Providing support in relation to the implementation of the EU Soil Thematic Strategy

Drivers and transboundary impacts of soil degradation

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Content

Executive summary

This report presents evidence of the societal challenges of transboundary impacts, the drivers, and consequences of soil degradation, as well as data and knowledge gaps. The message conveyed by the report is that there is clear evidence of transboundary impacts and drivers of soil degradation and that it has physical, ecological, economic and social causes. Soil degradation does not stop at borders.

Soil degradation in general rises increasing public attention after decades of awareness raising efforts. However, transboundary impacts of soil degradation are rarely addressed in literature. This is one of the key findings when conducting an in-depth literature review as was done for this report. Many sources highlight the transboundary nature of soil but there are few assessing the proportion of transboundary impacts of soil degradation in Europe. The report follows the DPSIR approach (Driver, Pressure, State, Impact and Response), which presents a useful framework for systemic analysis of characteristic relationships of soil degradation. In this sense, Section 2 presents the key impacts of transboundary soil degradation based on drivers (e.g. lifestyle preferences, climate change and economic growth), pressures (such as land use management, waste management, extreme weather events, industrial activities, energy production and urbanisation) and impacts (such as landslides, soil compaction, soil contamination, soil erosion, desertification, soil sealing and soil organic matter decline).

The (transboundary) impacts presented in Section 2 are very diverse and cover accelerated climate change, loss of biodiversity, human health and water security at the local to global level. Moreover, the EU consumption pattern has an impact on land use with high environmental and social impacts including land degradation outside Europe, the so called 'EU's land footprint'. As a response (Section 3) there are currently many ongoing activities across Europe focusing on soils and soil protection that have the potential to also raise awareness and address the transboundary drivers and impacts of soil degradation. Moreover, many international strategies and initiatives also aim at addressing soils and transboundary effects of soil degradation such as the Land Degradation Neutrality (LDN) Target Setting programme, which is an UNCCD programme, or the Voluntary Guidelines for Sustainable Soil Management, developed by the Global Soil Partnership and adopted by the FAO. Specific legislation at EU level is still missing but several directives and regulations address soil degradation, very few also transboundary effects such as the EU Water Framework Directive[1] or the Floods Directive[2].

Key aspects that need to be addressed are political actions at different levels and data availability and harmonization to increase awareness about transboundary effects of soil degradation and trigger actions at various levels. Political actions are required including transboundary regional planning that requires a masterplan at different levels, and across borders, even globally.

It would include initiating a process of assessing the costs of degradation and a discussion at European level on who bears these costs. The process of data assessment and harmonization is ongoing, including activities at EU level, e.g. Copernicus programme, the European Soil Data Center (ESDAC) or LUCAS-

[1] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

[2] Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks.

soil topsoil survey. Some member states have also national soil monitoring and soil information systems collecting information on soil. However, data access and availability are still being severely hindered due to different reasons including incompatible data formats and access to data from different actor groups. Whenever data are available, these need to be harmonized to be comparable across the EU, which requires new approaches to modelling and calibration methods for data acquisition and evaluation. Data from across Europe need to be linked and mapped as well as monitored, which is the objective of EU programmes such as LUCAS, ESDAC, Copernicus or Corine Land Cover.

Based on the findings of the report on drivers of soil degradation that have a transboundary dimension as well the transboundary impact, recommendations for further activities are proposed:

- Drivers and transboundary impacts are not limited to the EU or Europe. Some impacts such as climate change, food security, biodiversity loss have a global dimension. Therefore, the topic of transboundary impact of soil degradation has to be dealt at European level (e.g. it has to become an essential part of European sector policies and especially development policies) but also at global level.

- Due to the direct and indirect costs of degradation, there is a great need for cooperation between countries to address challenges, a need for exchange of knowledge and closing knowledge gaps and a need for harmonized data for an effective soil policy. It has to be supported by policy measures monitored by European and national institutions. To address this need, awareness is needed for the detrimental impacts of inaction as a first step.

- To improve the data base for decision making, transboundary environmental issues concerning the various forms of soil degradation as well as the assessment of socio-economic impacts in Europe and beyond should be included in priority lists of programmes such as the EU Framework Programme for Research and Innovation, Joint Programming Initiatives, Article 185 actions, ERA-NET, LIFE, COST, ESF or Cohesion Policy – nonetheless, transboundary local to regional and even crowdfunded research will facilitate the creation and exchange of knowledge and its transfer.

- Policy makers need clear messages as well as data and figures supporting these messages. An example is the identification of economic drivers and their translation into economic figures. It requires examples, study cases, simple and short policy briefs, clear figures, products that can be understood and shared by different users with different backgrounds and objectives. This information has to be communicated effectively.

1. Introduction

Soils are an essential and non-renewable natural resource hosting goods and services vital to ecosystems and human life (FAO, 2016a). They perform key environmental, economic and social functions essential to meet societal challenges not only at local but also at European and global levels. Healthy soils play a positive role in the delivery of ecosystem services (ESS). “Soil degradation is defined as a change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries. Degraded soils do not provide the normal goods and services of the particular soil in its ecosystem” (FAO, 2017).

Soil health and ecosystem services are linked to proper soil functions. However, these are increasingly under pressure and European society has been experiencing soil degradation for decades (Panagos et al., 2016; FAO, 2017). The types of soil degradation differ, but soil degradation is mainly caused, and accelerated, by human activity and land-use practices. The severity of soil degradation is outlined by Cherlet et al. (2013: III): “10% (about 2 million ha) of the European Union’s most productive soils show early signs of a decline in land productivity”.

Soil degradation is often considered as a local phenomenon, for example, even soil erosion by water or wind is often considered within the limited boundaries of a field. Also contaminated land is considered a local phenomenon. However, many degradation types have not only an on-site effect but also off-site effects. Table 1 summarizes typical off-site costs. Off-site effects of soil degradation and especially the transboundary effects are not yet well studied. Reports on sources of soil degradation and their impacts are rather dispersed and seldom integrated. Especially data and information about the cause-effect chains are missing to provide evidence.

To illustrate the linkages of the (often global) drivers, their relating local or regional pressures and their transboundary impacts, this report builds upon the DPSIR approach (Driver, Pressure, State, Impact and Response), which presents a useful framework for the systemic analysis of characteristic relationships of soil degradation.

The starting point of analysis is usually the natural megatrends as well as social and economic developments. In our analysis these are the so-called **drivers** of land use, which often result in soil degradation. These drivers are **lifestyle preferences**, **climate change** and **economic growth**. These drivers were selected as the most relevant according to the sources that were reviewed for this report. The three drivers reflect the individual, ecological and economic decision-making determinants:

- **Lifestyle preferences**: Individuals’ attitudes determining typically their decision-making, such as consumption, housing, mobility preferences.
- **Climate change**: Biotic and abiotic processes influencing the geogenic conditions, such as extreme weather events or desertification.
- **Economic growth**: Resource efficient quest for an increasing productivity and competitiveness supporting higher welfare, such as industrial activities and energy production.

Other drivers could be named that are important for soil management. For example, several sources also highlight population growth as an important driver. However, as it is difficult to separate it from the other three key drivers, we consider population growth as an element of lifestyle preferences, climate change and economic growth.

We do not claim to provide a complete picture of all potential drivers, but we do highlight those of obvious importance. This implicates that more relevant drivers, pressures and transboundary impacts of soil degradation might exist.

The identified drivers cause pressures on land and soil, for example, they result in changes of land use management (caused, for example) by economic growth, urbanisation (caused for example) by changing lifestyle preferences or extreme weather events (caused, for example) by accelerated climate change. These **pressures** to the current status of soil lead to soil degradation (a change in land use management could cause soil erosion or urbanisation could cause soil sealing) that can lead to broader **impacts**[3], e.g. losing biodiversity and ecosystem services (local impact) and or challenging food security (regional or even global impact) because of lower supply. At an extreme level, soil degradation can contribute to migration, threaten human health, endanger water, food security and biodiversity loss. In the context of this report, impact is not limited to physical and environmental impacts, but extends to economic (such as trade) and social (such as development, health and security) impacts. Prominent examples are migration, or food insecurity induced by flooding, desertification, pollution and sedimentation.

Figure 1 gives an overview of the investigated paths. For example, certain drivers will cause transboundary impacts in the form of challenging food security, increasing flood events, endangering water security or intensifying sedimentation. At the same time, not only the impacts, but also the drivers (the cause of degradation) can be distant and transboundary or trans-border[4]. The drivers discussed in this report are the most prominent ones according to the literature.

Figure 1 illustrates how important drivers of soil degradation are linked to pressures, which through changes in the state of soils lead to transboundary impacts. Each driver leads to a number of pressures; however, these are not always easy to describe and to be quantified. Therefore, this report focusses on the most plausible to be described in more detail. The key drivers for Europe identified from the literature are lifestyle preferences, climate change and economic growth.

