriner See (Aussensee), Mecklenburg-Western Pomerania.

4.2 Water Quantity

Before starting to analyse existing state and pressure indicators and related threshold indicators in the field of water quantity it is appropriate to give a short overview of the main terms and definitions to facilitate reading and avoid confusion of technical terms. This is advisable, as hydrologists and environmental accountants sometimes use different names for the same concept. The main sources for definitions used are the UN SEEA-W (United Nations, 2007), the FAO (FAO, 2010) and the Water Footprint Network.

(Total) water withdrawal/abstraction: Annual quantity of water withdrawn for agricultural, industrial and municipal purposes. It includes renewable freshwater resources as well as potential over-abstraction of renewable groundwater or withdrawal of fossil groundwater and potential use of desalinated water or treated wastewater. It does not include in-stream uses, which are characterized by a very low net consumption rate, such as recreation, navigation, hydropower, inland capture fisheries, etc. Total water abstraction can be broken down according to the type of source (e.g. surface water, groundwater, etc) and the type of use.The FAO states that the two terms withdrawal and abstraction are equivalent.

Water use: Refers to use of water by agriculture, industry, energy production and households, including in-stream uses such as fishing, recreation, transportation and waste disposal.

Water consumption: the part of water use which is not distributed by the water distribution sector to other economic units and does not return to the environment (to water resources, sea and ocean) because during use it has been incorporated into products, consumed by households or livestock. It is calculated as a difference between total use and total supply, thus it may include losses due to evaporation occurring in distribution and apparent losses due to illegal tapping and malfunctioning metering. Per definition, consumed water is not available for immediate or short-term reuse within the same watershed.

Blue water: Fresh surface and groundwater, i.e. the water in freshwater lakes, rivers and aquifers.

Green water: The precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporates or transpires through plants. Green water can be made productive for crop growth.

Greywater: Wastewater generated from domestic activities such as laundry, dishwashing, and bathing, which can be recycled on-site for uses such as landscape irrigation and constructed wetlands. Greywater differs from water from the toilets which is designated sewage or blackwater to indicate it contains human waste.

Renewable Water Resources: Long-term average annual flow of rivers and recharge of aquifers generated from endogenous precipitation.

Non-renewable water: Water in aquifers and other natural reservoirs that is not recharged, or is recharged so slowly (i.e. decades or centuries) that significant withdrawal will cause depletion.

4.2.1. State indicators

The most commonly used indicators on the state of available water resources include:

a. **Precipitation:** Any kind of water that falls from clouds as a liquid or a solid. Differentiation can be made between average precipitation in depth and in volume.

⇨ Actual numbers especially on green water use/consumption could be benchmarked with this indicator.

b. **Total renewable water resources:** The sum of internal renewable water resources (average annual flow of rivers and recharge of groundwater generated from precipitation) and incoming flows originating outside the country, taking into consideration the quantity of flows reserved to upstream and downstream countries through formal or informal agreements or treaties and reduction of flow due to upstream withdrawal. This gives the maximum theoretical amount of water actually available for the country. Differentiation can be made between surface water (which is the dominant source of freshwater) and groundwater.

⇨ An indicator of great importance as it constrains the actual water use. In order to increase its significance, reporting on the sub-annual level would be desirable. Total renewable and total non-renewable water resources together would be very relevant indicators, as they provide analysts and policy makers with a comprehensive picture of the actual circumstances.

c. **Exploitable water resources and dam capacity**: Exploitable water resources (also called manageable water resources or water development potential) are considered to be accessible for use, taking into consideration factors such as: the economic and environmental feasibility of storing floodwater behind dams, extracting groundwater, the physical possibility of storing water that naturally flows out to the sea, and minimum flow requirements (navigation, environmental services, aquatic life, etc). Dam capacity is the total cumulative storage capacity of all large dams. The value indicates the theoretical initial capacity, which does not change with time. The current or actual dam capacity is the state of the dams at a given time that can be decreased by silting.

⇨ An important indicator, as the total of renewable water resources is normally not necessarily accessible for use.

d. **Water dependency ratio**: Indicator expressing the percentage of total renewable water resources originating outside the country. This indicator may theoretically vary between 0% (a country which does not receive any water from neighbouring countries) and 100% (a country receiving all renewable water from upstream countries, without producing any of its own). This indicator does not consider the possible allocation of water to downstream countries.

4.2.2. Pressure indicators

Traditionally, water use estimates are based on water statistics which focus on measuring water withdrawals and direct water use (UN, FAO, World Bank statistics). The majority of these statistics only captures the use of blue water, which can be withdrawn for irrigation and other human uses (Rockström et al., 2009). This approach neglects two important aspects.

First, accounting only for water withdrawals neglects the water that is actually consumed. This includes water that has evaporated, transpired, incorporated into products or crops (heavily contaminated, or consumed by humans or animals) which often does not return to the same shed after treatment (Gleick and Palaniappan, 2010). While in national accounting the distinction is made between water use and water consumption, hydrologists often distinguish between 'non-consumptive use' and 'consumptive use' respectively (see, for instance, Gleick and Palaniappan, 2010; Hoekstra et al., 2009). The EEA (EEA, 2009) assumes that 80 % of total water abstracted for agriculture, 20 % for urban use, 20 % for industry and 5 % for energy production is consumed and not returned to the water bodies from where it was abstracted.

The second important aspect which has to be taken into account is whether the water used, for instance, in a production process is withdrawn from surface or ground water (blue water) or from rain water seeping into the soil (green water), as in the case of crop production (Falkenmark, 2003). The importance of green water has been increasingly acknowledged in the last years (Allan, 2006; Falkenmark et al., 2004; Molden, 2007; Rockström, 2001). It is argued that the historical engineering focus on blue water has led to the undervaluation of green water as an important complementary factor of production (Falkenmark, 2003; Rockström, 2001).

This broader perspective of water use accounting has been included in the UN System of Environmental-Economic Accounting for Water (UN SEEA-W; United Nations, 2007) which includes both green and blue water. So does the "Water Footprint" method introduced by Hoekstra and Hung (2002) which also includes a grey Water Footprint component for polluted water in addition to blue and green water (Hoekstra et al., 2009). Additionally, recently developed global models and datasets like GEPIC (Liu et al., 2007), H08 (Hanasaki et al., 2008), LPJmL (Rost et al., 2008) enable spatially explicit water use estimations including blue and green water consumption. Also the statistical office of the European Union, Eurostat, has acknowledged these important aspects and is planning to include blue and green water, as well as water use and water consumption in the new water accounting standard tables to be developed in a current project[43].

Consequently, pressure indicators related to water use quantities should take into account both of the above mentioned aspects. Therefore, the following three indicators are of significant relevance (all of which are available from the Eurostat New Cronos and from the FAO Aquastat database):

a. **Water withdrawal by sector**. Agricultural, municipal (households), and industrial water withdrawal

b. **Water withdrawal by source**: surface water, groundwater (non-/renewable), precipitation, non-conventional water (desalinated or treated water)

c. **Total water withdrawal per capita**. Total annual amount of water withdrawn (summed by sector) per capita.

However, as outlined above, these indicators have to be further elaborated in order to account for the quantities actually consumed and for the different sources of water.

"Water withdrawal by sector" has to be extended to include not only withdrawals but also quantities consumed. In the agricultural sector this would imply modelling water consumption by different crop types – e.g. using one of the models listed above and combining these data with information related to irrigation and withdrawal quantities. In the industrial sector the quantification of water consumption consists of a water balance, accounting for the withdrawals and subtracting the discharged (waste) water. A similar approach would be applicable in the municipal sector. The indicator could hence be split into "Water use by sector" and "Water consumption by sector".

Furthermore, it is of great importance to have a reasonable sector disaggregation (i.e. 60 economic sectors) in order to enable a detailed analysis of so-called "hot-spots" of especially high water use and consumption. This is a prerequisite to develop target-oriented policy measures aiming for a more sustainable water use.

"Water withdrawal by source" has to include rain/soil water, in order to account for the quantities of 'green' water. Also in this regard different models could be applied to support the calculations, especially in the agricultural but also in the industrial and domestic sector which often use rain water. So this indicator would have to be split into "Water use by source" and "Water consumption by source". Additionally, non-renewable water should be accounted for as a specific source.

"Total water withdrawal per capita": Once the other two indicators have been calculated this indicator can easily be calculated as well. A proposed name could be "Water consumption per capita" (and "Water use per capita").

4.2.3. Data availability

For the three state indicators mentioned above the main data source for the worldwide level is the FAO AQUASTAT database covering five regions and around 200 countries. The main data source for

[43] EUROSTAT Tender 2009/S 126-182782: Statistical services in the field of environmental statistics and accounts - Lot 3 – Environmental accounts: assistance to the methodological development of water and energy accounts. Duration 2010-2011.

available freshwater resources on the European level is the New Cronos database run by Eurostat. Eurostat collects these data by means of the joint questionnaire of the OECD and Eurostat (OECD and Eurostat, 2008) which also includes data on water use. Data are available on a yearly basis for the EU-27, the accession countries, the EFTA and some Balkan and Mediterranean countries.

While the Eurostat data would enable to calculate the indicators discussed above, the database faces major constraints, both in terms of availability as well as in terms of data quality.

The two tables below illustrate data availability for different categories in the New Cronos database. Thereby, the numbers in the cells define for how many countries values are available (out of a total of 27 EU Member States).

Table 20 Water balance indicators and available data in the 27 EU Member States reporting to New Cronos

	1970	1975	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Total gross abstraction of freshwater	14	13	19	2	1	1	1	18	4	3	2	8	14	17	13	15	15	18	17	17	20	19	17	19	18	19	20	19	16	13
Total net fresh water abstraction	2	4	6	1	1	1	1	7	1	1	2	2	7	11	9	10	9	9	8	8	10	9	10	12	11	12	14	14	12	10
Total water available for use within the territory	0	0	1	0	0	0	0	2	0	0	0	0	0	1	1	1	1	2	2	1	1	1	2	3	2	3	4	4	3	2
Losses by evaporation	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	1	1	3	4	5	5	6	6	6	4
Total water available for end users within the territory	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	1	1	2	3	2	3	3	3	1	1

Table 21 Renewable water resources indicators available data in the 27 EU Member States reporting to New Cronos

Renewable water resources EU27	1970	1975	1980	1985	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Precipitation	7	7	11	20	10	22	20	21	21	20	21	21	21	21	22	21	20	20	19	19	19	17	13
Actual evapotranspiration	7	6	9	19	7	20	19	19	19	18	19	20	20	20	21	19	18	18	18	17	17	13	11
Total fresh water resources	4	3	7	15	4	17	15	16	16	15	18	17	17	17	18	17	16	16	17	16	16	13	10
Recharge into the Aquifer	0	0	0	2	0	3	0	0	0	0	3	2	2	2	2	4	4	4	4	3	4	4	3
Recharge minus ecological discharge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0
Groundwater available for annual abstraction	1	1	1	7	2	7	6	8	8	9	9	7	7	7	8	8	8	7	7	7	7	6	5
Regular freshwater resources 95 per cent time	0	0	0	1	0	2	1	1	1	1	2	2	2	2	3	2	2	2	2	2	2	1	1

The table above should be read as follows: for the aggregated category of "Total gross abstraction of freshwater" only 13 out of the 27 EU Member States have reported data for the year 2007. The category "Total water available for end users within the territory" only contains one value. Hence, while the database structure (and the related questionnaire) foresees the collection of relevant data, the reporting still lacks behind. This is partly due to data availability at national statistical institutions, because the necessary accounting has not been implemented yet, and partly due to the fact that – especially in water-rich countries –water quantity has so far not attracted as much interest as water quality. Additionally, a lot of data on sectoral water use is subject to confidentiality, leading to more data gaps or low quality data.

On the international level, the AQUASTAT database is the best available data source. As in the case of the data on water use, data are available per 5-year period and show the most recent year data in each period for each variable. Despite the wide area coverage and long time series (1960-2010), the AQUASTAT database on water use still has significant data gaps (see Table 22), and there is a large potential for improvement regarding more detailed data. One example is its sectoral disaggregation into only three different sectors (municipal, industrial, agricultural).

Table 22 Data availability for different categories in the AQUASTAT database; number of countries with reported values (out of the 27 EU Member States)

EU27	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010
Average precipitation in volume (10^9 m3/yr)	21	21	21	21	21	21	25	27	27	27	0
Water resources: total renewable (actual) (10^9 m3/yr)	21	21	21	21	21	21	25	27	27	27	27
Agricultural water withdrawal (10^9 m3/yr)	0	0	2	3	6	6	9	9	23	3	0
Municipal water withdrawal (10^9 m3/yr)	0	0	2	4	7	7	10	7	23	1	0
Industrial water withdrawal (10^9 m3/yr)	0	0	2	3	5	5	8	7	23	1	0
Total water withdrawal (sum of sectors) (10^9 m3/yr)	0	0	2	3	8	7	6	7	23	1	0
Total water withdrawal per capita (m3/inhab/yr)	0	0	2	2	8	7	6	7	23	1	0

As water scarcity is predominantly a local or regional phenomenon, thresholds such as maximum renewable freshwater withdrawal are most appropriately monitored at the water basin level rather than on the national level (see, for example, the EU Water Framework Directive (Directive 2000/60/EC)European Parliament, 2000b). Elaborating water accounts at the river basin level requires geographically referenced data of water flows and discharges of pollutants, i.e. spatial identification of establishments, waste water treatment plants, etc. However, as on the national level, currently, there is still a need for better information on water availability and abstraction at the water basin level. Moreover, the European assessments are not taking enough stock of results and analysis at national and River Basin District (RBD) level. There is a lack of harmonisation in estimation and quality assurance methodologies. The limited disaggregated information which exists shows deficiencies of validity and homogeneity and provides very poor information on trends (Kristenen, 2010). Table 23 shows the data availability for the discerned sectors as reported by New Cronos.

Table 23 Data availability for the discerned sectors as reported by New Cronos, in number of EU countries where information is available

Annual water abstraction by source and by sector EU27	1970	1975	1980	1985	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Total gross abstraction	13	12	18	16	10	14	16	11	13	13	17	15	15	18	17	15	17	16	16	16	16	13	13
Abstraction by public water supply	8	11	17	15	11	15	15	12	14	15	17	15	17	20	19	17	20	21	20	21	19	16	15
Abstraction by agriculture, forestry, fishing (total)	7	6	11	10	5	11	13	11	12	14	16	13	13	16	16	16	18	20	19	19	17	15	13
Abstraction by agriculture, for irrigation purposes	6	6	11	9	5	11	10	8	9	9	14	9	10	13	12	14	14	16	16	16	16	15	12
Abstraction by mining and quarrying	3	2	5	6	5	11	7	7	8	8	12	9	9	9	7	5	6	6	7	8	9	10	11
Abstraction by manufacturing industry (total)	4	6	13	11	6	13	15	11	12	13	14	12	13	15	16	15	17	16	18	18	15	12	9
Abstraction by manufacturing industry, for foodprocessing industry	1	1	1	2	1	2	5	3	4	2	8	7	7	8	5	0	0	0	0	0	0	0	0
Abstraction by manufacturing industry, for cooling purposes	3	3	3	3	2	6	4	5	6	6	5	6	4	6	5	6	9	8	8	9	7	7	6
Abstraction by production of electricity, for cooling purposes	5	5	11	10	8	11	13	10	11	12	12	11	12	13	13	13	16	16	14	15	13	12	10
Abstraction by other activities	2	3	4	6	2	9	9	7	7	7	12	9	10	12	12	10	12	12	14	14	12	12	9
Abstraction by construction	1	1	2	2	1	4	4	4	4	4	5	5	6	7	4	3	4	3	3	4	4	2	1
Abstraction by households	2	2	4	4	2	4	2	3	3	4	7	7	5	6	6	9	10	10	9	9	9	8	5
Returned water (before use or without use) - (only available for total surfa	1	3	4	5	2	6	8	6	6	6	6	6	5	7	5	9	11	11	11	13	13	13	11
Net abstraction - (only available for total surface and groundwater)	2	4	6	6	2	7	10	9	10	9	9	8	7	9	8	10	12	12	13	13	13	12	11
Abstraction by any other economic activity (e.g. construction)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5

In the EU, water resource monitoring will be possible at sub-national level in the future when the Water Framework Directive becomes more widely implemented and more data will be collected.[44] The water accounting framework can in principle be compiled at any level of geographical disaggregation of a territory. However, experiences show that, so far, national statistical offices have not set their focus on sub-national water accounting. The WFD, which focuses mainly on qualitative aspects, could be an adequate tool to be combined with data inquiries for data on water use and consumption. At sub-national level, the options are usually to compile the accounts either at the level of administrative regions, river basins or accounting catchments.

Another important source for data on water consumption is the data compiled by the Water Footprint Network. The Water Footprint is the first indicator which comprehensively and directly relates consumptive water use and the consumption patterns of people, accounting for both blue and green water use. It can be used to analyse the major implications of water use for local, regional, as well as global problems such as water scarcity.