An introduction on soil degradation can be found in the annex.

[3] Please note that for the reason of visualisation in the Figure, but also the structure later in Section 2, the "state of soil" is summarised under impact in our illustration of the DPSIR approach.

[4] Within this report, transboundary is synonymous for trans-border.

Degradation	**Off-site costs (costs borne by third parties and society, such as public administration, private sectors, tax payers and society as a whole)** *(Off-site cost entries which are marked with * could be quantified)*				
Biodiversity	Costs linked to the loss of eco-system functions	Costs related to impacts on landscape and amenity values	Costs related to changes in genetic resources		
Sealing	Costs on biodiversity	Costs due to impacts on land-scape and amenity values	Costs due to fragmentation of habitats and disruption of mi-gration corridors for Wildlife	Cost linked to runoff water from housing and traffic areas, which is potentially contaminated	
Erosion	Costs of sediment dredging, treatment and disposal* and sediment load in surface waters	Damage costs to infrastructure (e.g. roads and other transport infrastructure) and properties by sediments run off and flood-ing*	Costs due to necessary treat-ment of water (surface, groundwater)*	Costs due to damage to recreational functions*	Economic effects (e.g.) income losses and costs of healthcare
Decline of SOM	Costs related to an increased release of greenhouse gases from soil*	Costs due to loss of biodiversity and biological activity in soil	Costs due to the loss of fertil-ity and increased use of ferti-lizers to maintain yields level		
Compaction	Costs due to reduced water in-filtration into the soil	Costs due to increased leaching of soil nitrogen	Costs linked to increased emissions of greenhouse gases due to poor aeration of soil		
Salinisation	Costs due to damage to infra-structure (roads/bridges) from shallow saline groundwater*	Costs due to damage to water supply infrastructure*	Environmental costs, e.g. im-pacts on native vegetation, ri-parian ecosystems and wet-lands*	Costs due to negative effects on tour-ism*	
Landslides	Impact on human lives and well-being	Damage to property and infra-structure	Indirect negative effects on economic activities due to in-terruption of transport routes	Ruptures of underground pipelines, dis-location of storage tanks, release of chemicals stored at ground level and contamination of surface waters with as-sociated off-site costs as described al-ready under erosion	
Contamina-tion	Costs of increased health care needs for people affected by	Costs of treatment of surface water, groundwater or drinking	Costs for insurance companies and costs for increased food safety controls	Costs of dredging and disposing of con-taminated sediments downstream	Costs for the depre-ciation of surround-ing land*

	contamination* and increased food safety controls	water contaminated through the soil*			

Table 1: Off-site costs of soil degradation based on the impact assessment for the Soil Thematic Strategy (EC, 2006)

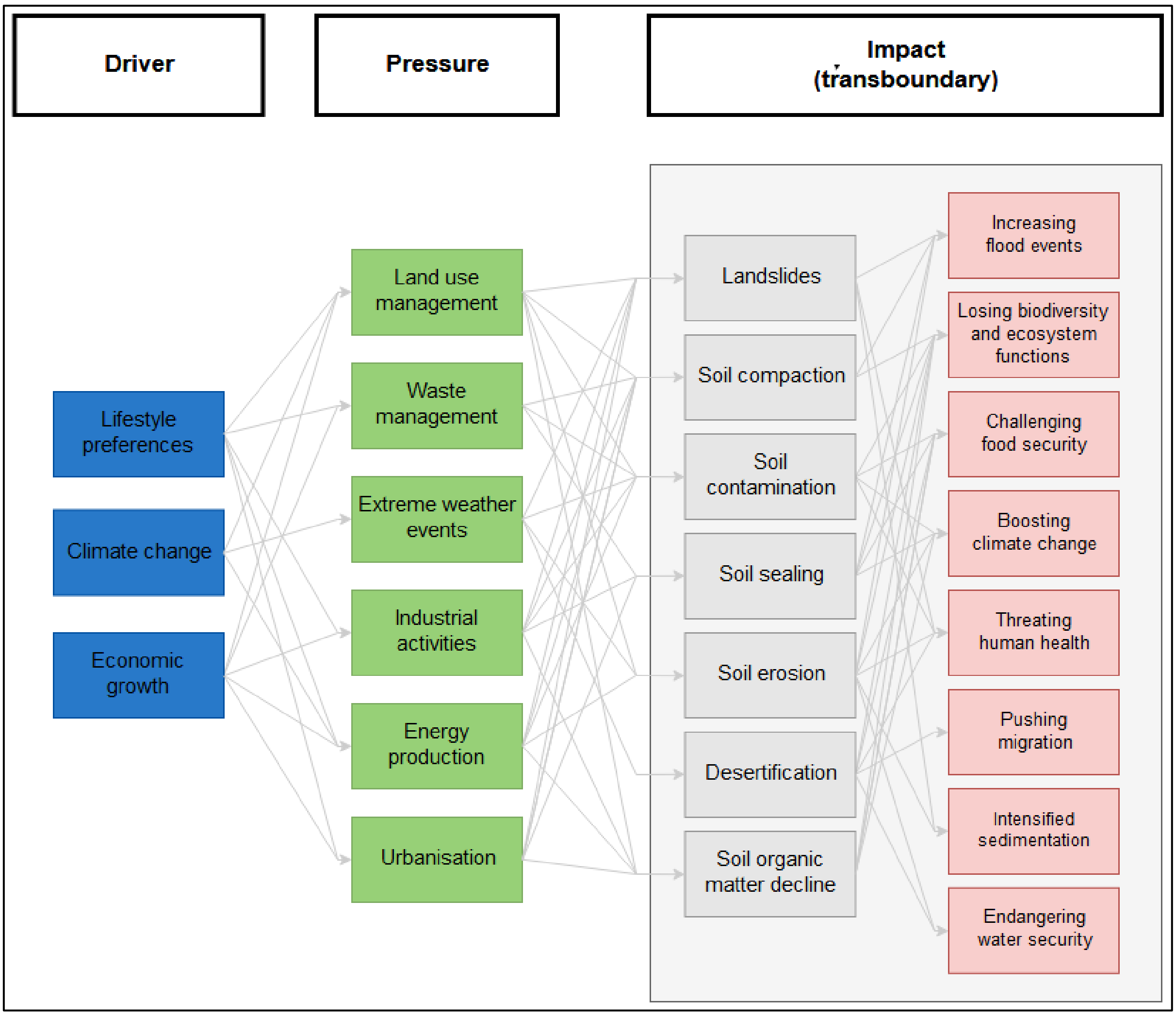

Figure 1: DPSIR approach applied to soil degradation from a transboundary perspective (Source: Own compilation).

Due to the complexity of relationships and the fact that many studies are performed with specific administrative / national or regional boundaries, it is very difficult to measure the exact proportion of transboundary impacts and to find available data on drivers or pressures for Europe. Notwithstanding, as will be shown, the evidence for the existence of transboundary impacts is apparent.

The responses as an element of the DPSIR framework are not illustrated in Figure 1, but they are addressed in an individual section (Section 3) in this report. The challenges of protecting our soils from further degradation are manifold to reduce the negative impacts, especially in transboundary contexts. However, policy responses are few and soil degradation in general, and transboundary impacts of soil degradation in particular, have not yet reached broad societal or political attention, even though many organisations provide factual information, strategies and key messages.

Examples are the Soil Thematic Strategy[5], consisting of four pillars to avoid soil degradation in the EU, or the UN Convention to Combat Desertification (UN, 1994), that aims at reaching land degradation neutrality (see for example Orr et al., 2017). A key challenge is that even though the links between drivers, pressures and impacts can be visualised as in Figure 1, most of them cannot be easily quantified. This limits the ability to illustrate the severity and urgency for action at a supranational level. Even when quantification is possible, numbers may strongly differ between countries, e.g. data are collected using different methods or the years in which data were collected differ, so data are not comparable. Moreover, while some countries have time series to identify changes others do not. To summarise, more data and information are needed to quantify the relationships and strengthen the evidence.

Chapter 2 illustrates how the drivers are linked to pressures and impacts in a transboundary context, making explicit the current knowledge and especially data gaps. Examples from EU member states demonstrating how soil degradation impacts on other countries are given. Soil degradation outside the EU, as a driver of migration and a major threat to global security, will also be addressed. Chapter 3 highlights the most relevant responses by focusing on policies and data provision and monitoring. The report concludes in Chapter 4 with recommendations for further action.

The target groups of this report are policy makers, but also experts in urban land, water management and development aid. The message conveyed by the report is that despite obvious information and data gaps, there are clear drivers that cause transboundary impacts (e.g. physical, ecological, economic and social) due to soil degradation.

[5] COM(2006) 231.Communication from the Commission on the Thematic Strategy for Soil Protection.

2. Transboundary impacts soil degradation based on drivers and pressures

This section provides specific and memorable examples for the interlinkages between drivers, pressures and their (transboundary) impacts. Each of the three drivers is described in an individual subsection, including the pressures that are caused by the driver (highlighted in green and linked with bold arrows). For each driver at least one pressure is described in more detail.

The aim of the section is not to provide a complete representation of all possible pressures that are caused by a specific driver but rather to illustrate with plausible examples the interlinkages between a driver and the pressure. Also note that many pressures could be caused by several of the drivers. To omit repetition, we focus on the driver-pressure-links for which we found good examples and evidence. For each pressure, at least one example is given in this section.

Finally, examples of the types of degradation and the transboundary impacts (highlighted in red and linked with bold arrows) of the specific pressure are described. This means that with each sub-section the reader learns how a specific driver leads to a specific soil threat (pressure) that causes soil degradation (e.g. landslides or soil erosion) with transboundary impacts (e.g. increasing flood events).

2.1 Lifestyle preferences

Lifestyle preferences, i.e. individuals' attitudes determining typically their decision-making, are associated with various **pressures:** Land use management, waste management, industrial activities, energy production and urbanisation. These pressures cause **transboundary impacts**, including increasing flood events, losing biodiversity and ecosystem functions, challenging food security, boosting climate change, threating human health, affecting sedimentation and endangering water security. (see Figure 2). Lifestyle preferences investigated as a driver of soil degradation have diverse facets, not least a clear link to increasing welfare. With an increasing world population, food demand is increasing and food consumption patterns are changing with economic growth, in particular meat consumption which is associated with increasing demand for land. In addition, people around the globe, including aging population in European countries, demand higher living standards that include larger houses, increasing mobility and social facilities. In city centres, these amenities are rare so that people tend to move outside the cities while aiming at staying close to urban areas. Another trend is that people move from rural areas to cities because of the job and education opportunities. It is estimated that in 2020 about 80% of people in the EU will be living in cities, in some member states the percentage will be considerably higher (EC, 2013b).

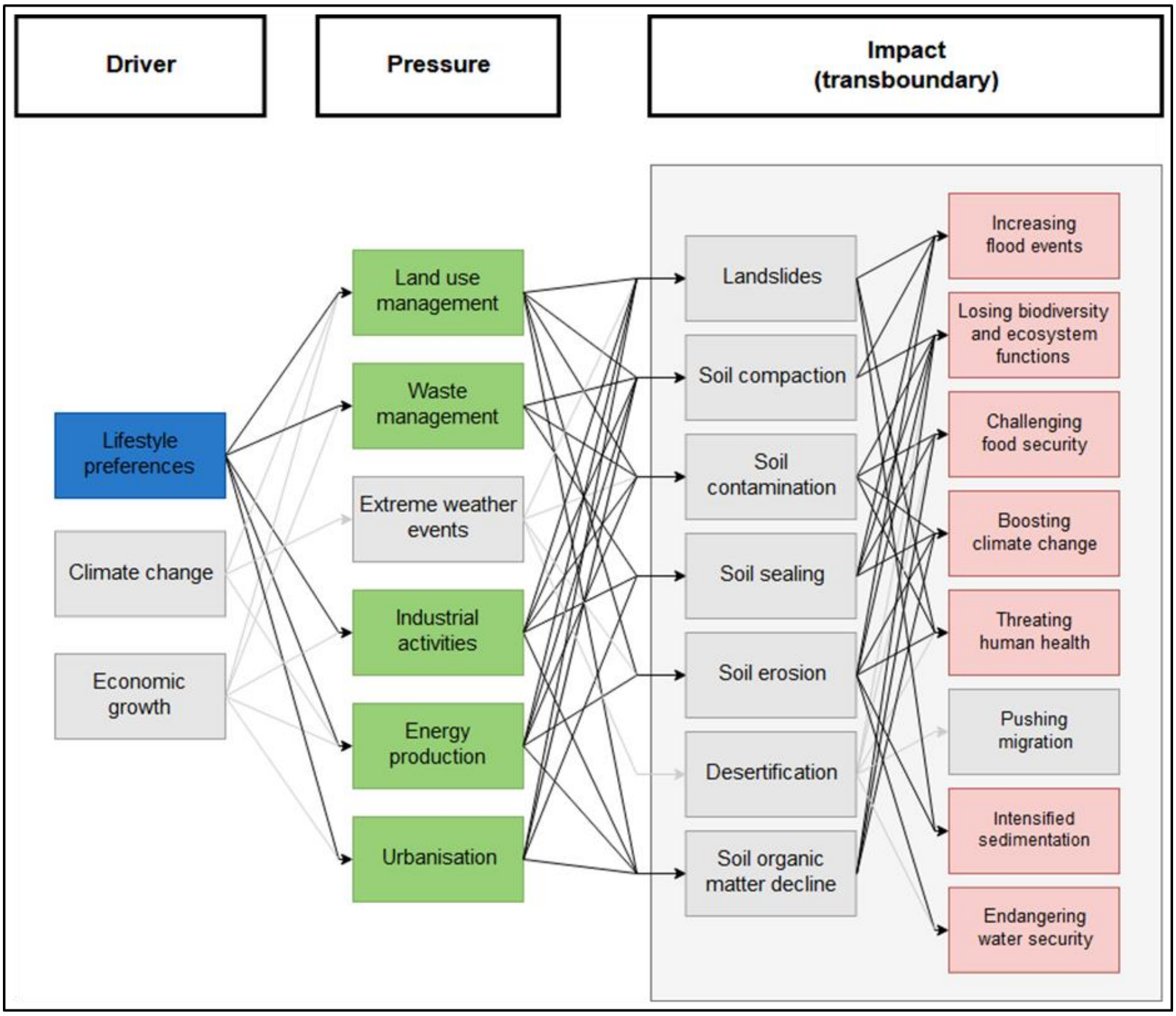

Figure 2: DPSIR approach applied to soil degradation from a transboundary perspective for the driver lifestyle preferences (Source: Own compilation).

2.1.1 Pressure from lifestyle preferences: Urbanisation

Europe is increasingly urbanising (Figure 3) and many social and economic activities depend on the availability of land. The quest for new housing, business facilities and transportation infrastructure leads to dramatic soil degradation in the form of land take and soil sealing. Soil sealing is a major and direct soil degradation impact of urbanisation. Impermeable asphalt is still the most frequently used material to cover soils. The type of material used is decisive for the degree of loss of soil environmental functions (Prokop et al., 2011; EU, 2013b).

Urbanisation processes as a consequence of the movement of people to cities generates various pressures on land and soil. The term ‘urban sprawl’ is commonly used to describe physical expansion of urban areas. Direct effects of soil sealing are easier to be assessed than effects prompted by related causes that often accomplish urbanisation, such as climate change, changes in soil functions, social changes, economic changes, mobility, etc. However, different methods have been proposed for quantification, e.g. using indicator-based calculations, datasets from remote sensing and estimates resulting from multivariate analysis (see e.g. Behnisch et al., 2016).

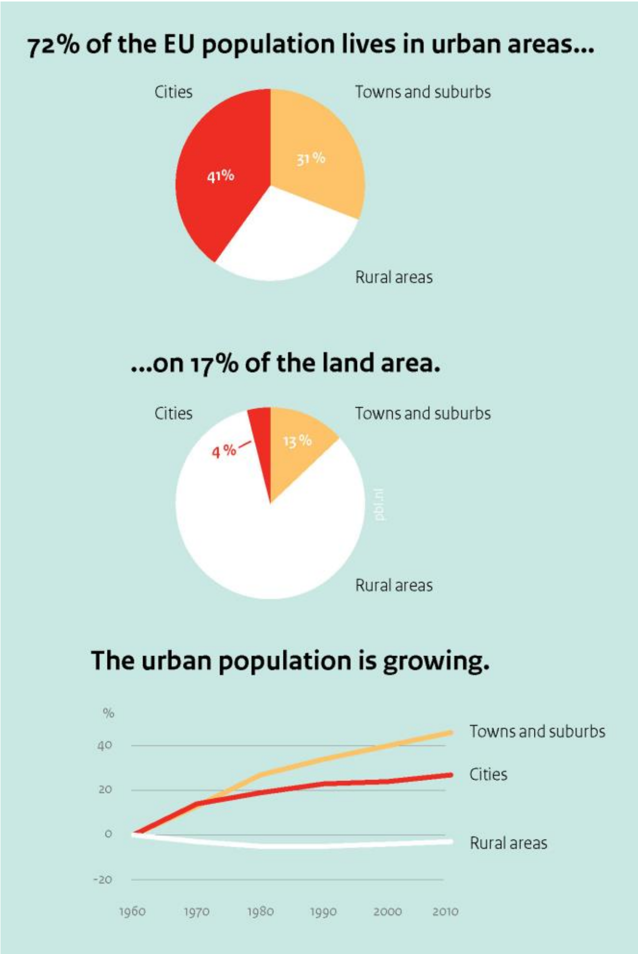

Figure 3: European population living in land and urban areas (Source: Nabielek et al., 2016: 12)

Land degradation due to desertification or loss of fertility triggers land abandonment and migration from rural to urban areas in some parts of Europe. As a consequence, some people leave their land and move to other parts of Europe (intra-EU movements of people). Several examples exist for the transnational occurrence of urbanisation in Europe. As discussed in Sohn & Stambolic (2015), as a result of the European integration, border regions inside Europe are attractive industrial and housing areas. Table 2 presents examples of European cross-border metropolitan regions.