Currently, the only available world-wide water footprint datasets are presented in the study *Water Footprint of Nations* (Chapagain and Hoekstra, 2004). In this study, the virtual water content of agricultural products and livestock products is estimated by using the methodology developed by the same authors. The study calculates the water footprint for each nation of the world for the period 1997-2001 for the agricultural sector based on the total volume of crop produced and its corresponding virtual water content. While the virtual water content of crop products is calculated using a financial allocation method (product and value fractions), the content of an industrial product is calculated using the average virtual water content per dollar added value in the industrial sector. The study does not show green, blue and grey water footprints individually, and a simplified approach was used for industrial products.

Water accounting – the organisation and representation of statistical water data – is gaining increasing attention within national and international (statistical) institutions around the world. In the European Union there are two, partly related, initiatives: (1) the accounting requirements determined in the Water Framework Directive (European Parliament, 2000a) which include specifications mainly on water quality data on the river basin level; and (2) an initiative to set up improved water accounts for EU countries pushed by Eurostat, in accordance with the EEA, National Statistical Institutes (NSIs), as well as international organisations such as the OECD as a part of the European Strategy for Environmental Accounting (ESEA; EUROSTAT, 2003). Thereby, Eurostat is developing a new set of standard water accounting tables to ensure internationally comprehensive and comparable data collection (see above). Eurostat decided to focus efforts first on the development of physical flow accounts and to use a framework of physical Supply and Use tables (PSUTs) constituting the most suitable conceptual approach to record all water flows entering, flowing within, or leaving the economy in a consistent way.

[44] The WFD requires Member States to formulate a river basin management plan for each river basin district within their territory, and in the case of an international river basin district, Member States shall ensure coordination with other Member States or third countries with the aim of producing a single international river basin plan. An increasing number of Member States are producing these plans – both at the national level (see for example Lebensministerium, 2005) and internationally (see for example ICDPR, 2009).

Aiming for more reliable data collected and calculated in a uniform way and structure as well as developing a robust conceptual model for the calculation of irrigation and crop requirements (as well as for water requirements in industrial processes) at the European and international level will ensure the provision of a comprehensive and reliable dataset which can be used for the calculation of the above described indicators. As various initiatives (Eurostat, UN SEEA-W, Water Footprint Network) are working in this direction, it can be regarded as state-of-the-art in environmental accounting to take these developments into account when thinking about thresholds indicators for water use.

4.2.4. Suggested threshold indicators

Water scarcity is predominantly a local and temporally restricted phenomenon. However, the spatial and temporal dimension of water statistics has not attracted much interest until the adoption of the Water Framework Directive. The time and geographical resolution is of great importance, as water stresses can be artificially balanced out by looking only at annual and national figures. Consequently, thresholds are most appropriately monitored at the monthly and water basin level (see, for example, the EU Water Framework Directive (Directive 2000/60/EC), European Parliament, 2000b). However, while the spatial aspect of data collection seems to be realisable in the short term (various accounting schemes foresee a disaggregation to the level of catchment areas or administrative districts), refining the temporal interval of accounting to less than one year appears to be challenging, though desirable.

Threshold indicators linked to water consumption

One could suggest "Maximum renewable freshwater withdrawal" as a very straightforward threshold indicator, which can even build on readily available data; it is defined as water withdrawal as a percentage of total available (and exploitable) water resources. However, as explained above, not all water abstracted is actually consumed. Water abstracted for irrigation in agriculture will for the most part be evapotranspirated and incorporated in agricultural products (= consumed) whereas a significant proportion of the water abstracted for domestic or industrial purposes (e.g. drinking, washing, cooling, electricity production, etc.) is returned to the water resources after use and thus becomes available again for further downstream users within the same basin. Therefore, a pure water use indicator (without separation of water used and water actually consumed) alone can give a misleading picture of the available freshwater resources and danger zones. Additional information about water use and water consumption has to be provided. Consequently, it is more appropriate to disaggregate the Maximum renewable freshwater withdrawal indicator into a set of different indicators, relating available water resources to actual amounts of water consumption.

As elaborated on in chapter 4.2.2, the currently existing pressure indicators still have their shortcomings, as they do not account for the quantities actually consumed and for the different sources of water, respectively. Provided that these improvements are made, threshold indicators have to disclose where the limits in water consumption in relation to different water sources are. Hence, we suggest the following threshold indicators for water quantity:

a. **Maximum non-renewable water use**: non-renewable water use as a percentage of total available (and exploitable) non-renewable water resources. Non-renewable water resources are stock limited, which means that they are depleted when the use of water from a groundwater aquifer far exceeds the natural recharge rate – in most cases these are so-called 'fossil' aquifers.
b. **Maximum blue water consumption**: blue water consumption as a percentage of total available (and exploitable) blue water resources
c. **Maximum green water consumption**: green water consumption as a percentage of total available (and exploitable) green water resources

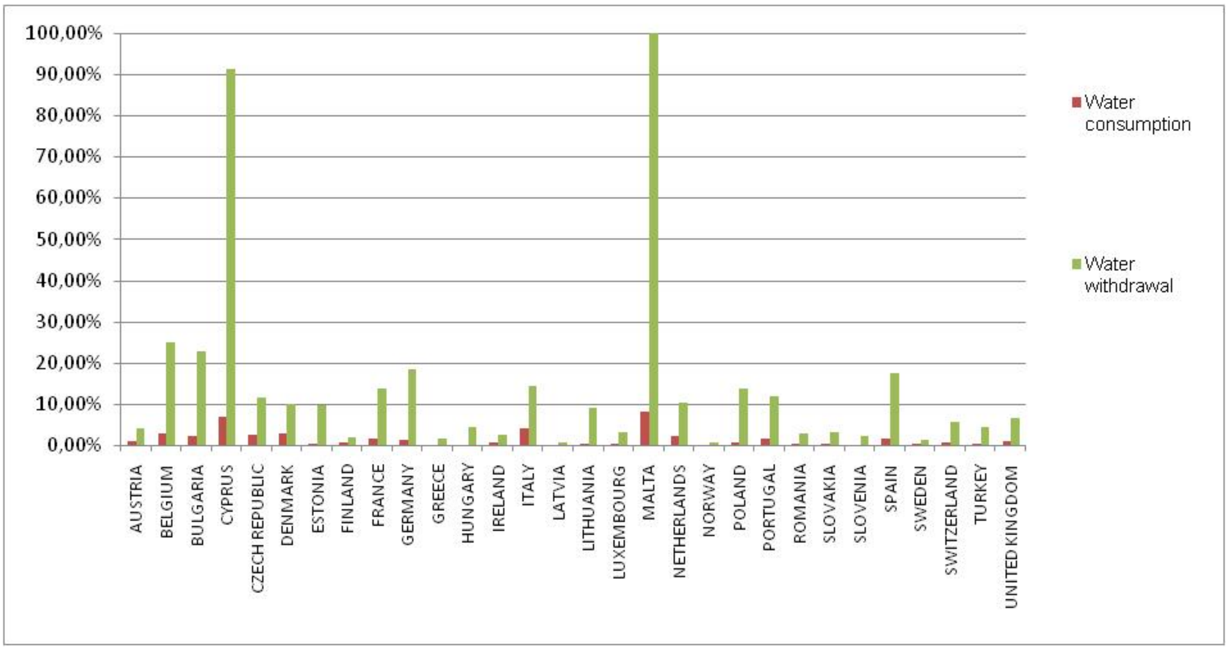
Table 24 Water quantity threshold indicators - consumption

Maximum non-renewable water use		
	Non-renewable water use	Total available (and exploitable) non-renewable water resources
Unit of measurement	Mill m³/year (month)	Mill m³/year (month)
Data source/s	Still not specifically accounted	Still not specifically accounted
Update of data (How often is the indicator updated?)	-	-
Data quality / issues	Accounting foreseen in the new Eurostat Standard Tables	Accounting foreseen in the new Eurostat Standard Tables
Maximum blue water consumption		
	Blue water consumption	Total available (and exploitable) blue water resources
Unit of measurement	Mill m³/year (month)	Mill m³/year (month)
Data source/s	Water Footprint Network – on an aggregated level; also planned for new Eurostat Questionnaire EXIOBASE available from 2011 onwards for 44 countries and regions	a) Aquastat b) Eurostat
Update of data (How often is the indicator updated?)	WF data: irregularly; the EXIOBASE shall be updated throughout the CREEA project	a) regularly – 5-year-period-data b) biannually – yearly data
Data quality / issues	Both WF and EXIOBASE data are at the state of the art in water accounting	a) data gaps especially for more recent years b) data gaps due to lack of accounting obligation
Maximum green water consumption		
	Green water consumption	Total available (and exploitable) green water resources
Unit of measurement	Mill m³/year (month)	Mill m³/year (month)
Data source/s	Water Footprint Network – on an aggregated level; also planned for new Eurostat Questionnaire EXIOBASE available from 2011 onwards for 44 countries and regions	Aquastat; also planned for new Eurostat Questionnaire
Update of data (How often is the indicator updated?)	WF data: irregularly; the EXIOBASE shall be updated throughout the CREEA project starting in spring 2011.	Regularly – 5-year-period-data; Eurostat yearly data
Data quality / issues	Both WF and EXIOBASE data are at the state of the art in water accounting	data gaps especially for more recent years

Additionally, a comparison of water abstraction with the rate at which water reserves are renewed would give a good overview of depletion of water reserves, but the necessary data are not available (EUROSTAT, 2004).

The suggested indicators can be seen as an approach tackling the problem of water scarcity from the consumer side. Applying this set of indicators would allocate a specific amount of consumable water per accounting unit (time and space) to each economic sector and in so far makes sure that sustainable limits are not surpassed. Given the above mentioned restricted data availability, especially in terms of sectoral disaggregation, in a first step these values might only be calculable for a restricted number of countries or sectors respectively. However, the EU FP-6 research project EXIOPOL (www.feem-project.net/exiopol), for instance, sets up an environmentally extended input-output framework and database. The so-called EXIOBASE contains data on blue and green water use as well as consumption for 13 crop types, 12 types of cattle, six sectors of manufacturing industry, two sectors of energy production, and the domestic sector. These data are available for 43 countries and a region called "rest of the world". The follow-up project CREEA (EU FP-7) will further develop the database, in order to enable more comprehensive and meaningful analyses. In the following, first preliminary calculations will be presented to demonstrate examples of the presented indicators (Figure 16).

Figure 16 Ratio of blue water abstraction per available total freshwater resources



Sources: Own calculations based on Alcamo et al. (2003), Eurostat (2010), and FAO (2010).

The graph shows that Belgium, Bulgaria, Cyprus, Germany, Malta, and Spain reach the water scarcity threshold of 20% as defined by the EEA (see section 3.5.1). Malta has the highest ratio of blue water abstraction per available total freshwater resources (333 % and as such outside of the boundaries of the graph). Any ratio above 100% means that water demand has to be satisfied through withdrawals from non-renewable sources or through imports. Note that Cyprus and Malta do also have very high shares of water consumption values in available resources.

<u>**Threshold indicators linked to the impacts of human activities**</u>

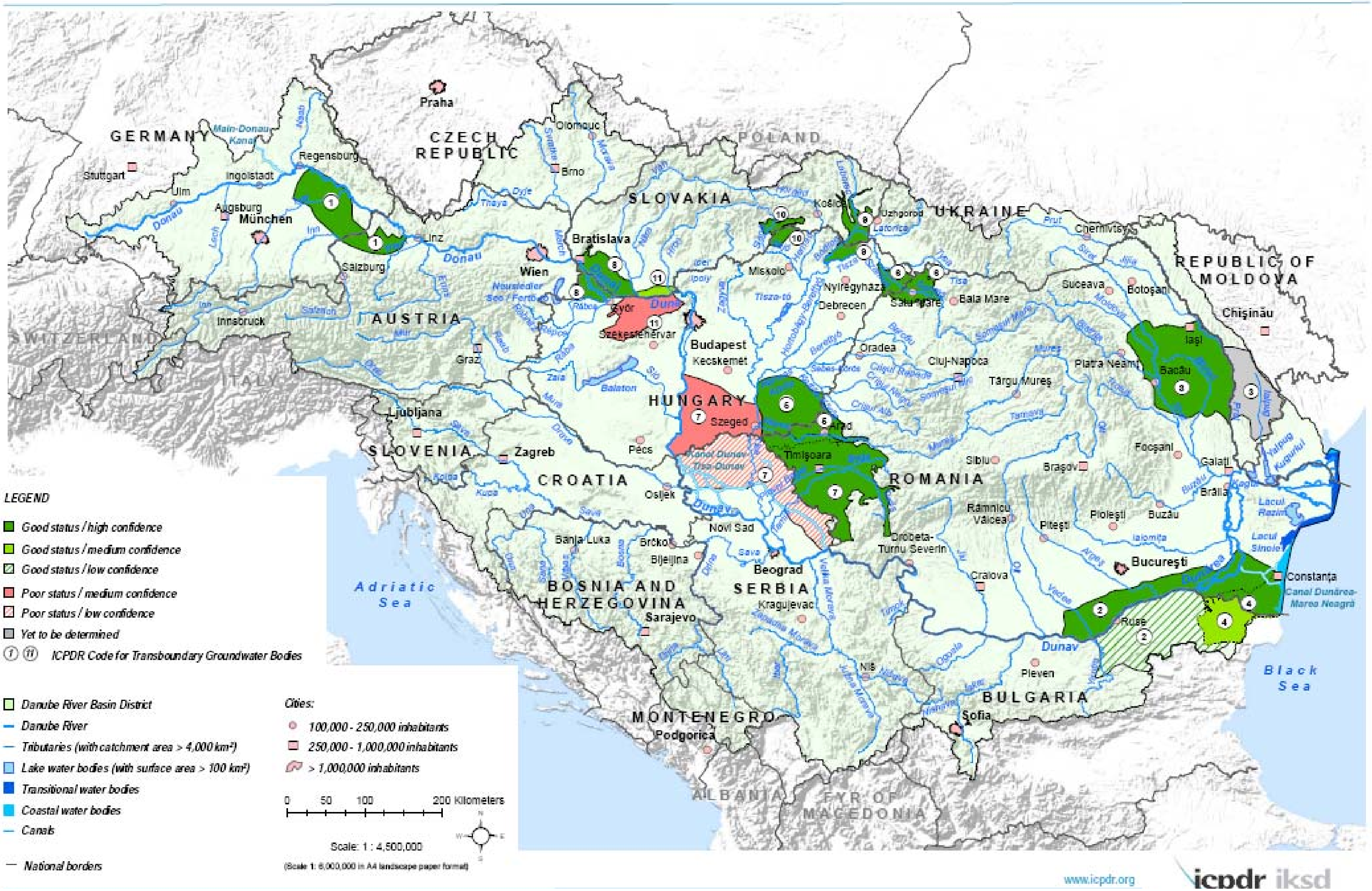
If the theme of freshwater quantity thresholds were to be tackled from the impact side, a possible approach would be to use indicators such as "Groundwater quantitative status" and (for surface water) "minimal flow requirements" and to define thresholds for these. Taking the Danube River Basin District Management Plan (ICPDR, 2009) as an example, ***a groundwater body has a good quantitative status when "the level of water in the groundwater body is such that the available groundwater resource is not exceeded by the long-term annual average rate of abstraction***". These values are measured regularly and consequently could be used as threshold values.

Figure 17 gives an example for the illustration of the quality of different transboundary groundwater bodies within the Danube river basin. Thereby, groundwater bodies are coloured from green to red to demonstrate good or bad water quality, respectively. Similarly, streams can be evaluated regarding hydrological pressure types and provoked alterations. The criteria for the respective pressure/impact analysis in the Danube River Basin District Management Plan (ICPDR, 2009), are presented in Table 25. These indicators are reported regularly. They can be illustrated comprehensively (see Figure 17 and Figure 18) and could be used to monitor thresholds. Note, however, that although the river basin management plans had to be prepared by December 2009, various countries have not finished them yet (e.g. Italy). Hence, data availability is still unsatisfying.