Table 2: Cross-border metropolitan regions identified in European Spatial PlanningObservation Network (ESPON) and by Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR)

Entities	ESPON		BBSR	
	Cross-border dimension [% of population]	**Population** [million]	**Cross-border dimension** [% of surface]	**Population** [million]
Aachen-Liège-Maastricht (B-D-NL)	49.7	3.1	33.87	3.5
Arnhem·Nijmegen (NL-D)	11.7	1.2	–	–
Basel (CH-D-F)	52.0	1.0	80.90	2.4
Bruxelles/Brussel (B-NL)	–	–	18.78	6.7
Eindhoven (NL-B)	–	–	15.78	2.6
Genève (CH-F)	31.4	0.7	91.68	1.3
Gent (B-NL)	–	–	17.70	2.1
Graz (A-SLO)	–	–	11.24	1.2
Groningen (NL-D)	–	–	11.42	1.7
Innsbruck (A-D)	–	–	30.40	0.6
Katowice-Ostrava (PL-CZ)	18.6	5.3	–	–
København-Malmö (DK-S)	33.8	2.8	54.74	2.9
Lausanne (CH-F)	–	–	13.06	0.8
Lille (F-B)	16.8	3.1	23.66	3.6
Luxembourg (L-F-D-B)	61.8	1.0	77.50	1.8
Nice (F-I-MC)	9.0	1.2	15.16	1.4
Saarbrücken (D-F)	13.0	1.1	–	–
Salzburg (A-D)	–	–	31.83	1.0
Skopje (MK-RKS)	–	–	21.56	1.4
Strasbourg (F-D)	24.8	0.8	25.99	1.6
Twente-Nordhorn (NL-D)	23.6	0.6	–	–
Vilnius (LT-BY)	–	–	18.29	0.9
Wien-Bratislava (A-SK-H)	23.3	3.4	39.68	4.1
Zagreb (HR-SLO)	–	–	15.81	1.5

Source: Sohn and Stambolic, 2015: 180

In these cross-border urban entities, high and still increasing land prices in cities and urban areas accompany urban sprawl. As a consequence, transport infrastructure needs to be developed, taking even more land. Moreover, in urban areas soil compaction is driven by construction works and related machinery traffic. Destruction of the soil profile during construction works increases susceptibility to compaction (Schjønning et al., 2015). Furthermore, inhabitants commuting cross-border usually consume where goods are cheapest often causing high environmental footprints.

The phenomenon is also discussed in popular press, e. g. in the Basel area (Figure 4) or the area around Szczecin[6]. The examples show that society needs to trade off the economic and social advantages of open borders with uncontrolled negative environmental impacts.

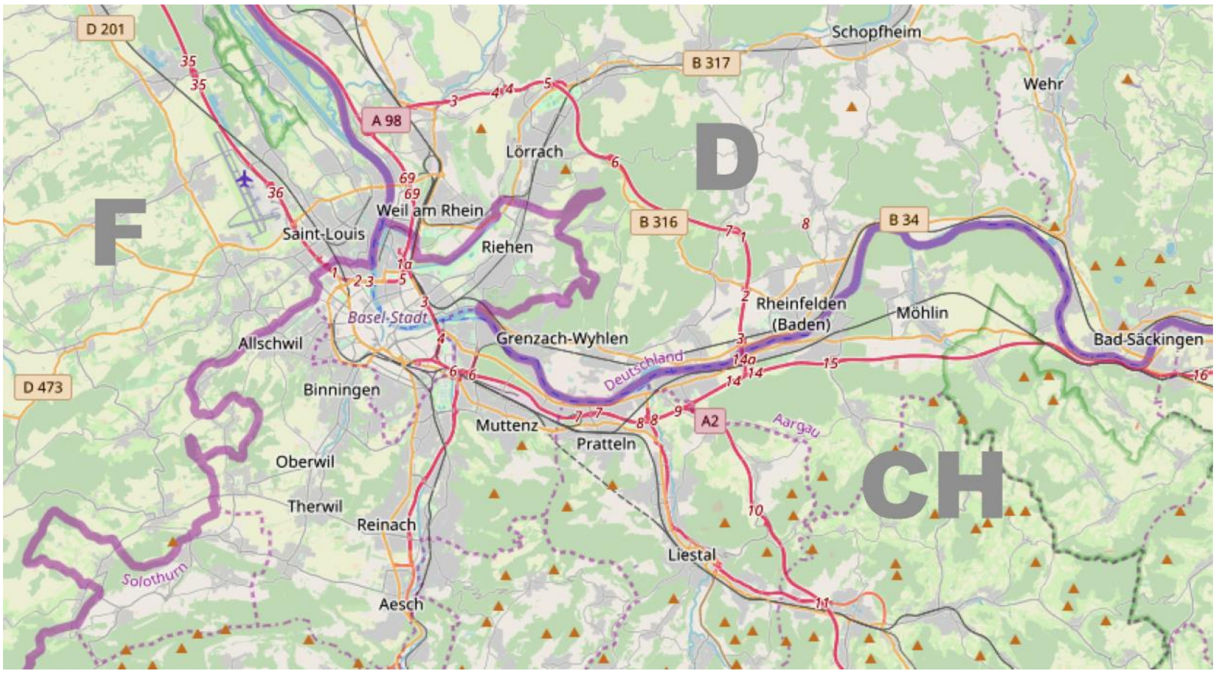

Figure 4: Illustration of tri-lateral metropolitan area of Basel (Source: www.openstreetmap.org).

A further example for a cross-border urbanizing region is Alsace, located in East-France and very close to German and Swiss borders. A large part of the local population lives in the urban area. The three most important nearby cities are Strasbourg, Mulhouse and Colmar. The region is a transboundary network of commuting as well as shopping centres and leisure spots not only for French citizens, but also for German and Swiss citizens (Wackermann, 2000).

Also, the transportation of construction materials across Europe is an indirect transboundary soil use effect. Exemplary is the case of The Netherlands, which obtains 68 percent of their raw materials from abroad. Two thirds of the raw materials come from other European countries. The road construction sector in the Netherlands imports raw materials for asphalt and concrete from abroad, such as

[6] Source: https://www.deutschlandfunkkultur.de/polnische-zuwanderer-in-brandenburg-neues-leben-fuer-die.1001.de.html?dram:article_id=336539 (9/11/2018).

“Graziet”, a type of rock. Because of its favourable characteristics it is imported from Central Germany to the Netherlands and used in road construction.

Another material is “Bims” a light volcanic material that is imported from Iceland and Germany as filler material. In the past sand was applied, but in areas with soft soils, the lighter volcanic material is becoming more popular to avoid soil subsidence.

As KBU (2017) points out by removing lime, sand and gravel, the landscape is fundamentally changed. This has serious effects on soil structure and on groundwater balance. Substances released from open-cast mines by rain or groundwater can reach the groundwater or surface waters. This can acidify water or load them with iron or other metals – with devastating transboundary impacts.

2.1.2 Transboundary impacts of urbanisation

Losing biodiversity and ecosystem functions

The “conversion of natural areas into agricultural land, forestry, climate change, encroachment from expanding human settlements, infrastructure and fragmentation” have been identified by Van der Esch et al. (2017: 67) as major causes for the severe decline of biodiversity up to 2010. Soil sealing decreases or might even stop the intensity of biological processes in the soil.

Soil sealing leads to a long-term loss of environmental soil functions. Water cycle processes get deteriorated, increasing the risk of floods. The loss of filter and buffer functions often lead to groundwater level changes and can cause contamination by persistent chemicals and by pathogens (Siebielec et al., 2015). Such urbanisation consequences are not processes that stop at borders. Prosperous regions affect suburbanisation and country fragmentation in the surroundings. Municipalities in these areas compete for increasing tax revenues but are losing natural capital and have high external costs due to environmental impacts.

The consequences of the loss of biodiversity and ecosystem functions include a reduction in food and biomass production. The increasing demand for food and biomass is satisfied through imports that are expensive and, in turn, put increasing pressure on ecosystems and especially soils elsewhere. De Schutter and Lutter (2016: 3) point out that “in 2010, the amount of land used to satisfy EU consumption, solely of agricultural goods and services, amounted to 269 million hectares – representing 43% more agricultural land than is available within the EU itself and an area almost the size of France and Italy used outside of EU borders. The significant use of land outside of the EU is potentially linked with high environmental and social impacts"

Biodiversity loss is estimated to increase from 34% in 2010 to 38-46% by 2050 under different scenarios. To slow down the rate of biodiversity loss, the expansion of agricultural areas must be halted. If the expansion of cropland including bio-energy crop plantations, infrastructure and urbanisation intensifies, the loss of biodiversity will continue.

Challenging food security

> "Translated into productivity, land take in the EU from 1990 to 2006 alone resulted in a loss of food-production capability equivalent to more than 6 million tonnes of wheat." (EC, 2013: 6)

The main impacts of sealing are the loss of fertile agricultural land and the shift of food production to other areas, so a trans-border impact is always expected. This is the most intense form of land take, and it is an essentially irreversible process: a sealed soil is unable to perform most of its functions (Huber et al., 2008; Prokop et al., 2011). Urbanisation, for example, represents an increase of sealed areas (or artificial surfaces) over time, at the expense of rural areas, usually agricultural land (Siebielec et al., 2015). It has been estimated that urban sprawl has produced the loss of 3.3 million hectares of arable land per year between 2000 and 2030 (Tal, 2018). According to d'Amour et al. (2017) between 2% and 3% of staple crop production will be lost to urbanising areas in Europe by 2030, including circa a million tonnes per year for maize. Another example can be found in the region of Alsace, where the increasing urbanisation has besides positive impacts also negative impacts on the living quality in big cities. Urbanisation and its economic consequences endanger the groundwater resources of the Rhine river with the consequence that agriculture production in the area between Colmar and Mulhouse became dependent on artificial irrigation in order to remain competitive (Wackermann, 2000).

Boosting climate change

As pointed out by KBU (2017), soils play a central role in climate change. Their ability to store carbon makes them the world's second largest greenhouse gas storage, after oceans. Worldwide, about 1,500 billion tonnes of carbon are bound to the soil in the form of organic matter (humus).

KBU (2017) also points out that an important foundation for urban planning is wood - one of the oldest building materials of humanity. Large quantities of carbon are stored in the forests and their associated soils, which are released into the atmosphere as carbon dioxide as a result of deforestation – and consequent use of the wood, often in neighbouring countries.

2.2 Climate Change

Climate change describes a process of a significant change in climate such as temperature, rainfall and wind. It can be natural and human induced. Human activities such as deforestation, urbanisation and desertification but also emissions of carbon dioxide, methane and nitrous oxide from agriculture lead to significant changes in climate, e.g. increasing temperature of air and ocean, ice and snow melting that lead to a rising sea level, flooding and other impacts. Natural factors that can force climate change are for example changes in solar intensity, volcanic eruptions and changes in oceans circulation (EPA, 2018). Climate change leads to warmer climate conditions and causes periods with droughts in specific areas. The effects of climate change on soils include increased mineralization and decreased soil organic matter (van den Akker et al., 2016). As soils host the largest terrestrial carbon pool, they play a crucial role in the global carbon balance, which is clearly transboundary.

Climate change causes various **pressures** such as land use change, extreme weather events and energy production. These pressures induce **transboundary impacts:** increasing flood events, losing biodiversity and ecosystem functions, challenging food security, boosting climate change, threating human health, pushing migration, affecting sedimentation, or endangering water security (see Figure 5).

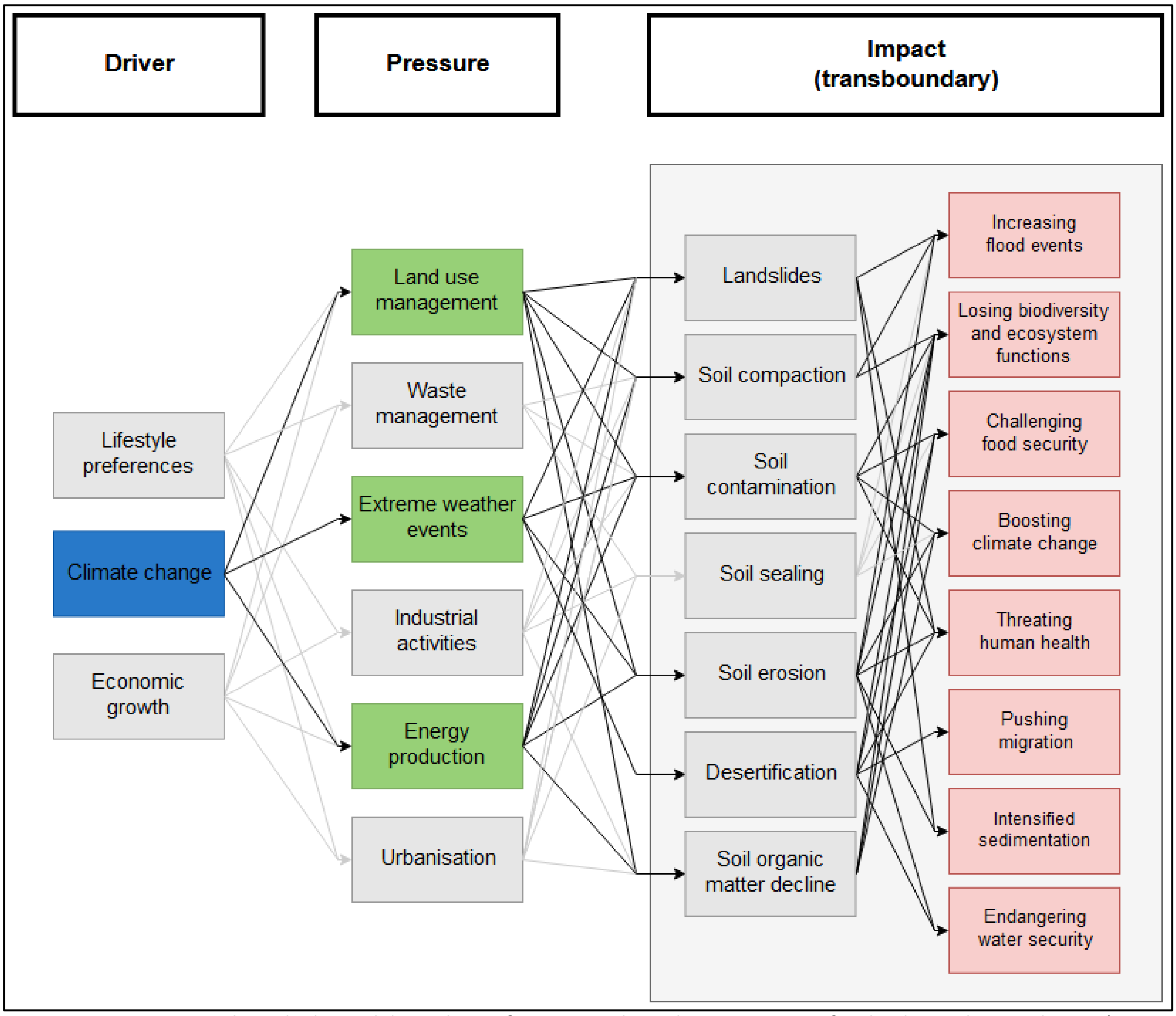

Figure 5: *DPSIR approach applied to soil degradation from a transboundary perspective for the driver climate change (Source: Own compilation).*

2.2.1 Pressure from climate change: Extreme weather events

Climate change leads to higher frequency of extreme weather events such as droughts, storms or heavy rain events. The prognostics for climate change are different in various regions in Europe. Countries along the Atlantic Ocean will suffer heavier rainfalls and higher risk of flooding. The temperature in the Alps and the Pyrenees will increase, leading to increasing snow and glacier melting. In the Mediterranean, climate change will increase heat extremes, drought, wildfires and crop failure (Neslen, 2017). Figure 6 shows a map with the effects of climate change in Europe. Intense or long-lasting rainfall will lead to saturated soils and formation of lakes.