Table 25 Hydrological pressure types, provoked alterations and criteria for the respective pressure/impact analysis

Hydrological pressure	Provoked alteration	Criteria for pressure assessment
Impoundment	Alteration/reduction in flow velocity and flow regime of the river	Danube River: Impoundment length during low flow conditions >10 km Danube tributaries: Impoundment length during low flow conditions >1 km
Water abstraction/ residual water	Alteration in quantity and dynamics of discharge/flow in the river	Flow below dam <50% of mean annual minimum flow[46] in a specific time period (comparable with Q95)
Hydropeaking	Alteration of flow dynamics/discharge pattern in river and water quantity	Water level fluctuation >1m/day or even less in the case of known/observed negative effects on biology

Figure 17 Danube River Basin District – quantitative status groundwater



Source: ICPDR, 2009

Figure 18 Danube River Basin District – Hydrological alterations/water abstractions; current situation (2009)

Source: ICPDR, 2009

Table 26 Water quantity threshold indicators - impact

Groundwater quantitative status		
	Water abstractions	Groundwater regeneration
Unit of measurement	Mill m³/year (month)	Mill m³/year (month)
Data source/s	River Basin Management Plans (RBMP)	River Basin Management Plans (RBMP)
Update of data (How often is the indicator updated?)	Yearly	Yearly
Data quality / issues	Still various RBMP missing	Still various RBMP missing

Hydrological pressures on streams			
	Impoundment length	Flow volume	Water level fluctuation
Unit of measurement	meter	m³	Mio m³/year (month)
Data source/s	RBMP	RBMP	RBMP
Update of data (How often is the indicator updated?)	Yearly	Yearly	Yearly
Data quality / issues	Still various RBMP missing	Still various RBMP missing	Still various RBMP missing

4.2.5. Advantages and disadvantages of the suggested threshold indicators

Table 27 Advantages and disadvantages of suggested threshold indicators

Water quantity - consumption			
	Maximum non-renewable water use	**Maximum blue water consumption**	**Maximum green water consumption**
Advantages	• Addresses non-renewable (fossil) water abstraction as the irreversible part of human water use	• Consumption indicator most directly linked to human activities (e.g. irrigation, water used in food production, etc.) • Includes sub-indicator use (abstraction) of blue water and can be illustrated on a level of its components	• Most comprehensive threshold indicator also including evapotranspiration of plants • Includes sub-indicator use (abstraction) of green water and can be illustrated on a level of its components
Disadvantages	• Data to calculate threshold indicator currently not available, as data on abstraction of non-renewable water missing • Does not comprehensively cover all water sources and thus needs to be complemented by additional threshold indicators	• Data only available by private network (Water Footprint Network), not by statistical institutions	• Data only available by private network (Water Footprint Network), not by statistical institutions

Water quantity - impacts		
	Groundwater quantitative status	**Hydrological pressures on streams**
Advantages	• Addresses the direct impact on groundwater bodies • Data should be created on a regular basis • Data on grounwater body, not on national level	• Addresses the direct impact on streams • Data should be created on a regular basis • Data on river basin, not on national level
Disadvantages	• Still some RBMP are missing • Unsure interval of data updates	• Still some RBMP are missing • Unsure interval of data updates

4.2.6. Interpretation of threshold indicators

Water is a vital resource for different aspects related to the survival of humankind. The provision of drinking water, water for agricultural as well as industrial use and the maintenance of ecosystem function play a crucial role in our societies. Given the complex interrelations between the different uses of water it is not possible to use only one threshold indicator to measure if a certain limit of water abstraction and/or consumption is about to be (or has already been) surpassed. Consequently, we suggest a set of three complementary indicators on human water consumption to comprehensively cover the different types and sources of water (blue/green and renewable/non-renewable). Alternatively, we present two indicators related to the impact of human activities on water resources. While the latter set of indicators has the advantage of better data availability due to the anchorage of data collection in the Water Framework Directive, the first seems more appropriate, as it would enable to proactively steer human water consumption. Another option might be to calibrate the first set with the help of the second.

Maximum non-renewable water use indicates the maximum use of water from aquifers and other natural reservoirs that are either not recharged or recharged so slowly (i.e. decades or centuries), that significant withdrawal will cause depletion. The indicator shows non-renewable water use as a percentage of total available (and exploitable) non-renewable water resources. As non-renewable water resources are limited in stock, they are depleted when the use of water far exceeds the natural recharge rate.

Maximum blue water consumption indicates the maximum consumption of fresh surface and groundwater (i.e. water in freshwater lakes, rivers and aquifers), which can be withdrawn for irrigation and other human uses before potentially irreversible consequences occur. The indicator is defined as the (criticality) ratio of blue water consumption-to-availability. Rough estimates for threshold values with regard to blue water scarcity / stress have been suggested by the EEA’s Water Exploitation Index and by Molden et al (2007), varying from 20% to 75% respectively.

Maximum green water consumption indicates the maximum consumption of water in the soil before potentially irreversible consequences occur. The indicator measures the ration of green water consumption to total available (and exploitable) green water resources. So far, no estimates exist on threshold values for this indicator.

These three indicators cover the main types and sources of water. Setting a limit to the appropriation of water enables preventing depletion of water resources and the negative impacts of diminished water bodies, such as the loss of habitats etc. It also can be used for an active control of water appropriation by different stakeholders which allows for proactive water management and water governance.

For an effective application of the suggested set of indicators the water consumption of different economic sectors has to be analysed. This is foreseen in the European Strategy for Environmental

Accounts (ESEA) and in the process of implementation carried out by Eurostat. Such an analysis will not only enable to identify sectors of especially high values of water consumption but also to calibrate the suggested indicators, in order to make sure sustainable thresholds are not surpassed.

4.2.6. Conclusions and recommendations

Currently, it is not possible to calculate the indicator "maximum non-renewable resource use" due to the lack of data. With the future plans for accounting foreseen in the new Eurostat Standard Tables [45], however, it may be possible to get first assessments. It would be recommendable to underline the importance of these database developments given the increasing dangers of water scarcity in some parts of Europe and the need early alerts in order to respond in time.

Even though data availability makes it possible to calculate "maximum blue water consumption" at the aggregate level, more regional analysis is required to get a precise picture of the situation in terms of water scarcity in specifically affected areas. To make use of the suggested threshold indicator, the existing data gaps (especially for more recent years, and due to lack of accounting obligation) will have to be filled, the collection of river-basin level data is needed, and more regular reporting should be encouraged.

The collection and regular update of data is also highly recommendable for green water, as scarcity can lead to severe damage to soils and plants.

In general, data is not readily available for all the underlying pressure indicators, and the available data still lack completeness and quality. However, due to the increasing relevance of the topic, various institutions (Eurostat, UNStat, etc.) are working on an improvement of accounting structures, data comprehensiveness and quality.

Ideally, the pressure and threshold indicators are calculated for a much disaggregated level – with regard to geography, time and economic structure. The designation of specific threshold values, for example for each economic sector, would have to be adjusted to its absolute water consumption on the one hand and an estimation of possible improvements and minimum requirements on the other hand.

The application of the threshold indicators should be embedded in a comprehensive strategy for water policy oriented at integrated water resources management (IWRM) and should be closely related to steering measures such as creating incentives (e.g. via tax abatements or special types of subsidies) for a more responsible handling of water resources especially as input in production processes but also with regard to wastewater treatment.

From the macro-economic point of view, the threshold values should be linked to information on flows of 'virtual water' (water used for the production of exported products) between nations. Based on such information, new trade strategies can be designed, such as the restructuring of imports or the establishment of special trade agreements including compensatory measures on the part of the importing country.

[45] EUROSTAT Tender 2009/S 126-182782: Statistical services in the field of environmental statistics and accounts - Lot 3 – Environmental accounts: assistance to the methodological development of water and energy accounts. Duration 2010-2011.

4.3 Soil erosion

4.3.1. State indicators

Tolerable soil erosion and soil formation

Threshold levels of accelerated erosion have been defined in the literature as “tolerable” rates of soil erosion in comparison with estimates of natural rates of soil formation. The comprehensive literature review on soil erosion and formation rates carried out in the context of the ENVASSO project (2008) and complemented by the work of Verheijen et al. (2009) on “Tolerable versus actual erosion rates in Europe”, provides an excellent overview of the state of the art regarding the concept of tolerable erosion rates and their relation to soil formation rates and actual soil erosion rates.

The concept of ‘tolerable’ rate of soil erosion includes an aspect of human judgment in addition to scientific evidence of natural rates of soil formation. The concept of ‘tolerance’ proposed by the abovementioned authors integrates two perspectives: quantity of soil loss and fulfilment of soil functions. The first perspective prioritises soil quantity and thus defines an erosion rate as tolerable if it does not exceed the soil formation rate. From the second perspective, soil erosion is tolerable as long as a particular soil function or functions is/are not affected (often favouring productive functions i.e. food and biomass production, and regulative functions above other functions such as habitat, gene pool, physical, informative and cultural functions). Verheijen et al. (2009) thus suggest integrating both approaches and using a more holistic definition of tolerable soil erosion as “any mean annual cumulative (all erosion types combined) soil erosion rate at which a deterioration of one or more (primary) soil functions (e.g. habitat, production, storing, filtering) does not occur”. ‘Tolerable soil erosion’ is thus a conceptual term, based on a judgement of affected soil functions that can be quantified in ‘tolerable rates of soil erosion’ with units conventionally in t /ha /year.”In this context, natural ‘soil formation rates’ are used as a basis for establishing ‘tolerable soil erosion rates’. However, soil formation processes and rates differ substantially throughout Europe. In accordance with the current state of scientific knowledge for Europe, tolerable soil erosion rates (= mean rates for natural soil formation), for hill slope soils overlying hard rock parent material, range from ca. 0.3 to 1.4 t /ha/ year depending on the driving factors of soil formation i.e. weathering (e.g. parent material, climate, land use) and desert-source dust deposition (e.g. geographic position; distance to source).

Based on reported values of soil formation rates, a global upper limit of approximately one t /ha /year for mineral soils was proposed by Verheijen et al. (2009). In addition to this approximate upper limit, Verheijen et al. (2009) argue that ‘relevant local components of soil functions that are impacted by soil erosion (e.g. surface water turbidity effects on aquatic wildlife or siltation of reservoirs) can be used to set tolerable soil erosion rates below the upper limit determined by soil formation rates’.

Uncertainty

Verheijen et al. (2009) note that difficulties in establishing threshold rates of erosion are also related to differing societal and political interpretations and judgments on “tolerable” erosion rates, but also to regional and even local disparities in estimated and measured soil erosion rates (see

Table 28). As regards soil formation rates, to some extent a consensus on mean rates of soil formation still needs to be reached. Judgement on tolerance is based on the wider perspective of society as a whole, taking into consideration economic aspects, for example.

Table 28 Identified threshold levels in the literature

Approach	Threshold	Source
Soil formation for conditions prevalent in Europe	the upper limit of tolerable soil erosion, as equal to soil formation, is ca. 1.4 t/ha/year while the lower limit is ca. 0.3 t/ha/year (for hill slope soils overlying hard rock parent material)	Verheijen et al., 2009
Precautionary approach	Average tolerable erosion rate is 1 t/ha/year	Verheijen et al., 2009; Jones et al., 2005
Identification of risk areas	An estimated soil loss > 2 t/ha/yr could be a more appropriate threshold for the delineation of risk areas at Tier 1[46] than 1 t/ha/yr	Eckelmann et al. (2006)
European range	'In some cases, rates of soil erosion larger than 1 t /ha/year are regarded as tolerable from the wider perspective of society as a whole (…) it may be realistic to propose different rates of soil erosion that are tolerable in different parts of Europe.' The proposed threshold varies between 1 to 2 t /ha/year	Huber et al. (2008)
Soil formation in the long term (50-100 years)	'Resulting changes to the soil cover allow natural forces of erosion to remove the soil much more rapidly than soil-forming processes can replace it. Any soil loss > 1 t /ha /year can be considered irreversible within a span of 50-100 years'	Jones et al., (2004) and EEA (1999)
Management approach	'[...] what is tolerable has to be linked to all relevant functions. Thus, the rate of erosion, which is dependent on so many things and is variable in space and dynamic in time, is not a good indicator for this purpose. Management practices should minimise the risk of soil loss. [...] We know that agricultural land-use inevitably means soil loss and that the losses vary from site to site and from situation to situation. The only possible thing to do is to minimise soil loss as far as possible."	(Dorren et al., 2004)

Huber et al. (2008) raise the question of proposing different threshold values for tolerable soil erosion rates in different parts of Europe, e.g. higher for southern Europe than for northern Europe. This aspect, however, needs further research. It should be noted that in its proposal for a Soil Framework Directive (European Commission, 2006c) the European Commission has refrained from suggesting a uniform soil erosion target rate for the EU (see section 3.7.6 above). It has on the contrary suggested that Member States should themselves set appropriate target rates, which can vary from area to area in their national territory to ensure the protection of soil functions and a sustainable soil use. Examples from threshold levels currently in use in Switzerland and Norway have been presented above (see section 3.7.3).

Due to changing climate conditions, there is much uncertainty about the spatio-temporal structure and effect of this change on soil erosion, including the socio-economic and agronomic adaptation changes that may follow them (Boardman and Favis-Mortlock, 1993; Nearing et al., 2004; Phillips et al., 1993). For this reason Verheijen et al. (2009) propose the development of 'moving tolerable rates' with climate change scenarios to support the policy sector.

[46] "Tiers" correspond to different work steps, each requiring different data. Tier 1 corresponds to risk area identification, Tier 2 corresponds to measures/implementation plans to protect soils within the risk zones (Eckelmann et al., 2006).

Based on the difficulty of setting and implementing general or regional tolerance values the approach of Dorren et al. (2004) focuses on the importance of land management and agricultural practices in reducing the impact of soil erosion. Instead of threshold values they propose case to case assessments based on questions regarding the site specific value or function of the soil for the environment and for human activities and also about potential for soil erosion reduction through management practices (see box 3 below).

Box 3: Questions of interest for site assessment of tolerable soil erosion (Source: Dorren et al., 2004)

Site specific assessments of erosion should consider the following questions:

I. Does soil erosion take place?
II. Is a reduction of soil erosion possible and using which measures?
III. Does, in case of the desired land-use, an inevitable amount of soil loss remain and can it be accepted (both on-site and off-site)?

The last question leads to an individual tolerance of the particular site/soil and its use. To assess this kind of tolerance the following aspects are to be taken into account, e. g.:

- ✓ functions of the soil in its natural environment,
- ✓ functions of the soil with respect to its use,
- ✓ important site and soil properties (texture, depth, organic matter content, soil hydrology etc.) and those which lead to sheet, rill or gully erosion,
- ✓ rarity of the particular soil, natural monument, cultural or archaeological monument,
- ✓ position of the site in the surrounding landscape, sensitive neighbouring sites, especially surface waters, natural protection sites, or settlements and civil infrastructure, in relation to potential off-site impacts.
- ✓ off-site effect of the loss of soil in the catchment area, on downstream dams, canals, harbours, and on climate change (in case erosion causes the mineralisation of topsoil carbon).

In conclusion, an exercise of setting regional or even local or site specific threshold levels of erosion would be valuable and more research is definitely needed in this regard. However the literature review and expert interviews carried out for this study show that a threshold value of **1 t /ha/ year** , based on a comparison with mean natural soil formation rates, is generally accepted as a tolerable rate of soil erosion in our current socio-economic context. Site specific exceptions above and below this threshold are of course realistic and necessary in some cases. Indicators of a danger zone or of a zone of tolerable erosion are thus also related to soil formation indicators.

For the purpose of this study the indicator of acceptable state represents a European threshold value of erosion of 1 t $ha^{-1}yr^{-1}$.

4.3.2. Pressure indicators

Two types of indicators can be used to reflect the existing erosion pressure on soils: (1) soil erosion rates as recorded at field and plot level[47], and (2) estimated soil erosion rates derived from modelled soil erosion.

Measured actual soil erosion rates

The range of reported erosion rates for tilled arable soils is many times greater than the range of reported soil formation rates. Verheijen et al. (2009) explains that this can be because 'soil formation is affected little by human activities, whereas today most soil erosion is anthropogenically induced. It should also be noted that soil erosion only appears to exceed tolerable rates when the soil is under cultivation or affected by other human disturbance'. This statement is supported by the fact that arable agriculture accounts for ca. 70% of soil erosion in Europe, as estimated by Boardman and Poesen (2006), while approximately 88% of soil erosion in Europe is human-induced (Yang et al., 2003 in Verheijen et al., 2009).

Reported evidence of actual soil erosion rates exceeding tolerable erosion rates in Europe (Verheijen et al., 2009):

- For tilled, arable land in Europe, on average, 3 to 40 times greater than the upper limit of tolerable soil erosion (ca. 3-40 t /ha/year), accepting substantial spatio-temporal variation.
- Several other researchers quote soil erosion rates in Europe, also for soils under arable land use, of between 10 and 20 t /ha/year (Richter, 1983, Lal, 1998; Yang et al., 2003).
- Reported rates of erosion by water in Britain vary from 1 t /ha/year up to 20 t /ha/year (for localised and rare events) (Arden-Clarke and Evans, 1993).

Gobin et al. (2004) present an overview of observed (at field or catchment scale) and measured (at plot scale) rates of erosion across Europe[48] (see Table 29). They note that median values would better reflect extreme values that are characteristic for erosion and that the comparison is difficult due to different observation and measurement techniques. Plot measurements, for instance, are more adequate for capturing temporal variations and field observations for reflecting spatial variations in the surveyed area. The authors argue that together with the method and period of observation or measurement, the site-specific physical factors (climate, topography, land use, land management) need to be taken into account while interpreting the presented results. These latter are best captured through a spatial analysis and assessment of the soil erosion problem (Gobin et al., 2004). -.

[47] These refer to on-the-ground measurements as opposed to estimates derived from a spatial computer model of soil erosion rates. Fields and plots are frequently used terms to describe relatively small areas of land, i.e., at the local level.