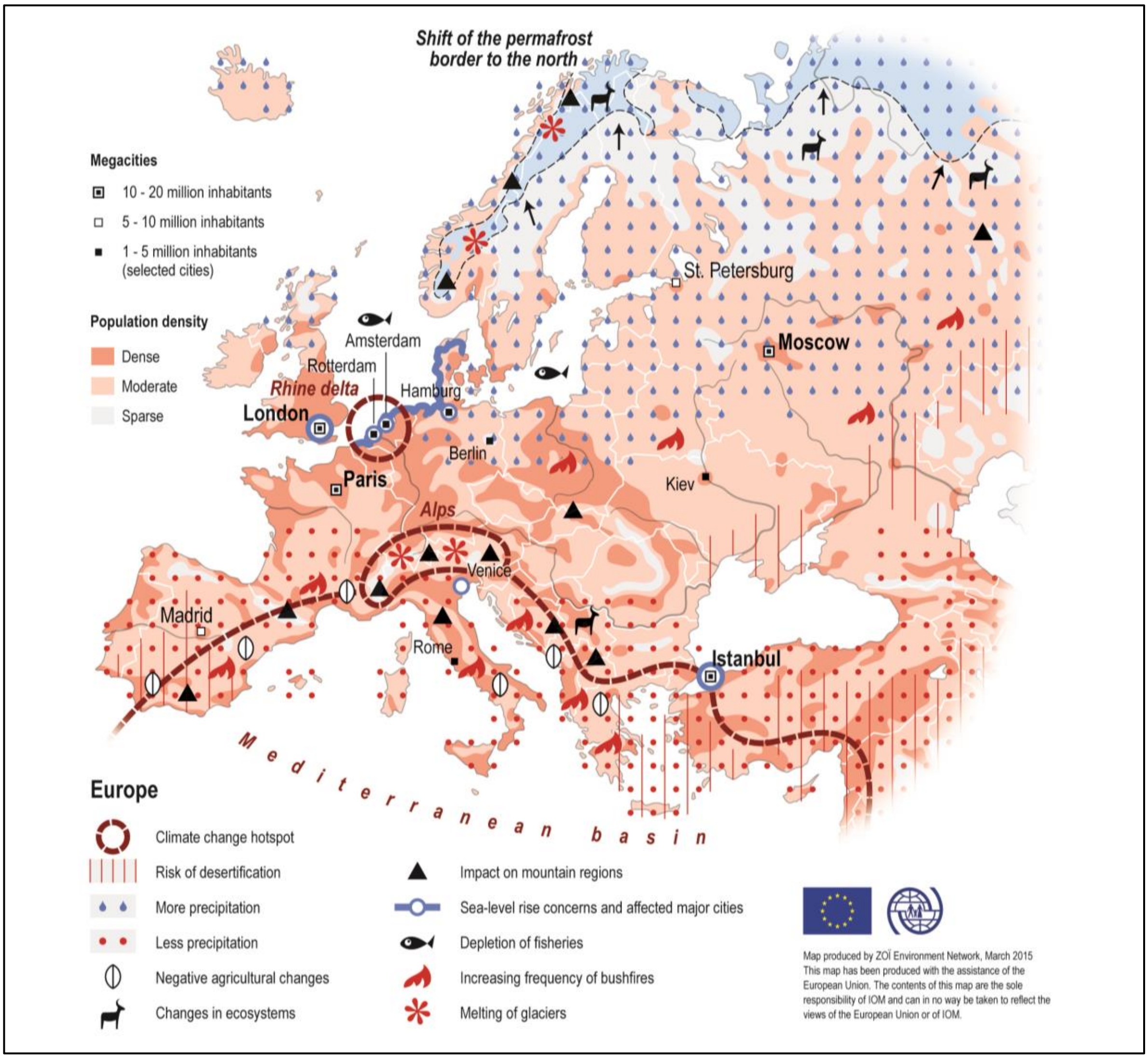

Figure 6: Climate change in Europe (Source: United Nations Geospatial Section, 2012).

An increase of landslides associated to extreme rainfall events is expected in the future due to climate change. Moreover, rainfall on dried out soils is often lost by superficial runoff and cannot be stored. The average expected economic loss per year due to landslides in Europe is approximately 4.7 billion Euro (Haque et al., 2016). The highest annual economic loss associated with landslides occurs in Italy, with 3.9 billion Euro, whereas in Germany the annual total loss is about 0.3 billion Euro per year (Haque et al., 2016). Figure 7 shows the example of rainfall surplus in the Netherlands between 1st April 2018 to 7th August 2018 (KNMI, 2018).

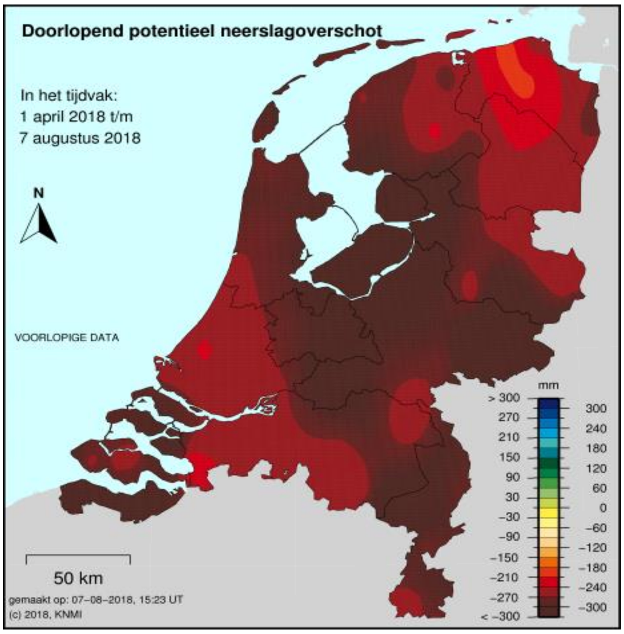

Figure 7: Rainfall surplus in the Netherlands between 1 April 2018 - 7 August 2018 (Source: KNMI, 2018).

Droughts can have many different effects on soils that can ultimately lead to desertification. The most prominent are soil erosion and soil nutrient loss, but additional effects are possible, such as the collapse of peat levees. Droughts also constitute a threat for water security and contribute to heat island effects in cities that can cause rotting fundaments of houses, especially in historical cities where the water level is decreasing. "Europe is increasingly affected by desertification. The risk of desertification is most serious in southern Portugal, parts of Spain and southern Italy, south-eastern Greece, Malta, Cyprus, and the areas bordering the Black Sea in Bulgaria and Romania. Studies have reported these areas to be often impacted by soil erosion, salinisation, loss of soil organic carbon, loss of biodiversity and landslides" (ECA 2018: 7). However, desertification is not only triggered by climate-related processes (aggravated by climate change) but also by human activities, such as inappropriate land and soil management.

The biggest impact of drought is expected in southern European countries, such as Greece, Portugal, Spain, Cyprus, Bulgaria and Malta (Schlanger, 2018). The agricultural sector will also suffer from drought. In addition to insufficient water, salt water intrusion will be increasingly important. This process has been described in the estuary of rivers located in the west of the Netherlands, up to water intake points. Saline water cannot be used for irrigation.

Heatwaves constitute a further impact of climate change. The heatwave of 2018 was hotter than usual and more widespread (Vaughan, 2018). The greatest increase of heatwaves is being described in capital cities of Greece, Cyprus, Czech Republic, Italy, Bulgaria, Sweden, Malta and Austria (Schlanger, 2018). Figure 8 shows which impact heatwaves had from 19th July 2017 to 24th July 2018.

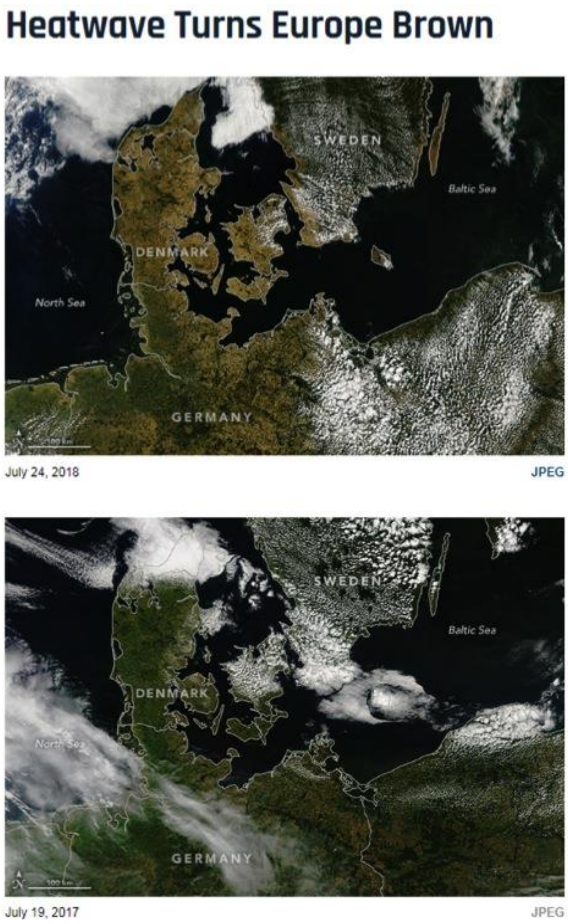

Figure 8: Heatwaves in Europe (Source: ESA, 2018).