[48] This indicates differences of method and scale of measurement either allowing more precise measurements (and laboratory analysis for example) of evolution and effects of erosion especially in time on small plots, or more focused on displacement patterns of soil at field or wider catchment scale.

Table 29 Ranges[49] of soil erosion rates in arable fields across Europe

Ranges of soil erosion rates in arable fields across Europe

Location	Method	Range (average) ($t\,ha^{-1}$ per year)	Period of observation (year)	Reference
Southern Sweden	Observation (935 fields)	0.0–9.5[a] (0.6)	3	Alström and Åkerman (1992)
Southern Sweden	Plot measurements (six plots)	0.0–10.7 (0.2)	3	Alström and Åkerman (1992)
England–Wales	Observation (1705 fields)	0.1–5.5[a] (2.99)	5	Evans (1993)
England	Plot measurements (eight plots)	0.0–19.4 (2.1)	3	Quinton (1994)
Belgium	Observation (86 fields)	0.0–35.0 (3.6)	4	Govers (1991)
Belgium	Plot measurements (12 plots)	0.1–20.0 (7.8)	6	Bollinne (1982)
Netherlands (Limburg)	Plot measurements (12 plots)	0.1–3.4 (5.7)	4	Kwaad (1994)
Northern France	Observation (35 catchments)	0.0–13.2[a] (1.4)	3	Ludwig et al. (1995)
Austria	Plot measurements (nine plots)	0.0–30.1 (3.7)	5	Klik et al. (2002)
Sardinia	Plot measurements (10 plots)	0.2–9.1 (0.9)	3	Lucci and Della Lena (1994)
Italy	Plot measurements (49 plots)	0.2–83.3 (8.7)	6	Bazoffi et al. (1986)
Greece	Plot measurements (18 plots)	0.7–4.6 (1.4)	4	Kosmas et al. (1997)
Portugal	Plot measurements (16 plots)	0.0–35.8 (1.2)	16	Roxo et al. (1996)

[a] Bulk density estimated at $1.3\,t\,m^{-3}$ (Evans, 1995).

Source: Gobin et al., 2004

Estimated soil erosion rates

Suggested indicators of soil erosion:

In the framework of the ENVASSO project a well-defined set of indicators of erosion was proposed on the basis of sound science. They were selected based on several criteria: relevance for assessing the soil threat, ease of application (focused on thresholds), linkage to policy aims and applicability in a pan-European context.

Table 30 The selected TOP 3 indicators from the ENVASSO project

Key issue	Key question	Candidate indicator	Units	Baseline	Threshold
Water erosion	What is the current status of water erosion in Europe?	Estimated soil loss by rill, inter-rill, and sheet erosion	t /ha/year	North. Europe: 0-3 t /ha/year South. Europe: 0-5 t /ha/year	North. Europe: 1-2 t /ha/year South. Europe: 1-2 t /ha/year
Wind erosion	What is the current status of wind erosion in Europe?	Estimated soil loss by wind erosion	t /ha/year	North. Europe: 0-2 t /ha/year South. Europe: 0-2 t /ha/year	North. Europe: 2 t /ha/year South. Europe: 2 t /ha/year
Tillage erosion	What is the current loss of soil by tillage practices, land levelling and crop harvest (root	Estimated soil loss by tillage erosion	t /ha/year	North. Europe: 0-3 t /ha/year South. Europe: 0-5 t /ha/year	North. Europe: 2 t /ha/year South. Europe: 2 t /ha/year

49 The presented ranges include averages. It should be noted that median values would be more adequate in reflecting the range of soil erosion rates.

	crops)?				

Source: Huber et al. (2007)

Estimated soil loss by rill, inter-rill, and sheet erosion was selected as a **headline indicator** for soil erosion because soil loss by water in Europe is the most extensive form of erosion. Furthermore, it is possible to obtain estimates of soil erosion by water for the whole of Europe by modelling but not by other methods. Support indicators, e.g. measured soil loss, are used for calibration and validation of model estimates.

Estimated soil loss by wind erosion was selected because wind erosion is a significant cause of soil loss in Europe, although less extensive than water erosion. It may be possible to model wind erosion at European scale in the near future (the models are currently under development – personal communication with F. Verheijen, 17/05/2010). Support indicator should be used for validating the modelled estimates.

Estimated soil loss by tillage erosion was selected because tillage erosion has been recently recognised as a significant form of soil erosion in Europe. It can be modelled to provide estimated soil loss using a support indicator for calibration and validation.

These indicators were proposed by the authors of the ENVASSO project as a result of an extensive literature review, the thorough and systematic evaluation of measurement methodology, input parameter definition, geographical coverage, spatial resolution and availability of baselines and threshold values, and the identification of information gaps and data requirements. The output of the ENVASSO project thus provides the most recent and adequate basis for the identification of soil erosion pressure indicators in the framework of this study. It should thus be noted that the indicators proposed in the ENVASSO project represent best possible indicators on the basis of various criteria including measurability (referring to the practicability of the indicator depending on efforts needed for monitoring, data gathering and for indicator calculation), but not necessarily the criterion of currently being operational (indicator available or in use). Additional examples of theoretical or best possible indicators can be found in Box 4 below.

Modelling soil erosion

Modelling is currently the best option to generate comparable information on soil loss throughout Europe. At European scale, soil erosion by water has most often been the focus of modelling efforts. Several model approaches such as USLE,[50] the INRA approach[51] or PESERA[52] are available to estimate the extent of soil erosion in Europe. The USLE model (and revised USLE - RUSLE) is extensively cited and used and represents a standardised approach. It has the advantage of necessitating relatively little input data, it is nevertheless known to overestimate regional erosion and

[50] USLE (Universal Soil Loss Equation): 'The USLE is a simple empirical model, based on regression analyses of rates of soil loss from erosion plots in the USA. The model is designed to estimate long-term annual erosion rates on agricultural fields' (Jones et al., 2004).

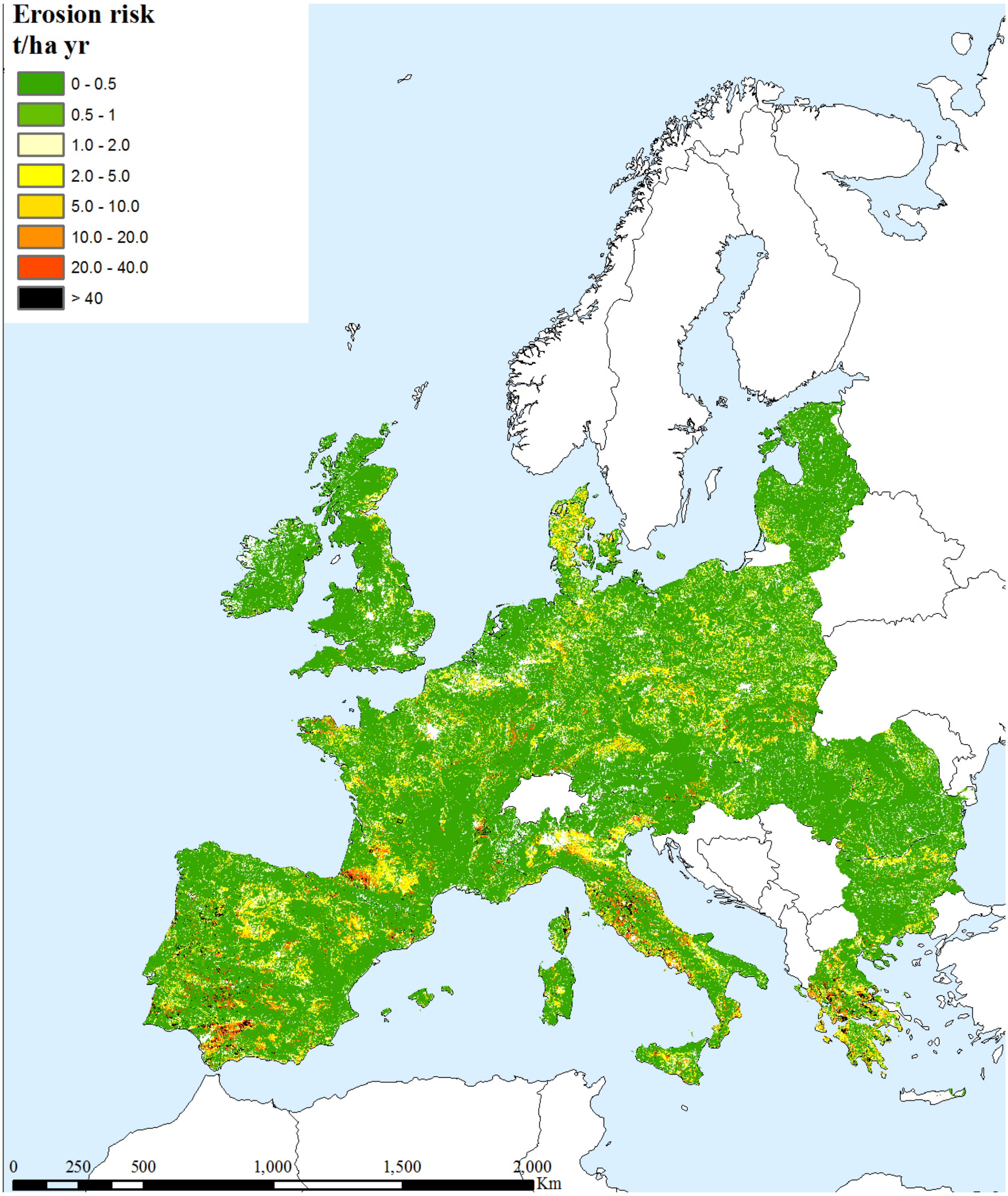
[51] Approach elaborated by INRA (Institut National de la Recherche Agronomique, France). It is an intermediate step towards erosion modelling at the European scale, subsequent to USLE and prior to the PESERA project. (Jones et al., 2004)

[52] PESERA (Pan-European Soil Erosion Risk Assessment) is the most conceptually appropriate model because it takes into account: 1. Runoff and eroded sediments separately, 2. Daily frequency distribution of rainfall, month by month, which allows the model to account for both regular and exceptional events; 3. Dynamics of crusting and vegetation cover month by month; 4. Other climatic information such as freezing days etc., that in part determine for snow effects (Van-Camp et al. 2004)

is not appropriate to predict soil losses on individual parcels or for individual years (rather long term average annual rate of erosion on a field slope) (Huber et al., 2008).

For the time being, the data needs for the indicator on ‘estimated actual soil erosion by water’ in Europe are best met by the PESERA model. This model was developed in the framework of a research project in 2003 and generated a Pan European Soil Erosion Risk Assessment map illustrating modelled soil erosion estimates in t/ha/y at a 1km x 1km resolution. PESERA (Kirkby et al. 2004) provides the only Europe-wide estimates of soil erosion by water that are based on a harmonised approach and standard data sets. It is thus most adapted to regional assessments of soil erosion by water. By applying a common methodology throughout Europe, based on physical understanding, the PESERA model is able to identify major differences between regions and to highlight areas particularly at risk. Due to the fact that PESERA is a physically based model, it provides information on the state of soil erosion at any given time and can support the identification and understanding of links between factors causing erosion. The model is policy relevant as it can assist the assessment of impacts of agricultural policy through scenario analysis for different land use and climate changes (Van Camp, 2004). The results of the model at European scale have been illustrated in the form of a map (Figure 19 below) showing soil erosion risk in t/ha/y.

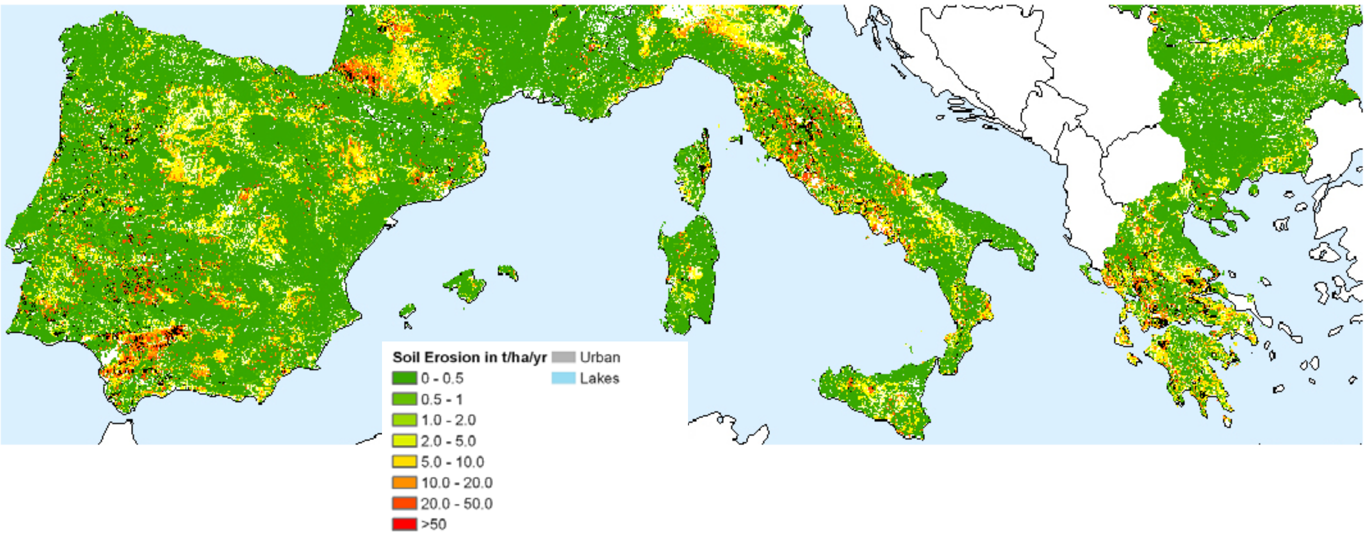
Figure 19 The PESERA map



Source: "Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73)." Kirkby, M.J., Jones, R.J.A., Irvine, B., Gobin, A, Govers, G., Cerdan, O., Van Rompaey, A.J.J., Le Bissonnais, Y., Daroussin, J., King, D., Montanarella, L., Grimm, M., Vieillefont, V., Puigdefabregas, J., Boer, M., Kosmas, C., Yassoglou, N., Tsara, M., Mantel, S., Van Lynden, G.J. and Huting, J.(2004). European Soil Bureau Research Report No.16, EUR 21176, 18pp. and 1 map in ISO B1 format. Office for Official Publications of the European Communities, Luxembourg.

The yellow, orange, red and black areas on the map show where erosion rates by water have already crossed the one ton per ha per year erosion threshold. A focus on Mediterranean regions (Figure 20) clearly shows that these regions are particularly at risk of soil erosion by water and have in many areas reached very critical levels of erosion beyond a threshold of 1 t /ha/year.

Figure 20 The PESERA map – Focus on Mediterranean areas



The following calculations (Table 31) can be made based on the PESERA map data in order to look at the land area at risk of soil erosion by water, for each range of estimated soil erosion, as a percentage of the total Pan-European land area (for a total area of 3,283,993 km^2, not including water and urban areas, glaciers, etc.).[53]

Table 31 Area affected by soil erosion by water according to the PESERA map, in km^2 and in % of total EU surface:

Range of soil erosion by water in t/ha/year	**Area in km^2**	**Percentage with respect to the total EU area**
> 0.5	801 347	24.4 %
<= 1	2 706 529	82.5 %
> 1	**577 464**	**17.5 %**
> 10	103 292	3 %
1<x<2	186 308	5.5 %
2<x<10	287 864	8.7 %

Source: Personal communication with Marc Van Liedekerke, JRC, 30/08/2010

Nevertheless, it should be stressed that the PESERA model also suffers from inconsistencies between estimated results of soil erosion by water in certain geographical areas and measured rates of erosion in these areas (e.g. Po valley, region east of Bayonne, Welsh borderlands, e.a..)[54]. Low resolution and poor quality of input data cause errors and uncertainties. (Van Camp, 2004) There is thus a clear need

[53] Similar area estimates at Member State scale could be derived from the raw data of the PESERA map but could not directly be provided by the JRC.

[54] For more details please see Kirkby et al., 2004.

for increased measurements in order to continue the calibration and validation of the model (which has not been updated since 2003). (See also section 4.3.3. on data availability and uncertainty)

Models have also been developed for soil erosion by wind and tillage and have in some cases been applied at national scales (e.g. RWEQ – Revised universal Wind Erosion Equation, WATEM model). WATEM simulates local erosion and deposition by tillage and water and focuses more on the spatial than on the temporal variability of parameters. Soil loss by water is assessed through an adapted version of the Revised Universal Soil loss equation (RUSLE). The tillage component of WATEM uses a diffusion-type equation whereby the intensity of the tillage process is described by one parameter.[55]

Summary of operational and theoretical indicators of soil erosion pressure in Europe

Based on a desk review, other indicators of soil erosion developed in Europe could be identified. Box 4 gives an overview of the most relevant, theoretical and operational, erosion pressure indicators. These are either also based on the PESERA model or on other models of soil erosion by water e.g. USLE approach. Some of the indicators are based on national measurements or expert judgment or on proxy indicators of soil erosion.

Box 4: Summary of the main indicators of soil erosion pressure developed in Europe

Existing indicators at EU scale:

- Areas at risk of soil erosion (estimate of soil loss due to water, t /ha/year), JRC (PESERA Model) 2004 (see Figure 19)
- Estimated change in water erosion rate for Europe (1990 - 2000), JRC 2007 (see **Error! Reference source not found.**)
- Soil erosion from agricultural land: This indicator quantifies the amount of soil loss per year by erosion from agricultural land in selected countries (t/ha/y) and also, the percentage of the area affected (agricultural and non-agricultural land) by erosion in selected countries in relation to the total area of the country. (EEA, State of the environment report No 3/2003) it is in part based on the results of questionnaires (2002) and on national reports

Theoretical best indicators (see also Table 30 above) showing the range of best practice indicators, based on expert judgement (data is not always available to sufficiently "fill in" these indicators):

1. ENVASSO Top 3 indicators of soil erosion in Europe
   - Estimated soil loss by rill, inter-rill, and sheet erosion
   - Estimated soil loss by wind erosion
   - Estimated soil loss by tillage erosion

2.In their identification of indicators for pan-European assessment and monitoring of soil erosion by water, **Gobin et al. (2004) propose various indicators of erosion** (Proposed indicator, Unit, Data source):

- Gully density, km km^{-2}, verified with LUCAS
- Percentage of area affected by soil erosion per region, % and km^2 , Based on modelled risk analysis (PESERA)
- Extent of total soil loss by soil erosion, t ha^{-1}, Based on modelled risk analysis (PESERA)
- Sediment delivery ratio of selected rivers, t m^{-3} , EuroWaterNet
- Soil depth and water storage capacity, mm and m mm^{-1}, LUCAS, European Soil Database

3. OECD primary agri-environmental indicators on soil erosion.
From the 2008 Environmental Performance of Agriculture in OECD Countries since 1990 (OECD,

[55] https://www.kuleuven.be/geography/frg/modelling/erosion/watemhome/index.htm

2008b):

- Agricultural land area classified as having moderate to severe water erosion risk
- Trends in agricultural land area classified as having moderate to severe water erosion risk
- Agricultural land area classified as having moderate to severe wind erosion risk

Online OECD statistics database[56] (no data available)

- Area of agricultural land affected by water erosion in terms of different classes of erosion
- Total agricultural land area affected by water erosion (Hectares)
  - Tolerable water erosion (<6.0 t $ha^{-1}yr^{-1}$) (Hectares)
  - Low water erosion (6.0-10.9 t $ha^{-1}yr^{-1}$) (Hectares)
  - Moderate water erosion (11.0-21.9 t $ha^{-1}yr^{-1}$) (Hectares)
  - High water erosion (22.0-32.9 t $ha^{-1}yr^{-1}$) (Hectares)
  - Severe water erosion (>33.0 t $ha^{-1}yr^{-1}$) (Hectares)
- Area of agricultural land affected by wind erosion in terms of different classes of erosion
- Total agricultural land area affected by wind erosion (Hectares)
  - Tolerable wind erosion (<6.0 t $ha^{-1}yr^{-1}$) (Hectares)
  - Low wind erosion (6.0-10.9 t $ha^{-1}yr^{-1}$) (Hectares)
  - Moderate wind erosion (11.0-21.9 t $ha^{-1}yr^{-1}$) (Hectares)
  - High wind erosion (22.0-32.9 t $ha^{-1}yr^{-1}$) (Hectares)
  - Severe wind erosion (>33.0 t $ha^{-1}yr^{-1}$) (Hectares)

4. Land at risk of soil erosion (Eurostat sustainable development indicator not yet available)

4.3.3. Data availability and uncertainty

Data availability by type of soil erosion

Soil erosion research has focused traditionally on erosion by water (rill, inter-rill, gully, sheet), as it is the most commonly recognised form of erosion in Europe. Water erosion is thus best documented, with wind erosion a poor second. Over the last ten to 15 years, the focus has broadened to include other important types of erosion, namely tillage erosion, crop harvesting and slope engineering or land levelling. Nevertheless, even for soil loss by water, actual measurements and sampling of soil loss remain too scarce and can suffer from biases. According to Verheijen, ‘thresholds and areas at risk of erosion can be identified and monitored most efficiently through monitoring of basic soil parameters, but in practice even inventories of these basic data are sometimes lacking’ (pers. communication with F. Verheijen, 17/05/2010).

Modelled estimates of soil erosion

The existing European Soil Database[57] can provide a basis to roughly identify the areas most at risk of soil erosion (Van-Camp et al., 2004). This database also serves as an input for the PESERA model which is based on four data sources: the European Soil Database, CORINE land cover, climate data

[56] OECD Statistics database, last accessed 11/10/2010: http://stats.oecd.org/Index.aspx

[57] The soil database is a simplified representation of the diversity and spatial variability of the soil coverage, based on the FAO terminology and refined and adapted to tale in account the specificities of European landscapes. For more information please see http://139.191.1.96/ESDB_Archive/ESDB/index.htm

from the MARS Project and a Digital Elevation Model. Its output is a soil erosion estimate (t/ha/yr) at 1km resolution. Improvements of this model can be made by using better climate data, potentially available from national archives. Moreover, a frequent land cover updating is needed, because changes in land use have a major impact on erosion rates (Kirkby et al. 2004). It is clear that any model also needs quality input data for calibration of the model and in order to validate its estimates. As Robert Jones who was responsible for the JRC's input to the PESERA project puts it, 'the quality of the output of any model is dependent on the quality of the input data'. In his opinion data availability and quality on slopes, land use, land cover, as well as remote sensing accuracy has improved these last years since the PESERA project finished' (pers. Communication, 23/06/2010). As presented by Jones et al. (2004) the following data at European level would be needed in order for models such as PESERA to give satisfactory results:

1. Soil parameter data derived from 1:250,000 scale surveys;
2. Digital elevation model (DEM) at 250m minimum resolution;
3. Climatic data (e.g. precipitation) at 10km x 10km resolution;
4. Land/crop cover data at 250m resolution that are up to date.

The challenge with modelling erosion by wind is finding high resolution meteorological data in order to account for the important variable of wind speed but also data related to field dimensions and field boundary characteristics. The WATEM model for tillage erosion has been applied locally and could be applied at EU scale using similar datasets as the ones needed for soil erosion by water but requires curvature data for slopes of higher resolution than 1km. An additional impediment is the lack of spatial data on management parameters (tillage and cultivation practice, directionality, speed etc.) (Huber et al., 2008).

Concerning the status of estimation of soil erosion at national levels, in 2004, Jones et al. presented the following information (Table 31) on data availability and used approaches.

Table 32 Assessment of erosion: use of models and observation at national level (2004)

Country	Model	Observat.	Other	Soil	Land use	Topography	Climate
Albania	?						
Austria	USLE			1:50,000	250m	250m	commune
Belgium	RUSLE	Regional		1:25,000	250m	20m	
Bosnia Herz.	?						
Bulgaria	USLE			?	?	?	?
Croatia	?						
Cyprus	?						
Czech Rep.	USLE	Regional		1:200,000	100m	1:25,000	1:50,000
Denmark	?						
Estonia	?						
Finland	USLE	Regional					
France	National	Regional		1:1,000,000			
Germany	National	Regional	wind	1:1,000,000		High resol.	?
Greece	?						
Hungary	USLE			1:100,000	100m	1:100,000	?
Iceland	?						
Ireland	N						
Italy	USLE			1:250,000	100m	250m	366 stns
Latvia	?						
Lithuania	?						
Luxembourg	?						
Mace-FYROM	?						
Malta	?						
Montenegro	?						
Norway	USLE	National		?	?	?	?
Poland	?						
Portugal	?						
Romania	USLE						
Serbia	?						
Slovakia	USLE	National		1:500,000	250m	High resol.	1:5,000
Slovenia	?						
Spain	USLE	National		1:1,000,000	?	?	?
Sweden	?						
Switzerland	USLE			?	?	?	?
The Netherlands	?						
United Kingdom	N	National		1:250,000	1:250,000	?	5km

Legend	USLE	Universal Soil Loss Equation
	National	National models
	Observation	Survey by experts, regional and national
	?	Not Known
	N	Not used

Measured data on soil erosion

Quantitative measurement data of actual erosion rates and soil formation rates is used to calibrate the models. Such measurements however are carried out sporadically throughout Europe and usually take place at experimental research sites, where research groups have been able to install equipment to make regular measurements. So far only few good quality long-term erosion data sets have been collected. Some Member States have established soil monitoring networks, for which methodology and coverage vary considerably. The present geographical coverage is very heterogeneous between and within countries. National and regional networks are much denser in northern and eastern parts of Europe than in southern countries. In order to validate estimated soil losses obtained from models in the future, fully instrumented measuring sites in the main agro-ecological zones of Europe should progressively be established (or re-established) (Eckelmann et al. 2006). Recommendations of the European research project RAMSOIL (Risk Assessment Methodologies for Soil threats) highlight that a minimum density of sites should be achieved over Europe with a present median density of 1 site per 300 km². This density enables almost all the soil type and land use combinations in Europe to be covered. On this subject Robert Jones, who was involved in the PESERA and ENVASSO projects, recommended establishing at the very least a network of benchmark erosion monitoring sites across the EU. ‘Approximately 10 sites per Member State or even 100 across the EU would be the absolute minimum needed to obtain the necessary monitoring and data gathering. Existing sites (appr. 50-60 in the EU) have no standardised approach nor have they operated over the same timescale' (R. Jones, pers. Communication, 23/06/2010). The additional challenge to be addressed thus concerns the harmonisation of soil monitoring networks, which would require a common minimum set of mandatory parameters which are systematically measured (at least once) or monitored (with different frequencies). Moreover, analytical techniques must be harmonised, for example, by combining several techniques, on all samples or on a subset of samples, to ensure data comparability over time and between Member States.

Currently, an exercise has been started through EIONET[58] to collect data for soil erosion and soil organic carbon directly from Member States on a voluntary basis. This should allow an update and improvement of modelled data at European level, (Pers. communication with Marc Van Liedekerke, JRC, 30/08/2010)

In conclusion, measurements and monitoring of soil erosion trends across Europe are not sufficiently developed. Local and regional modeling data of soil erosion exist (mainly for water but in some cases also for tillage and wind erosion), these are most often based on the USLE and RUSLE models or on expert judgment.. In the context of this study the PESERA model of water erosion is the most relevant model available as it is able to identify major differences between regions and to highlight areas particularly at risk, allowing regional and national comparisons at EU scale. Due to the fact that PESERA is a physically based model, it provides information on the state of soil erosion at any given time and can support the identification and understanding of links between factors causing erosion. Nevertheless, as PESERA estimates result from a 2003 research project they can be further improved especially through updated datasets (e.g. with CLC 2006) and calibration through actual erosion measurements.

Uncertainty

Both land use and soil system relationships are complex, 'with feedbacks providing different meta-stable situations and non-linear, sometimes delayed, responses to change. This implies that some changes in external conditions may not cause a perceptible change in the soil condition, while others may cause acute, or gradual, degradation or improvement' (FAO et al., 1997). Thresholds in these areas are thus often surrounded by a large uncertainty zone and have a very local component.

It should be emphasised that uncertainty in the context of defining threshold values for soil erosion is also related to a high extent to normative frameworks. It is in other words related to a societal and economic definition of what can be interpreted as tolerable erosion. In view of the very close relation that exists between erosion rates and land use and agricultural production, the issue of setting and respecting tolerable rates of erosion is very much dependent on the recognition and commitment of certain key pressure sectors.

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[58] European Environment Information and Observation Network: a partnership network of the European Environment Agency (EEA) and its member and cooperating countries involving experts and national institutions. The network supports the collection and organisation of data and the development and dissemination of information concerning Europe's environment. see http://www.eionet.europa.eu/

Finally, expert statements have stressed the sensitivity and thus the uncertainty related to calculated estimates due to variations that can be observed in soil erosion estimates depending on the scale or resolution of the input data. (Communication with Markus Erhard, EEA)

As highlighted above, the uncertainty that surrounds a threshold indicator on tolerable soil erosion rates is strongly related to the data availability, measurement and monitoring of soil formation and soil loss across regional differences, contributing factors and parameters and combinations and effects of soil erosion types. The main factors of uncertainty and their ways of remediation can be summarised as follows:

- Soil formation processes, and identifying which factors are part of these, for example, dust deposition and mineral weathering, are still very much uncertain. More research is needed here even though several models have already confirmed the order of magnitude of soil formation rates. These are key to establishing tolerable erosion rates in accordance with the conservation of the soil mass balance.

- More research on how soil functions can be affected by accelerated soil loss and on the off-site impacts of soil erosion could contribute to a qualitative understanding of "tolerable" erosion rates.

- The challenge of scaling and extrapolation: Due to the difficulty in erosion research to define 'scaling rules' and to extrapolate erosion measurements. As long as the scaling issue is not solved, Verheijen et al. (2009) recommend continuing collecting data at the various possible temporal and spatial scales, representative of environmental as well as land use and soil management factors.

- Harmonised monitoring methods should be established and soil erosion parameters should be tested more systematically in order to identify and flag risk areas. Measurements are needed to validate and calibrate erosion risk estimates based on modelling. (see recommendations on monitoring network above)

- More accurate and spatially differentiated data on the different types of erosion (water, wind and translocation) is needed to generate a better understanding of actual total soil erosion rates and need for action.

- Effect of climate change on soil erosion and soil formation rates need to be researched.

4.3.4. Suggested threshold indicators

In the context of this study the choice of a threshold indicator depends on various aspects: its feasibility (depending mainly on existing data and estimates), its relevance to policy in terms of its causal link to human activities and of the importance and recurrence of the pressure across Europe.

Most estimates, measurements and risk assessments are related to soil erosion by water as this is the most widespread and severe form of erosion in Europe. Tillage erosion is also highly relevant in the context of this study, given that soil erosion by tillage is entirely caused by anthropogenic activity. Its drivers and pressures can thus be more easily delimited and could be better targeted by policy makers. However, and as is the case for soil erosion by wind, measured information on tillage erosion is still scarce and not carried out systematically.

For these reasons the main threshold indicator suggested here for soil erosion combines a European mean threshold value of 1 t/ha/year with an indicator of soil erosion by water (estimated soil loss by rill, inter-rill, and sheet erosion). As water erosion is the most common and widespread cause of soil loss in Europe this indicator represents the most useful and extensively applicable threshold indicator of soil erosion. The data needed to develop the proposed threshold indicator for water erosion are already available through the output of the PESERA model (assessment of soil erosion by water in t/ha/year). Estimates are available at a 1kmX1km scale but should be updated and the model should further be validated via comparison with actual measurements.

In order to also acknowledge the importance of other types of erosion when assessing total soil erosion as compared to a threshold value, the main threshold indicator of erosion by water could potentially be complemented with assessments of soil loss through tillage and wind erosion in areas where these agents of erosion play an important role. (See section 3.7.2 on geographical occurrence of soil erosion).[59] The indicator could then reflect added up estimates of water and tillage erosion (and wind erosion) vs. a mean threshold value of 1 t/ha/year (see complemented threshold indicator in Table 33 below)

Table 33 Actual soil erosion by water vs. Tolerable soil erosion rate

	Estimated soil erosion by water vs. Tolerable soil erosion rate	
	Estimated soil loss by rill, inter-rill, and sheet erosion	Tolerable rate of soil erosion
Unit of measurement	t/ha/y	t/ha/y⁻
Data source/s	Modelled risk assessment (PESERA). Based on the European Soil Database, CORINE land cover, climate data from the MARS Project and a Digital Elevation Model.	European mean threshold value of 1 t/ha/y
Temporal coverage	Oct 2003 (PESERA map) 1990-2000 available (Estimated change in erosion rate) Needed: yearly rate of erosion	Tolerable rate is defined on a time scale of 50 to 100 years
Geographical coverage	EU	Can be applied across EU as a reference value
Update of data	Last updated in October 2003 in the framework of the PESERA FP5 project. Data from CLC 2000 have been used to update the model in 2007 in order to develop a map of estimated change in erosion rate between 1990 and 2000.	Not applicable
Access to data (free/fee)	Free	Not applicable
Links / references	Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73): http://eusoils.jrc.ec.europa.eu/ESDB_Archive/pesera/pesera_data.html Selvaradjou, S-K., Montanarella, L., and Panagos, P. 2007. Estimated Change in Erosion Rate for Europe (1990 - 2000) : http://eusoils.jrc.ec.europa.eu/esdb_archive/pesera/CER.html	Verheijen et al., 2009; Huber et al., 2008; Jones et al., 2005 & 2004; EEA 1999

[59] Tillage erosion is confined to land that is periodically cultivated for growing arable crops and wind erosion is generally confined to areas that have light textured soil that is bare of vegetation and dry when strong winds commonly blow. The location of land that is regularly cultivated is generally well known and the areas susceptible to wind can readily be identified and are not extensive in Europe.