2.2.2 Transboundary impacts of extreme weather events

Increasing flood events

The loss of soil ecosystem functions, such as a reduction of soil water holding capacity, can have a negative impact on water availability (e.g. water scarcity) and lead to higher risks of flooding (Van der Esch et al., 2017). Sea level rise increases the risk of coastal flooding, the erosion of coastal land and salinization of low-lying agricultural areas. Natural areas such as coastal wetlands and mangroves are at most risk. At the same time, coastal wetlands (and in tropical countries, mangroves) protect our coasts against natural hazards such as storms, tsunamis and coastal erosion. Also in Europe regions along the North Sea coast are affected by sea level rising. Regions that are not higher than 5 metres above the sea level are particularly endangered by floods. In the Baltic Sea, regions not higher than 3 metres above the sea level are concerned. Along these coast lines live around 3.2 million people, which may be affected through the increasing risk of floods (Spiegel Online, 2018).

Depending on geographical conditions, off-site effects of soil erosion by water and wind will cross national boundaries. Climate indirectly triggers water erosion through its influence on soil properties and soil cover. Soil texture, depth, structure, organic matter content and the presence of a surface crust strongly determine soil infiltration and soil water storage capacity, and therefore the response of soil to precipitation events. However, if future erosion rates exceed present rates, off-site impacts may become more widespread and more intense than today (Mullan, 2013). As an example, the costs of a landslide event in Italy exceeded 33 million Euro (Hervas, 2003). Overall losses for floods in the period 1998-2009 were about 52 billion Euro in EU-28. The EM-DAT database[7] includes a total of 594 flood events registered in EU-28 between 1990 and 2017, with a total registered damage of 141,980 million US Dollar. For the period 2002-2013, the average cost per flood event in the EU-28 was 360 million Euro (Fenn et al., 2014).

Floods of transboundary rivers are more severe than those of national rivers because they affect larger areas (Bakker, 2007). Moreover, floodwaters carry pollutants or are mixed with contaminated water from drains and agricultural land, resulting in a removal of topsoil and in some cases cross-border pollution. Southern Europe suffers mostly from flash floods, potentially more disastrous than other types of floods. Countries with flood-prone areas at the North Sea coast include The Netherlands, UK, Denmark, Belgium and Germany. Critical areas of coastal flood as a result of storm surges include the cities of Amsterdam, Hamburg, Copenhagen, London, Porto, Norwich and Riga.

Future climate scenarios show that further intensification of the hydrological cycle can be expected for a large part of Europe, which will result in more intensive floods and droughts. Under a +2°C global warming scenario extreme floods are expected in Spain, Greece, France, Ireland and Albania, according to Roudier et al. (2016). Furthermore, simulations reveal an increase in flood risk due to extreme rainfall in Western Europe, the British Isles and northern Italy (Rojas et al., 2012). Conversely, the flood risk would not increase in eastern Germany, Poland, Southern Sweden and in the Baltic countries due to a reduction in floods provoked by snow melting.

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[7] Source: http://emdat.be (9/11/2018)

So far, according to Blöschl et al. (2017), increased temperatures have led to earlier spring snowmelt floods in North-East Europe and delayed winter storms have led to later winter floods in the North Sea region and some parts of the Mediterranean coast. Additionally, earlier soil water saturation has led to earlier winter floods in Western Europe.

The analysis of shared river floods per year in Europe shows a steady increase of transboundary floods over the years. Europe has experienced the second highest number of transboundary floods between 1985 and 2005, with countries affected in the Danube and Rhine basins. When comparing the economic damage caused by floods of transboundary rivers by continent, Europe shows the highest accumulated damage with a total of 90 billion US Dollars between 1985 and 2005, which "is 90 times larger than the damage in North America, 40 times larger than in Africa, nine times larger than in South America and still four times higher than in Asia" (Bakker, 2009: 280).

Threatening human health

The number of forest fires increased aggravated by inappropriate land and soil management and by climate extreme events, such as droughts. In 2018 Europe experienced a number of forest fires. The roaring temperatures and a long period of drought were the main reasons for the increase of forest fires in Sweden (see Figure 9). Forest fires caused 74 casualties across different villages of Greece (Perper, 2018). Not only the fire itself threats humans, but also the have negative impacts for the respiratory system of humans (see Figure 10). Through the 2018 heatwave forest fires increased in southern Portugal (BBC, 2018). Since these forest fires in Portugal were near to the border of Spain, fires crossed to Spanish boundary (Neuroth, 2018).

Figure 9: Forest fire (Source: maxpixel.net).

Figure 10: Forest fire (Source: pixabay.com).

A further transboundary impact on human health is the transport and deposit of Saharan dust in southern Europe (see Figure 11). This was particularly important in Greece: African dust turned much of southern Greece into a landscape more akin to the planet Mars (see Figure 12) (Kokkindis, 2018). From the northern leafy suburbs to the Acropolis and the historical centre and all the way south to Piraeus, a thick orange cloud of dust blanketed the Greek capital as doctors warned vulnerable people to stay indoors (Carlowicz, 2018).

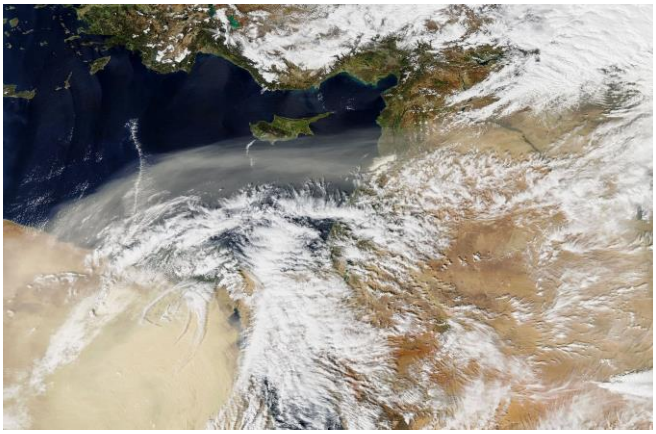

Figure 11: Saharan Dust over the Eastern Mediterranean (Source: wikimedia.org).

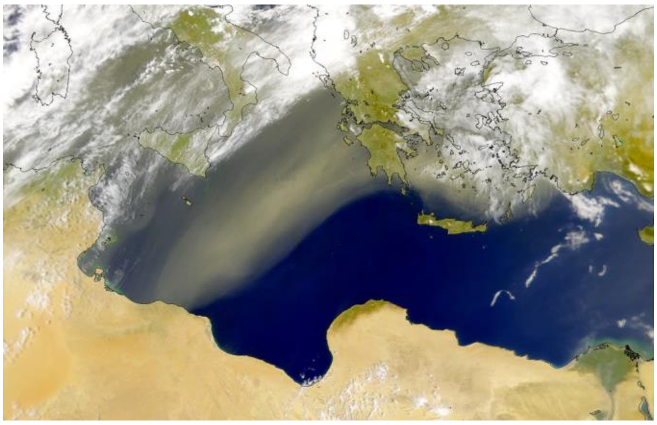

Figure 12: Sirocco from Libya (Source: wikimedia.org).

The transport of soil particles by wind and the harmful chemical substances such as glyphosate attached to them across long distances and intra-EU borders are another threat to human health. Especially because the pesticide residues transported by the wind can end up not only in the atmosphere but also in water bodies and again soils (Silva et al., 2018).

Intensified sedimentation

Sediment transport resulting from soil erosion gained importance in the context of river basin management and the European Water Framework Directive (EU WFD)[8]. "There are about one hundred transboundary river basins in the EU, 25 of which have identified soil erosion linked to agriculture as a problem" (Bucella, 2015: 4). The river Rhine is a known example of the transboundary impact of sediment transport (Asselmann et al., 2003). Estimates of sediment supply are about 117 million tonnes per year for the whole river under the current climate and land use. Especially the transport of **contaminated sediments** in transboundary river basins can have adverse effects on the environment, human health and the economy across borders. Because sediments move through the river basin to the sea, such effects can occur not only locally but also far from the source of the contamination.

[8] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

In the future, the Alps will continue playing an important role as source of sediments, whereas a reduction of sediment supply is expected in the German river sector due to land use changes. The increasing temperatures in the Alps are expected to lead to snow and glacier melting, inducing sedimentation transport in the valleys below. In the Danube river region, soil erosion in one country may result in reservoir siltation in another country downstream.

If the eroded sediments are deposited in an international river, soil erosion by water will have transboundary impacts for downstream countries, particularly through the increase and potential contamination of sediment load. When contaminated soils are water eroded, pollutants can cross boundaries, particularly during storm and flood events. This happens frequently when polluted, industrialized river banks are eroded. Peak loads are transported downstream, often crossing borders. Limitations in source control policies in an upstream country force the problem on to downstream countries.

"The Port of Rotterdam has to dredge every year between four and seven cubic meter of sediments, a good half of which are brought down by the river Rhine as an effect of unsustainable soil erosion upstream" (Bucella, 2015: 4).