4.3.5. Advantages and disadvantages of the suggested threshold indicator

The indicator of "Estimated soil loss by water (rill, inter-rill, and sheet erosion) vs. Tolerable soil erosion rate" is feasible due to the availability of modelled estimates at the relevant EU scale and representative of the main erosion threat across the EU.

Nevertheless, to obtain a more accurate and complete picture of approaching the soil erosion threshold in particular areas of Europe, a combined indicator, which would also take into account soil losses by tillage (and wind), would be sensible. More information on the role of tillage erosion in reaching a soil erosion threshold could significantly help policy makers at better targeting the most damaging soil management practices causing tillage, crop harvest and land levelling erosion and bring it above tolerable levels. The advantages and disadvantages of adding up further estimates of tillage and wind erosion to the proposed threshold indicator of erosion by water are presented in the table below. However in the context of this study 'Estimated soil loss by water erosion vs. Tolerable soil erosion rate' remains the main proposed threshold indicator due to its relevance and applicability throughout Europe.

As regards the reference value of tolerable erosion (erosion threshold), further specification of regionally or locally defined levels of tolerance would be helpful in obtaining a more nuanced picture. These regional levels of tolerance could reflect regional differences in soil formation rates, regional preference and societal prioritisation of land use (see site specific assessments as presented by Dorren et al., 2004 in box 3 above) and local vulnerability due to site-specific conditions. This latter aspect is however already integrated in a model such as PESERA for the assessment of areas at risk of water erosion.

Table 34 Advantages and disadvantages of suggested threshold indicator for soil erosion

	Estimated soil loss by water (rill, inter-rill, and sheet) erosion vs. Tolerable soil erosion rate	**Complementary indicator: Total estimated soil loss by water, tillage and wind erosion vs. Tolerable soil erosion rate**
Advantages	Huber et al., 2008 (ENVASSO): • Accurate estimates of soil loss can be obtained from erosion models that already exist, for example: PESERA (Kirkby et al. 2004); USLE (Wischmeier and Smith, 1978); RUSLE (Renard et al., 1997); Morgan et al. (1984) and Morgan (2001). • These estimates exist for the whole of Europe. • PESERA can offer quantitative information (at a 1km resolution).	• In areas also subject to tillage or wind erosion the estimate of the total pressure would better reflect actual erosion. Huber et al., 2008 (ENVASSO): • Models that estimate soil loss from tillage operations are available (e.g. Govers et al., 1996, Van Oost et al., 2000). • Accurate estimates of soil loss by wind are needed to implement soil protection measures and these can be obtained from existing wind erosion models (Quine et al., 2006). • The processes leading to wind erosion are well researched and understood.
	A generally accepted benchmark for tolerable rate of erosion is 1 t/ha/year	
Disadvantages	Huber et al., 2008 (ENVASSO): • Rill, inter-rill, and sheet erosion is difficult to estimate because of the complexity of erosion	• Challenge of adding up estimates or of integrating all types of erosion in one model that can be applied at EU scale – reduced feasibility.

	processes involved and a lack of sufficiently accurate data. • Gully erosion is not estimated – there is no reliable method or model for estimating soil erosion by gully erosion. • Modelling errors contribute to uncertainty of estimated values. • Very few sites exist in Europe where water erosion has been measured systematically enough to provide sufficient data for model calibration and validation.	Huber et al., 2008 (ENVASSO): • As for water erosion by rill, inter-rill and sheet erosion, it is not (nor may it ever be) practicable to measure wind erosion and tillage erosion everywhere in Europe where agriculture is practiced • Tillage and wind erosion are even more difficult to estimate than water erosion and modelling errors are potentially significant. • Application of this indicator will depend on detailed data on tillage equipment and techniques employed, information which is widely lacking at the required scale for Europe. • There are far fewer data on wind strength and direction in Europe than there are rainfall data, which contributes further to the uncertainty of model estimates. • Wind erosion has been measured at even fewer sites in Europe than water erosion.
	Difficulty of establishing tolerable rate of erosion due to localised differences and realistically due to socio-economic pressure. A regionally or locally based set of tolerable rates of erosion across the EU is not available.	

4.3.6. Interpretation and use of threshold indicators

The establishment of the proposed water erosion threshold indicator, (modelled at five years intervals using updated climatic and land cover data (Huber et al., 2008) and calibrated with harmonised measurement data generated by a soil monitoring network and based on risk estimates), could on the one hand inform decision makers and practitioners at the appropriate governance level of the need to take action to combat erosion trends. On the other hand, through measurement of actual erosion rates, it would enable a better identification and targeting of key land management practices that have proved to reduce the risk of soil erosion by water.

The establishment of a monitoring infrastructure for measurements of soil erosion by water could also positively affect the further development of erosion models based on harmonised data input, standards and methods to be applied at a European scale.

In the broader context of the political debates on the upcoming CAP reform (beyond 2013) and on new commitments on biodiversity targets post-2010, but more particularly also on the proposal for a Directive on Soil Protection, the proposal of a threshold indicator of soil erosion by water could influence the policy process by anchoring soil erosion in the wider scientific discussion on planetary boundaries and limits to the use of natural resources. The high policy relevance of establishing a threshold indicator of soil erosion could also help stressing the relative efforts needed to adequately monitor the progress towards a soil erosion threshold.

In the new settings of the above-mentioned policy areas and depending on the priority that will be given to tackling soil degradation issues in the new EU policy frameworks, the proposed indicator could play a key role through the quantification and geographic localisation of the urgency and severity related to crossing tolerable rates of erosion as shown by erosion risk estimates. Acceptable levels of erosion would need to be adapted to local contexts, but at first it is necessary to set a reference limit value across the EU and to improve the knowledge that enables to follow erosion trends and to efficiently target policy measures at areas that have crossed tolerable levels of erosion. Based on a more accurate understanding of erosion trends, risk areas and local threshold values, the damage and cost of crossing a threshold could be better quantified in order to raise awareness of the economic consequences of crossing a soil erosion threshold.

4.3.7. Conclusions and recommendations

The accelerated loss or displacement of soil material due to land use and land management practices, mainly intensive agriculture, is an increasing problem in Europe. As soil formation is a very slow process, on a human time scale, the loss of soil is often an irreversible process. Recent research (Verheijen et al., 2009) leads to the conclusion that overall soil formation ranges from ca. 0.3 to 1.4 t /ha/ year. Therefore accepting a threshold of 1 t/ha/y, i.e. above the estimated average rate of soil formation, can critically be interpreted as a rather pragmatic approach to soil protection in order also to maintain current demand for soil productivity in Europe, e.g. food production.

The most widespread and severe form of soil loss across Europe is soil erosion by water; this is why the main erosion threshold indicator proposed addresses estimated erosion rates by water. Other agents of soil loss, namely tillage, root crop harvesting, land levelling and wind can nevertheless also play an import part in soil erosion processes in some regions of Europe. In the future these types of erosion and their interaction with water erosion should thus also be considered and novel ways of estimating their combined effect should be explored.

Currently, systematically measured and harmonised data on soil losses (for all agents of erosion) across the EU Member States are not available. Estimates, derived through modelling, are thus the best means available to determine which land areas are at risk of reaching intolerable rates of erosion. Various erosion models have been applied at local and regional levels but do not provide an adequate basis of analysis and comparison of erosion rates across regions and Member States. The PESERA model (2003) offers the only Europe-wide estimates of soil erosion by water that are based on a harmonised approach and standard data sets. However, there is still clearly a need for increased measurements to continue the calibration and validation of the model. Additionally, in some regions that are prone to tillage and wind erosion as well, it is necessary to consider these agents of erosion and to add up their estimates in order to obtain an accurate and complete estimate of the soil erosion state as compared to the threshold.

The development of the suggested threshold indicator should thus be considered within the framework of these remarks and could significantly be improved through the following recommendations:

1. Establishing a network of benchmark erosion monitoring sites across the EU to provide measured data to calibrate and validate existing models of soil erosion throughout Europe. Approximately ten sites per EU Member State would be a minimum to obtain the necessary monitoring and data gathering, but even 100 sites across the EU would be an improvement from the current situation. (R.Jones, Pers. Communication, 23/06/2010). Tillage erosion measurements can be targeted at intensively cultivated area with sensitive topographic characteristics and wind erosion measurement to areas with light textured bare soils where dry strong winds blow. Water erosion monitoring sites, on the other hand, should be established without such restrictions due to its more widespread occurrence. As it is not (nor may it ever be) practicable to measure erosion everywhere in Europe, modelled estimates of soil erosion are still an extremely valuable tool. Currently the improved availability of

measured data of soil erosion is nevertheless an important precondition for the further development and validation of models.

2. To refine the use of the threshold indicator and to adapt it to local or regional specificities more research is needed on variations in threshold levels, i.e. tolerable rate of erosion in function of soil formation rates and affected soil functions, at local and regional scales. It also needs to be considered that to adequately interpret the information that can be provided through the threshold indicator it has to be connected to information on the geographical distribution of human activities. This does not only include land cover and land use information but also, and more challenging, information on agricultural and land management practices.

4.4 Non-renewable resources

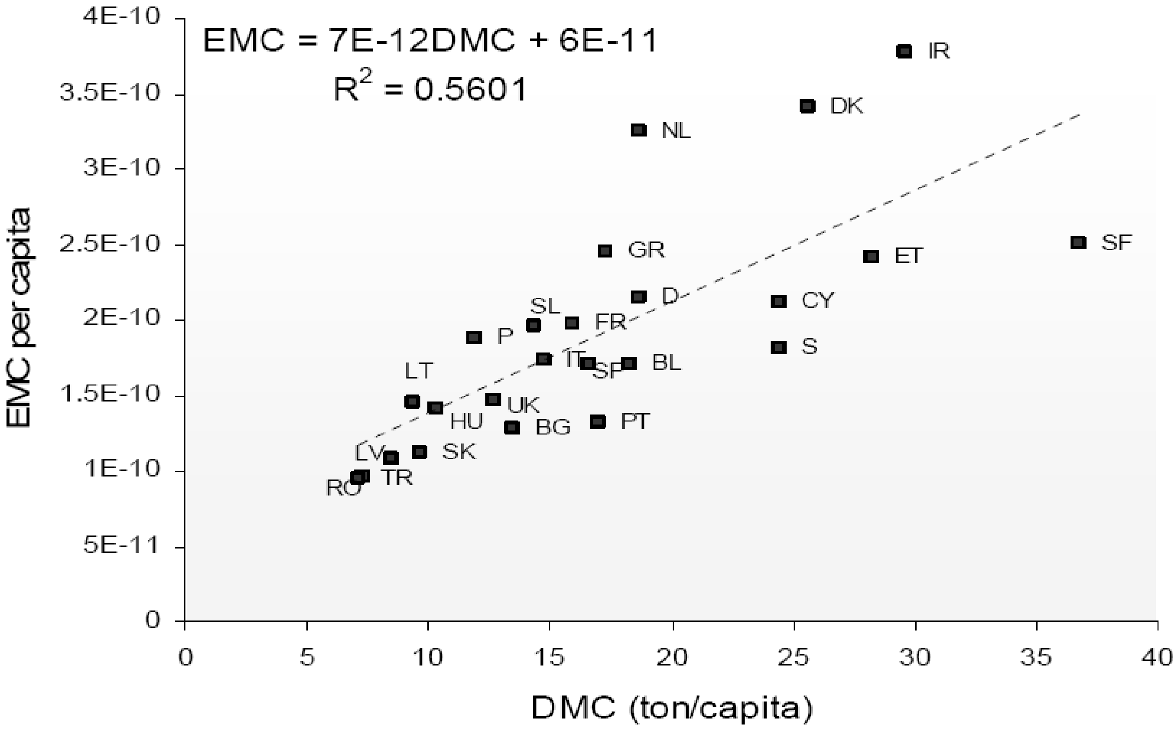
4.4.1. Material flow-based indicators and environmental impact thresholds

In the past few years, progress has been made towards calculating indicators which include the different potential of environmental harm exerted by different materials (i.e. one ton of sand has a different environmental profile than one ton of uranium). As the previous environmental threshold areas (4.1-4.3) have shown, environmentally unsustainable trends (e.g. in water quality and quantity) are often rooted in the (over-)use of specific non-renewable resources and their environmental impacts.

The most prominent approach to capture those impacts is the indicator "Environmentally Weighted Material Consumption" (EMC), developed by CML Institute at Leiden University, The Netherlands (van der Voet et al., 2009; van der Voet et al., 2005). The EMC was developed in order to allow tracking the contribution of different materials to environmental problems. Thereby, following the concept to multiply data on raw material and energy use with a factor representing their environmental impact, information on environmental impacts per mass unit is combined with information on the mass of material flows. This environmental impact information is derived from life cycle assessment (LCA) data sets, such as the Ecoinvent database (Frischknecht et al., 2007). The contribution of each material to environmental problems throughout its life cycle can thereby be estimated. The EMC covers a number of different environmental impacts, including climate change, ozone depletion, human health impacts, eco-toxicity, acidification, eutrophication and ionizing radiation. The results of EMC are expressed in relative terms, i.e. illustrating the contribution of single materials to the total global impact of all materials. In the EMC, no relations to possible threshold values of the different environmental impacts categories are provided.

Figure 21 illustrates the correlation between DMC per capita, i.e. the mass-based indicator, and EMC per capita for selected European countries in the year 2000.

Figure 21 Correlation between DMC per capita and EMC per capita (year 2000)



Source: Van der Voet et al. (2005)

The figure illustrates that around 56% of the changes in EMC can be explained by changes in DMC. It therefore shows that for around half of the EU countries, looking at DMC provides a useful proxy for the overall negative environmental impacts resulting from quantitative resource use. The correlation is very different for different countries. Countries with a high share of low-impact resources (e.g. products from forestry) in total resource use, such as Finland (SF), have a lower overall impact than expected from the DMC numbers, countries with very resource-intensive industries (such as the dairy industry in Ireland, IR) have higher impacts than expected from the absolute numbers of DMC.

Another impact-oriented indicator is the so-called “Environmental Impact Load” (EVIL), proposed and developed by IFEU institute in Heidelberg, Germany (IFEU, 2006a). The EVIL indicator is oriented at the approach of “ecological scarcities” and “critical loads“. EVIL relates the actual emissions stemming from to use of non-renewable resources to politically derived target values for these emissions. For example, 250 million tonnes of CO_2 equivalents are regarded as the amount of greenhouse gases that can be emitted by Germany (as a share of world wide emissions), in order to guarantee that global warming does not exceed 2° Celsius. This implies that 250 million tonnes of CO_2 equivalents equal 1 EVIL. If Germany emits more CO_2 equivalents, the critical load of 1 EVIL is surpassed. Following this approach, EVILs can be calculated for several environmental impacts: climate change, human health impacts, eco-toxicity, photo-oxidant formation and eutrophication. The main weakness of this method and indicator is that it has only been proposed recently and is still under development, even for Germany. This makes it unlikely that EVIL can be used in the near future in the European context.

Despite the plethora of available indicators and approaches to measure and monitor resource use (such as the DMI and DMC) and its environmental consequences (such as the EMC and EVIL) and despite evidence of the fact that human resource use has surpassed a level that the planet’s biocapacity can sustain, there are no rigorously and scientifically established suggestions as to the overall levels of non-renewable resource use that may be sustained.

Therefore, in order to derive threshold-type indicators for non-renewable resource use, we suggest using a proxy approach which would link current amounts of non-renewable resource use with negative environmental impacts that show threshold phenomena. We thus follow a similar approach as the one taken in EVIL, but scaling it up to the European scale. This would allow determining a maximum level of non-renewable resource use in terms of maximum levels of the related negative environmental impacts resulting from the extraction, processing and use of these non-renewable resources on the economy-wide level. Indeed, only the impacts occurring from resource use – in particular the outputs of waste, waste water and emissions – are those that can be addressed through a threshold perspective.

Our approach is to evaluate current levels of non-renewable resource use from the perspective of the state of environmental media, which are burdened by outputs (emissions, waste water, solid waste) stemming from non-renewable resource use. Environmental media include soil, water, atmosphere and biota. We decided to select the media of the atmosphere as an example for this study, as we need to select those outputs for which both emission data and related environmental threshold values are already available. As the chapters on soil and water in this report illustrate, no thresholds have so far been defined for those two types of environmental media for the EU or EU member states. For air emissions, thresholds and maximum emission levels have been defined for GHG emissions (see example of EVIL above). However, GHG emissions are not within the scope of this study as they have already been quite extensively studied elsewhere. Thresholds for other air emissions so far only exist for four types of emissions, which are reported under the National Emission Ceilings Directive (NECD): SO_2, NO_x, NH_3, and NMVOC. These four emissions are evaluated by the EEA in terms of their distance to the national target set under the NEC Directive (according to the 2009 NEC Directive status report, many EU countries exceeded their ceilings). Therefore, we selected those four types of air emissions to test the suitability of the suggested proxy indicator for non-renewable resource use.

4.4.2. Data availability

Regarding non-renewable resource use, data availability is in general good throughout the EU-27. Data for the DMC indicator is available in annual time series (from 2000) from the online database of EUROSTAT, and the non-renewable share of DMC can easily be calculated from available DMC numbers by material group. Therefore, the threshold indicator suggested for the theme of non-renewable resources is based on the DMC (non-renewable) data. Uncertainty in DMC arise in particular from the fact that DMC data has only been collected and reported by the national statistical offices since 2007, and many of these offices, in particular in Southern and Eastern Europe, do not yet have experiences with this type of data collection. It can be expected that data will be improved and revised in the coming years.

Data on SO_2, NO_x, NH_3, and NMVOC emissions in the EU are available for all 27 Member States since 2006. Under the National Emission Ceilings Directive (NECD), Member States must formally submit only two years of emissions data. This prevents any robust assessment of long-term emission trends (either within individual Member States or for the EU-27 as a whole) on the basis of data submitted under NECD. Nevertheless, a number of Member States do submit revised emissions data for the years back to 1990. The available data show that there has been a decrease in emissions of the four NECD pollutants (SO_2, NO_x, NH_3, and NMVOC) in most Member States. Several Member States have already reduced emissions to meet the requirements of NECD. A more complete picture of past emission trends in the European Community is provided by the European Community's emissions inventory submission to the United Nations Economic Commission for Europe (UNECE) pursuant to its Long-Range Transboundary Air Pollution (LRTAP) Convention.

Table 35 summarises the availability of data for the two datasets required to calculate the suggested proxy threshold indicator for non-renewable resource use.

Table 35 Data availability for the threshold indicator on non-renewable resource use

$DMC_{non\text{-}renewable}$ per capita in relation to SO_2, NO_x, NH_3, and NMVOC emissions		
	$DMC_{non\text{-}renewable}$ per capita	Emissions plus emission ceilings for SO_2, NO_x, NH_3, and NMVOC emissions
Unit of measurement	1000 tonnes	Emissions: 1000 tonnes National emission ceilings: 1000 tonnes
Data source/s	EUROSTAT	European Environment Agency (EEA)
Temporal coverage	2000-2008	Emission trends of Member States: 2006-2009 (for some countries back to 1990)
Geographical coverage	EU-27 countries plus Norway and Switzerland	EU-27
Update of data	Biannually	Every year
Access to data (free/fee)	Free	Free
Links / references	EUROSTAT Material Flow Accounts: http://nui.epp.eurostat.ec.europa.eu/nui/show.do?dataset=env_ac_mfa&lang=en	European Environment Agency (2010): Air pollutant emissions data viewer (NEC Directive): http://dataservice.eea.europa.eu/PivotApp/pivot.aspx?pivotid=468

4.4.3. Suggested proxy threshold indicator for non-renewable resource use and illustrative example

In order to assess whether a specific quantity of per capita non-renewable resource use is causing emissions below or above their emission ceiling in a specific country, we suggest comparing the DMC per capita (from the material flow accounts) with the indicator distance-to-NECD emissions target (from the air emissions data). As explained above, this suggested approach follows the concept of the EVIL indicator, however, using data which allow calculations of this indicator across all EU countries.

Illustrating this relationship in graphical form may look as follows: the bars representing $DMC_{non\text{-}renewable}$ per capita in a country is illustrated in a specific colour, which indicates whether the national emission ceiling has or has not been reached in this country. In the example illustrated below, a green $DMC_{non\text{-}renewable}$ per capita bar means that the specific air emissions generated by the amount of non-renewable resource use in the country are below the national emission ceiling. A red bar indicates that the $DMC_{non\text{-}renewable}$ per capita causes emissions higher than the national ceiling.

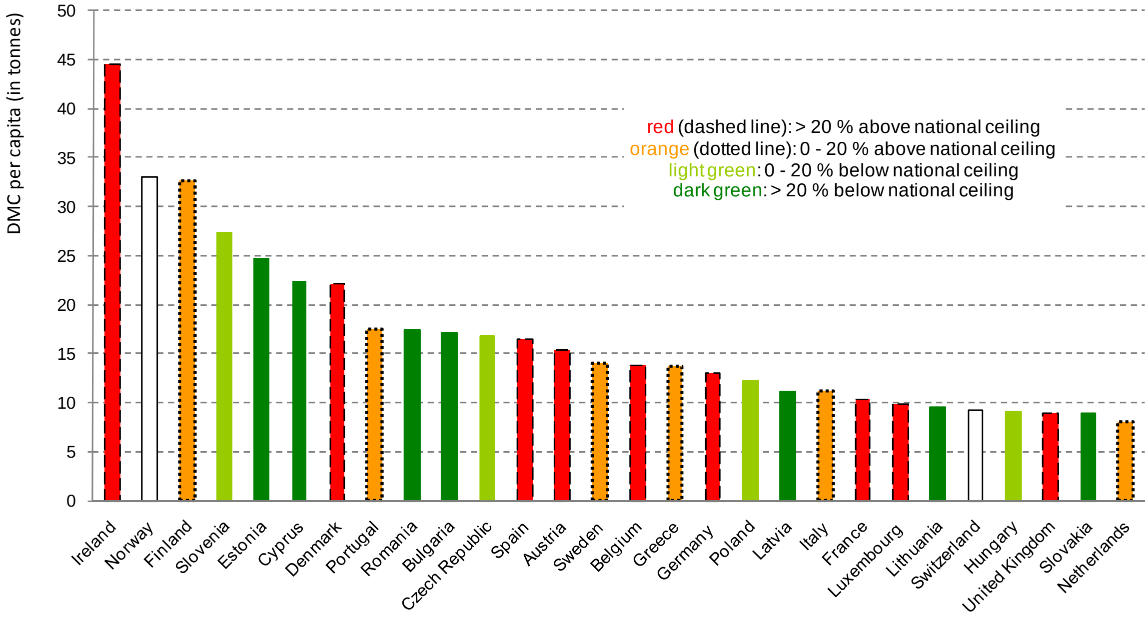
In the following, we provide illustrative examples for the suggested proxy threshold indicator for non-renewable resources. As explained above, the underlying data sources are the MFA data provided by EUROSTAT and the data on the actual emissions and emission ceilings as reported by the EEA.

For the illustrative example below, we select the case of NO_x from the four types of emissions, for which such calculations can currently be carried out (SO_2, NO_x, NH_3, and NMVOC). The selection was based on the fact that, according to the Thematic Strategy on air pollution, NO_x is the only of the four pollutants which contribute to all four categories of air quality: acidification (through the deposition of NO_x in freshwater and terrestrial ecosystems), eutrophication (through excessing the supply with nitrogen in ecosystems), ozone formation (being an important precursor substance to form tropospheric ozone) and particulate matter, which are chemically formed from NO_x emissions (see European Commission, 2005a). The following graphs thus evaluate the $DMC_{non\text{-}renewable}$ per capita data from the perspective of NO_x emissions. To complete the pilot calculations, we include graphs for the other three categories in the Annex.

The height of the bars illustrates the DMC (non-renewable) per capita numbers. The colour of the bars illustrate whether this DMC per capita causes emissions which are below or above the national emission ceiling:

- Red means that the emissions caused by per capita non-renewable resource use in the specific country are more than 20% above the national emission ceiling
- Orange means that emissions are between 0% and 20% above the ceiling.
- Light green illustrates that emissions are 0% to 20% below the emission ceiling.
- Dark green illustrates that emissions are more than 20% below the ceiling.
- Bars in white mean that no emission data was available for the country.

Figure 22 DMC (non-renewable) per capita in relation to national NOx emissions (2007)



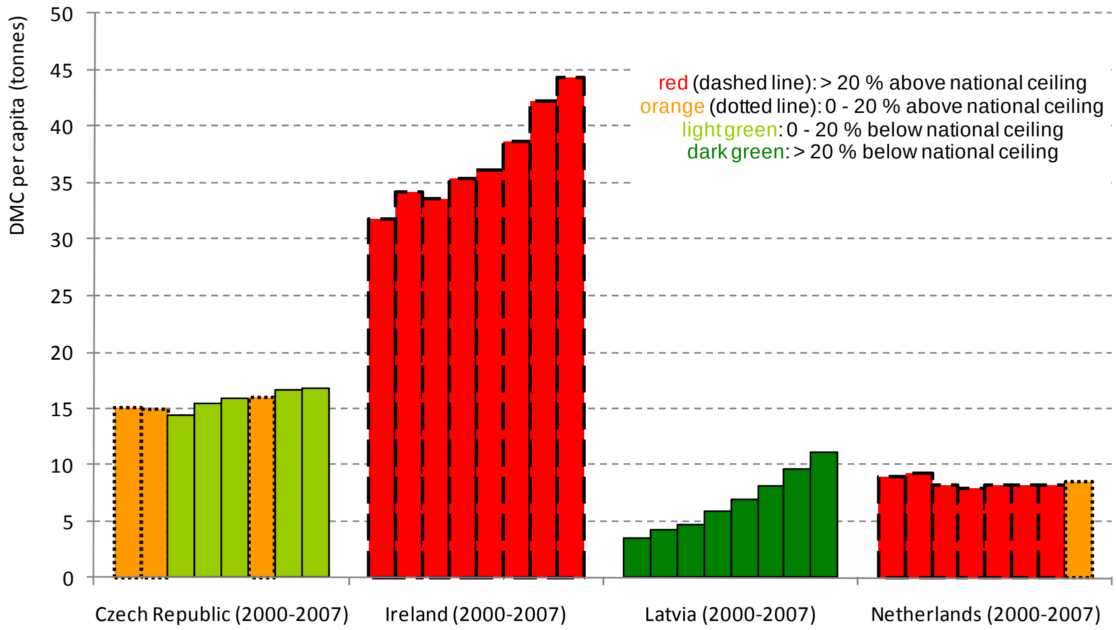
Source: own calculations based on EUROSTAT MFA data and EEA emission data

The figure illustrates that a large variety can be observed between different EU countries regarding NO_x emissions resulting from non-renewable resource use. Countries with very different levels of per capita DMC (non-renewable) are either emitting above or below national ceiling levels. For example, Ireland, with the highest DMC per capita level, emits almost 60% above the national emissions ceiling. On the other hand, Estonia, which also has high DMC (non-renewable) per capita, emits 43% below the national emission ceiling. Within the group of countries with the lowest DMC (non-renewable) per capita numbers, countries also perform very differently.

As illustrated in section 4.4.1 above, a correlation between DMC per capita and the overall environmental impacts per capita measured in terms of EMC can be observed for some EU countries, although with $R^2 = 0.56$, the overall correlation is not strong (see the detailed analysis in van der Voet et al., 2005). However, as Figure 22 above illustrates, the absolute amounts of per capita resource consumption provide no direct and linear indication whether or not a country is reaching its emission ceiling for NO_x (also for the other three types of air emissions, a similar picture is obtained, see illustrations in Annex 2).

In order to further test the suggested approach, we analyse time series for four selected countries which have different levels of per capita DMC and perform differently regarding their emission ceilings for NO_x.

Figure 23 DMC (non-renewable) per capita in relation to national NO_x emissions for four selected countries (2000-2007)



Source: own calculations based on EUROSTAT MFA data and EEA emission data

The four selected example countries show very different patterns. DMC (non-renewable) per capita has significantly increased in both Ireland and Latvia, and in both countries this change has not affected their performance regarding the NO_x emission ceiling. While Ireland reduced its NO_x emissions from around 140 ktonnes in 2000 to around 120 ktonnes in 2007, it is still far above the national emission ceiling (65 ktonnes). Latvia also had a steep increase in non-renewable resource consumption, in particular due to higher consumption of industrial and construction minerals. However, with emissions at around 40 ktonnes, Latvia is still far below its emission ceiling (61 ktonnes). DMC (non-renewable) was rather stable in both the Czech Republic and the Netherlands, but with a lower DMC (non-renewable), the Netherlands surpassed their NO_x emissions ceilings, whereas the Czech Republic, with emissions between 281 and 291 ktonnes, was meeting its emission ceiling (286 ktonnes).

The analysis of specific countries in a time series confirms that no linear relation can be observed between NO_x thresholds (using emissions ceilings as a proxy for NO_x thresholds) and per capita non-renewable DMC levels.

While on the aggregated level of all environmental impacts from resource use correlations of mass an impacts can at least to some extent be observed (van der Voet et al., 2005), the results presented here confirm the fact that a clear link between overall non-renewable resource use and specific environmental impacts (such as air pollution) does not exist. Possible reasons for this missing link are further explained in the "limitations" chapter below.

4.4.4. Limitations of the approach, summary of the advantages and disadvantages of the suggested proxy threshold indicator

While the basic data on resource use quantities as well as on air emissions are in general of good quality and availability for recent years, linking those two sets of data from an environmental threshold perspective involves uncertainties. In general, it is difficult to quantify the contribution of different non-renewable resources on the input side to specific output-oriented phenomena (air emissions in our case). The suggested proxy threshold indicator introduced in this report should illustrate whether the current overall non-renewable resource use in a country is causing emissions which are below or above a national emission ceiling.

The introduced method thus builds on the approach of EVIL as introduced for Germany (see above) but extends it to the European level and for the first time tests it across different EU countries. As EVIL data so far only exist for Germany, it is currently not possible to evaluate whether the original EVIL concept would deliver more consistent results in a cross-country comparison. In order to test the robustness of EVIL for cross-country comparisons, it would need to be tested with real data, whether correlations between non-renewable resource use and the surpassing of EVILs for specific pollutants can be observed. The pilot calculations undertaken in this study using EEA air pollution data suggest that in general the amounts of non-renewable resources consumed in a country are not related to the performance regarding a specific emission ceiling.

Therefore, it is important to note that large uncertainties can arise when conclusions are drawn about which inputs of non-renewable resources need to be reduced in order to decrease emissions below the threshold area. Furthermore, emission-abating technologies can significantly change the relation between resource inputs and outputs of emissions. Deriving conclusions for changing patterns of non-renewable resource use thus remains a challenging task.

Furthermore, establishing thresholds and threshold indicators for the use of non-renewable resources often involves normative decisions. For example, the EVIL indicator relates the extraction of specific abiotic resources and the resulting negative environmental impacts to an environmental target, which is defined in a political process. These target values change when scientific findings change or political estimations are revised (IFEU, 2006b). Applying such an approach includes the danger of not achieving a necessary environmental goal due to political barriers.

In the case of the suggested proxy threshold indicator for non-renewable resource use, the emission ceilings are a problematic part, as they were not set on a purely scientific basis. In a first step, they were formulated with the help of the Regional Air Pollution Information and Simulation (RAINS)-model (Amann et al., 2004), which assists in estimating national emissions, their dispersion including chemical reactions, and the harm they cause to the environment and human health. This information is constrained in an optimisation process with effect-orientated goals. RAINS then calculates least-cost solutions to the constraints relative to feasible abatement technology options in each country. In the last step, however, the necessary emission constraints are translated, 'following a considerable amount of further scientific debate and political negotiations, into emission level ceilings for individual countries' (Kelly et al., 2009: 30). The proxy threshold indicator suggested in this study would gain in robustness if emission ceilings derived only from a scientific perspective were be available. However, these underlying scientific data on science-based emissions ceilings are not published by either the EEA or the developers of the underlying RAINS model and were therefore not available to the authors of this study.

The table below presents a summary of the pros and cons of the proposed threshold proxy:

Table 36 Advantages and disadvantages of suggested proxy threshold indicator for non-renewable resource use

	$DMC_{non\text{-}renewable}$ per capita in relation to SO_2, NO_x, NH_3, and NMVOC emissions
Advantages	• Domestic Material Consumption (DMC) currently is the most commonly used indicator on resource use in Europe. DMC is included in several core European indicator sets (sustainable development indicators, structural indicators) • As the MFA data is collected on a level which disaggregates a number of materials, the biotic versus abiotic part of DMC can easily be separated • Emissions data for the four NECD pollutants is readily available for recent years • The suggested threshold indicator allows evaluating current levels of non-renewable resource use on the country level (in absolute and per capita terms) from an environmental threshold perspective. It illustrates whether a certain quantity of non-renewable resource use causes (air) emissions, which are above or below a national (air) emission ceiling
Disadvantages	• Difficult to derive resource-specific causal relations between amounts of resource use on the national level and emissions on the national level. Therefore difficult to derive specific policy suggestions in case non-renewable resource use is above a critical load, as emissions can be reduced by a large number of different actions (substitution of the quantity and quality of different non-renewable resources; applying pollution abatement technologies, etc.). • Both the underlying resource use indicator (DMC) as well as the emissions data do not cover life-cycle wide resource use and life-cycle wide emissions. The suggested proxy threshold indicator is therefore unable to capture burden shifting to other regions due to the outsourcing of resource- and pollution-intensive production. In order to change this, other MFA-based indicators, such as Raw Material Consumption would need to be applied, which include the non-renewable resources embodied in internationally traded products. Also the emission indicators would need to be based not on a territorial principle, i.e. emissions on the territory of a country, but on a consumption principle, i.e. total global emissions related to the consumption of a country. However, such comprehensive environmental indicators are currently unavailable for both the categories of resource use and emissions. • The emission ceilings provided by the EEA for the four NECD air pollutants actually represent political thresholds rather than scientific thresholds. The underlying scientific data are not published.

4.4.5. Interpretation of threshold indicator

The suggested threshold indicator provides an answer to the following key question: Is the current level of non-renewable resource use causing air emissions which are beyond an environmental threshold for those air emissions?

The threshold indicator thus allows an environmental evaluation of current levels of resource use only on an aggregated level. However, it does not allow deriving a clear and unambiguous answer on which non-renewable resource use needs to be reduced or managed differently when a certain threshold is surpassed, as the cause-impact relationship in the case of non-renewable resources is very complex. Typically, several categories of non-renewable resources contribute to one environmental problem (for example, a number of chemical substances, such as solvents, chlorofluorocarbons, formaldehyde, etc., contribute to the release of VOCs). Furthermore, the negative consequences, such as waste and emissions, are not linked to the amounts of resource use in a linear way, but are dependent on, inter alia, the (pollution abatement) technologies applied. All these limits are illustrated in the example presented earlier that fails to show a clear link between non-renewable DMC per capita and air pollutants emissions).

4.4.6. Conclusions and recommendations

The suggested proxy indicator was developed to answer the question whether a certain amount of non-renewable resource use causes air emissions which are below or above a certain national emission threshold. The developed approach was tested with real data available from EUROSTAT and the EEA. The approach therefore further developed threshold-oriented approaches to evaluate resource use, in particular the EVIL indicator developed for a German case study (IFEU, 2006a).

The hypothesis behind developing this approach was that a link can be observed between the amount of non-renewable consumed in a country and the resulting emissions from using these non-renewable resources, as other studies have to some extent indicated (see in particular the study by van der Voet et al., 2005 undertaken for DG Environment, from which Figure 21 was taken in chapter 4.4.1).

However, as the example figures in section 4.4.3 (and the additional examples in Annex 2) illustrate, there is no unambiguous conclusion on the relation between the consumption of non-renewable resources and the surpassing of certain air emission ceilings. Countries with very different levels of non-renewable resource consumption have emissions which are below or above the emission ceiling for that country. The direct policy relevance of this proxy indicator at its current stage of development in terms of deriving concrete policy actions therefore remains limited.

These findings lead to two main conclusions and corresponding recommendations for further testing and elaborating the suggested proxy threshold indicator:

1. Deriving specific policy actions requires a more detailed analysis of the links between non-renewable resource use and environmental impacts showing threshold phenomena. A large number of factors influence the process in which non-renewable resource use is transformed into specific air emissions. For the case of NO_x, these factors are the detailed composition of the non-renewable DMC, in particular the types and amounts of fossil fuels used for combustion and the applied production and emission abatement technologies. In order to define specific policy actions for single EU countries, detailed information on the sources of air emissions need to be compiled in a first step (i.e. which economic activities contribute most to certain air emissions). In a second step, the types of non-renewable resource inputs used in these economic activities need to be identified. Based on this detailed assessment, specific actions for the reduction of the use of specific non-renewable resources can then be elaborated.

2. The suggested threshold indicator needs to be tested with other threshold relevant data. The example illustrations provided in section 4.4.3 used EEA data on emissions and related emission ceilings, as these are currently the only threshold data available for air emissions. However, the national emission ceilings adopted by the EEA have not been derived from a purely scientific calculation. Rather, the emission ceilings were determined in a process of political negotiations. The underlying scientific data have neither been published by the EEA nor by the developers of the underlying RAINS model and were therefore not available to the authors of this study. This could be one of the reasons why no correlation between DMC (non-renewable) per capita numbers and the reaching of national emission ceilings could be observed. The robustness of the suggested proxy threshold indicator could therefore be increased if the indicator could be tested with more thresholds on emissions (and other negative impacts resulting from non-renewable resource use). Only when more data on ceilings and thresholds become available and the correlations with the non-renewable DMC have been tested, a final conclusion on the policy usefulness of this suggested approach and proxy threshold indicator can be drawn.

4. Conclusions

With climate change aggravating and human impacts on the Earth system continuously growing, investigating and monitoring environmental thresholds is likely to become more important to policy makers in the European Union. Thresholds indicate the limits of human intervention with the environment beyond which potentially disastrous consequences may occur. Their monitoring and use in planning and decision-making is prudent and a form of evidence-based policy.

The present report summarises the results of a study of the existence and data basis of threshold values in European environmental and ecological systems. The approach taken started with a review of the available literature on environmental thresholds and incorporated a series of interviews with experts (cf. Annex 1). Then, an initial list of seven areas that are relevant for environmental policy-making in the EU and that have demonstrated threshold behaviours – namely human exposure to toxic chemicals, fisheries, freshwater quality with focus on eutrophication, freshwater quantity, land use/land use change and soil erosion, and non-renewable resource use – was narrowed down to a list of four threshold issues that were studied in more depth: freshwater quality with a focus on eutrophication, freshwater quantity, soil erosion, and non-renewable resource use. For each of these areas, the study assessed the drivers and scale of the problem in Europe, supported with empirical evidence on the existence and use of thresholds. Numerical values were presented for those thresholds that were backed by rigorous science.

Water quality

Thresholds already exist for water quality: A well-established threshold of 50mg/l is set for nitrogen levels in groundwater by the EU's Nitrates Directive. This value was established to reduce the negative effects of agricultural effluents on ecosystems and public health. There is no corresponding threshold for phosphorus in the Nitrates Directive but the Drinking Water Directive established a maximum allowable concentrations of 5000 P_2O_5 $\mu g/l$ and, under the 2000 Water Framework Directive, EU Member States are implementing a system of water quality monitoring networks with associated local (watershed-specific) indicators for nitrogen, phosphorus and other parameters and priority substances. The WFD's specifications of water quality classes will therefore effectively serve as the threshold boundaries for achieving and maintaining "good ecological status" by 2015.

Data on eutrophication are among the most widely available water quality parameters, covering the entire EU territory and a substantial time frame of more than 20 years in many instances. Estimates generated from the EEA's WaterBase indicate that serious exceedances of nitrogen and phosphorus concentrations in European waterbodies are relatively rare. Time series at individual sites and at aggregated river or lake level show that eutrophication has declined in many countries over the past 20 years but is stagnating or increasing in others (Eastern EU, areas with intensive agriculture and livestock cultivation). For the future, the full implementation of the WFD will bring Europe much closer to managing its waters with ecological and human health in mind and to do so with meaningful, robust threshold indicators.

In this context, and in order to monitor thresholds in water quality, we suggest using the following indicators:

- Ratio of actual maximum to maximum allowable concentrations (MAC) of nitrogen and/or phosphorus;
- Ratio of actual daily load to Total Maximum Daily Load (TMDL) of nitrogen and/or phosphorus.

These threshold indicators would permit an immediate judgement on the status of freshwater bodies with respect to current concentration levels of nitrogen and phosphorus (for the indicators of Maximum Allowable Concentrations) or the influx of nitrogen and phosphorus (for the TMDL indicators) vis-à-vis their respective threshold levels.

However, the considerable spatial and temporal variation of threshold levels among waterbodies will continue to create challenges for monitoring and management of eutrophication. This is because the spatial and temporal resolution needed to design site-specific threshold values is very resource intensive and therefore unlikely to be implemented at very small spatial scales and with sufficient frequency. In addition, alert or danger zones are difficult to determine using scientific information alone and will more likely need to combine science with normative decisions.

Water quantity

The best available indicator for water quantity today is the Water Exploitation Index (WEI), which is used by the EEA to measure the percentage of available water that is being appropriated for human uses. According to this index, the warning threshold, which distinguishes a non-stressed from a water scarce region, is around 20%, with severe scarcity occurring where the WEI exceeds 40%. However, the WEI focuses on blue water abstraction, and takes neither green water sources nor water consumption into consideration.

We hence suggest using a wider set of indicators that would cover both water consumption and its impacts. From a *consumption perspective*, a set of three complementary indicators is suggested which comprehensively covers the different types and sources of water (blue/green and renewable/non-renewable) and looks at water scarcity. The consumption-oriented indicators could allocate a specific amount of consumable water per accounting unit (time and space) to each economic sector and thus help to ensure that sustainable limits are not surpassed. Well established *impact-oriented threshold* indicators, notably "groundwater quantitative status" and "hydrological pressures on streams" could be used to monitor the effects of water consumption on waterbodies' structure. Values for the impact-oriented threshold indicators are partly available already in the River Basin Management Plans of different Member States. They could also be used to calibrate the three consumption-oriented threshold indicators.

However, thresholds values are not yet established for all the above mentioned indicators. To do so, it will be necessary to combine information on actual available freshwater resources, the amounts of water specific sectors consume for their activities as well as the related impacts of this consumption. Data is not readily available for all the underlying pressure indicators, and the available data still lack in completeness and quality. However, due to the rising relevance of the topic, various institutions (Eurostat, UNStat, etc.) are working on an improvement of accounting structures, data comprehensiveness and quality. It will be important that other European institutions also put more effort in the further elaboration of methodologies and the collection of high quality data.

Soil erosion

A tolerable level of soil erosion refers to the amount of soil that can be lost per area and year without undermining the soil's capacity to regenerate. This would constitute a potential threshold for maintaining soil quality. We suggest establishing the threshold indicator "Estimated soil loss by water (rill, inter-rill, and sheet) erosion vs. Tolerable soil erosion rate". Modelled at five years intervals using updated climatic and land cover data and calibrated with harmonised measurement data generated by a soil monitoring network, this indicator would inform decision makers and practitioners at the various appropriate governance levels of the need to take action based on risk estimates. By measuring actual erosion rates it would improve the identification and targeting of land management practices that are able to reduce the risk of soil erosion.

Some EU Member States have established soil monitoring networks, for which methodology and coverage vary considerably. The present geographical coverage is very heterogeneous between and within countries. The determination of appropriate danger levels is more challenging because erosion events often occur during extreme weather events when danger zones are crossed within short periods of time and cannot be used as useful warning signals for policy or management interventions.

Non-renewable resources

Threshold levels for non-renewable resource use have been assessed in the study by using a proxy for one of the main consequences of this use, namely the emission of pollutants. Thresholds may be derived from existing critical loads of SO_2, NO_x, NH_3 and NMVOC emissions, as defined and monitored under the National Emission Ceilings Directive. The suggested threshold indicator – "$DMC_{non\text{-}renewable}$ per capita in relation to SO_2, NO_x, NH_3, and NMVOC emissions" – is a proxy that should allow an environmental evaluation of current levels of resource use on an aggregated (country) level. After testing the developed method with real data, our analysis does not show a linear relation between emission thresholds (using emission ceilings as a proxy) and per capita non-renewable DMC levels over time: Whether or not a country meets its national emission ceiling does not appear to depend on its level of per capita consumption of non-renewable resources

The proxy threshold indicator at its stage of development does not allow deriving a clear answer to the question which non-renewable resources should be reduced or managed differently when a certain threshold is surpassed. The cause-impact relationship in the case of non-renewable resources is very complex, as a specific environmental problem is typically caused by the use of different categories of non-renewable resources. For example, a number of chemical substances, such as solvents, chlorofluorocarbons, formaldehyde, etc., contribute to the release of VOCs. Negative effects of non-renewable resource use, such as waste and emissions, are not linked to the amounts of resource use in a linear way, but are dependent on the (pollution abatement) technologies applied. Therefore, deriving specific policy actions requires a more detailed analysis of the links between specific non-renewable resources and environmental impacts showing threshold phenomena.

Table 37 summarises the four areas of investigation, their proposed threshold indicators and available quantitative measures for these thresholds.

Table 37 Threshold areas, proposed indicators and available thresholds

Threshold theme	Suggested threshold indicator	Available threshold values
Water quality	Ratio of observed maximum concentration of nitrogen to maximum allowable concentration of nitrogen Ratio of observed maximum concentration of phosphorus to maximum allowable concentration of phosphorus Ratio of observed daily load to Total Maximum Daily Load of nitrogen Ratio of observed daily load to Total Maximum Daily Load of phosphorus	50 mg N/l (Nitrate Directive) Watershed-specific thresholds for permissible N and P concentrations as a result of WFD implementation.
Water quantity	Maximum blue water consumption Maximum green water consumption Maximum non-renewable water use Groundwater quantitative status Hydrological pressures on streams	No threshold values have been defined so far
Soil erosion	Estimated soil loss by water (rill, inter-rill, and sheet) erosion vs. Tolerable soil erosion rate Complementary indicator: Total estimated soil loss by water, tillage and wind erosion vs. Tolerable soil erosion rate	Upper limit of tolerable soil erosion, as equal to soil formation, is ca. 1.4 t/ha/year while the lower limit is ca. 0.3 t/ha/year (for hill slope soils overlying hard rock parent material) [Verheijen et al., 2009] Average tolerable erosion rate is 1 t/ha/year under a precautionary approach [Verheijen et al., 2009; Jones et al., 2005]
Non-renewable resources	$DMC_{non-renewable}$ per capita in relation to SO_2, NO_x, NH_3, and NMVOC emissions	Thresholds of national emission ceilings (for NO_x, SO_2, NH_3, NMVOC) exist; but derived thresholds for $DMC_{non-renewable}$ per capita have not been defined so far.

The way forward

In order to monitor and respect environmental thresholds, more research and data is needed. This report concludes that while thresholds are an active area of research in the EU and globally, there is a lack of studies, modelling and statistical data on environmental thresholds and danger zones. The study by Rockström et al. (2009) on planetary boundaries provided an important starting point for this project as did the debate on the physical limits to growth. While Rockström et al. focused on the global level, this report largely highlighted areas in which crossing environmental thresholds would lead to negative consequences for the European Union.

The study found that, while it is possible to develop threshold concepts and corresponding indicators for a variety of environmental issues that are of notable concern to the EU, including eutrophication of surface freshwaters, water quantity, soil erosion, and non-renewable resource use, it remains a challenge to determine exact values for thresholds and danger zones. The use of threshold indicators for EU monitoring and policy-making remains limited due to incomplete scientific knowledge and persistent uncertainty, data scarcity, measurement error, and the often pronounced effects of local conditions on the value of the threshold and local ecosystem behaviour (e.g., resilience, adaptation, rebound effects). More research is also needed on system feedback changes, a characteristic feature of a threshold. So far, the literature on these feedback effects is limited. In some cases (e.g. at the water basin level) extrapolations from similar closely related systems can be made. However, how to establish thresholds more rigorously is an important question for future research.

The study also identified areas of hope and positive developments. The Water Framework Directive's classification exercise for defining water quality classes according to ecological status is a requirement for all Member States and is generating threshold information for eutrophication and other forms of pollution. Indicators for water quality in terms of ecological status are under development as part of the WFD. While these indicators are largely not yet operational, they can be expected to be operational over the course of the next year or two. The proposed ratio indicators of observed to maximum allowable concentration and ratio of observed to TMDL can be computed for selected river basins and lakes, one of the main challenges being the determination of the threshold value (and a danger zone). Water quantity is recognised as a major limiting factor to life and human prosperity. Thresholds in this area are therefore of vital importance and are being further developed together with the necessary empirical information. Soil erosion is the subject of ongoing research and field studies and the methodologies continue to evolve and – hopefully – converge. While the suggested threshold indicator for non-renewable resource use ($DMC_{non\text{-}renewable}$ per capita in relation to SO_2, NO_x, NH_3, and NMVOC emissions) did not yield satisfactory results, it may nevertheless be an interesting indicator to investigate further, using purely scientifically derived national emission ceilings instead of the ones established under political influence in the NECD. This would be possible if the underlying data on science-based emissions ceilings were published by the EEA or the developers of the underlying RAINS model.

To be useful for policymaking, thresholds should be as accurate and precise as possible, the danger zones be balanced between indicating a true approach of the threshold value (as opposed to a false positive) yet give as much lead time as possible for response. Monitoring thresholds requires a rich database of empirical data. Given the current lack of data in this field, data collection and evaluation with regard to danger zones and thresholds should be a priority concern for policy makers. Therefore, the following **immediate actions** would be beneficial:

- Develop a searchable repository of existing threshold research for researchers and policy analysts.
- Identify areas of high priority according to (a) likelihood of exceedance of thresholds in the near future and (b) areas with least amounts of empirical and theoretical knowledge; and developing an action programme on how to address both (a) and (b).
- Improve the integration of threshold-related aspects into environmental data collection procedures at the European level, undertaken by EUROSTAT, EEA and other EU bodies.
- Increase the visibility and funding for European threshold-related research.
- Strengthen the relevance of threshold monitoring and research at the global level.

Finally, it should be noted that studying environmental thresholds involves some limitations. First, as the scientific knowledge of environmental thresholds is still limited, it is still impossible in many areas to present scientifically robust and reasonable values for thresholds. Therefore, danger zones are important to provide warnings in time. Secondly, it should be noted that thresholds are not constant over time and show regional and temporal variations. Therefore, national values may conceal important variations at regional scales. Nevertheless, even approximations are important because they indicate targets for policymakers and show the magnitude and direction of change over time. They may also serve as benchmarks and give direction for science. As more research will be done on environmental thresholds, these benchmarks are likely to be updated and refined.

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