Pushing migration

As previously mentioned, climate change contributes to migration and will force it in the next years (Apap, 2018). Migration can be defined as a strategy "to cope with temporal and geographical variability" (Foresight2011: 71) in order to change incomes and to secure livelihoods. It is estimated that millions of people are migrating globally each year due to degraded land (UNCCD, 2017). The number of migrants reached 258 million in 2017.

By 2050, the number of migrants could reach 200 million people, responding, in part, to increased environmental pressure (UNCCD, 2017; Apap, 2018). Hotspots of migration are the Sahel zone, the Middle East and Central Asia. About 40% of migration is linked to "[…] control or use of natural resources, such as land, water, minerals or oil" (UNCCD, 2017: 93). Land degradation and migration are often closely connected as they are influenced by population growth and the turn of "traditional or communal land tenure rights into private ownership" (UNCCD, 2017: 96).

Migrants responding to climate change are called 'climate refugees'. This term was not clearly defined or included in the 1951 Refugee Convention (Apap, 2018). Essam El-Hinnawi, from the UN Environment Programme (UNEP) "[…] defined 'environmental refugees as those people who have been forced to leave their traditional habitat, temporarily or permanently, because of marked environmental disruption (natural and/ or triggered by people) that jeopardized their existence and/ or seriously affected the quality of their life" (Apap, 2018: 4).

Seasonal migration includes for instance small-scale dryland farmers migrating for labour to cope with drought. Long-term migration from rural to urban communities is a social and economic process, partially driven by land degradation (UNCCD, 2017). According to this source, "in the future, climate change will influence the dynamic interactions of land degradation and migration by exacerbating natural phenomena that influence soil, water, and biodiversity, such as precipitation variability, droughts, and extreme weather events, and by affecting agricultural productivity, which in turn affects household incomes and the price of food" (UNCCD, 2017: 98).

Migration as a response to climate change is a serious issue not only in Africa but also in the EU. Displacement of people from rural areas to the cities (sometimes cross-border) is increasingly triggered by social and economic drivers and partly associated to land degradation and desertification. The consequence being land abandonment that can aggravate the degradation of soil and land, such as by increased soil erosion due to the fact that terraces or other protection measures are not maintained anymore.

Population in regions in coastal areas will be largely affected by climate change. Worldwide, in 2016, 24.2 million people had to be displaced due to natural disasters. Of them, 0.2% were located in Europe and Central Asia. The main part is affected in East Asia and the Pacific with 67.8% (Apap, 2018).

On the other hand, climate change leads to outmigration of the younger population. For example rural areas, such as mountain regions, are particularly vulnerable to the potential impacts of climate change, which can further impair the attractiveness of these regions for residents. These phenomena result in outmigration of the younger population, which in turn translates into a decline of human and social capital, a low rate of entrepreneurship and innovation and a general lower economic performance (ESPON, n.d.).

2.3 Economic growth

Economic growth as a driver includes especially globalization and the increasing world population with the increasing demand on goods, food and energy. It leads to the **pressures** land use management, waste management, industrial activities, energy production and urbanisation that have **transboundary impacts** such as increasing flood events, losing biodiversity and ecosystem functions, challenging food security, boosting climate change, threatening human health, affecting sedimentation, endangering water security (see Figure 13).

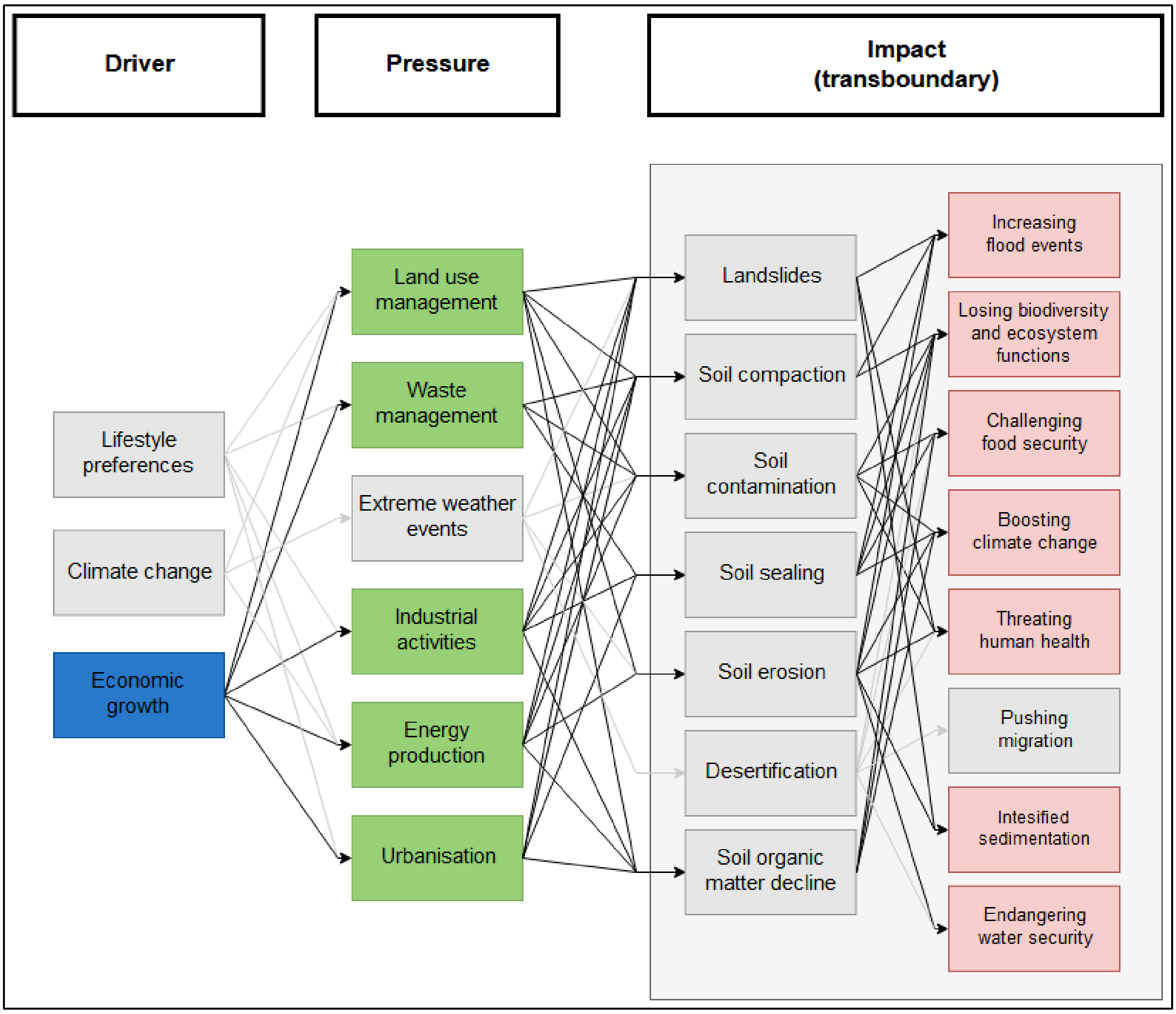

Figure 13: DPSIR approach applied to soil degradation from a transboundary perspective for the driver policies (Source: Own compilation).

2.3.1 Pressures from economic growth: Land use management, waste management, industrial activities and energy production

Land use management

About 95% of global food is produced in soil (FAO, 2015) and approximately 37.49% (as of 2015) of the global land area is already devoted to agriculture (The World Bank, 2018). With the growing world population and the described changes in lifestyle, it is expected that the cereal demand will increase up to 3 billion tonnes in 2050 (FAO, 2009).

On the one side, agriculture provides revenue for 10.8 million EU farmers and the output value of the agricultural industry (comprising output value of crops and animals, agricultural services and the goods and services produced from inseparable non-agricultural secondary activities) was an estimated 411.2 billion Euro in 2014. Agriculture and food commodities are very important economically, with 350 billion Euro trade on the internal market (for the year 2016) and 129.1 billion Euro trade in exports to third countries (in 2015) (EC, 2017), so it has a positive transboundary impact.

On the other side, much of the EU footprint of food and industrial products depends on cropland. Between 1995 and 2010 "[…] trade volumes and embedded cropland resources increased" (Fischer et al., 2017: 49). In 2010, the EU required 269 million hectares to satisfy the consumption within the EU which is 43% more land than the EU has available (De Schutter and Lutter, 2016). More than one fifth of the cropland required to satisfy the EU demand is located outside the EU, in countries such as Malaysia, Bangladesh, Thailand and Philippines (Fischer et al., 2017). Producing outside the EU, results in additional environmental and social impacts. Key regions providing European food security include 17 million ha from South America and Sub-Saharan Africa (Fischer et al., 2017). Fischer et al. (2017) showed that the cropland footprint in the EU decreased from 170 to 157 million ha in the period 1995 to 2010, whereas the consumption of non-food industrial products increased from 463 m^2 per capita in 1995 to 540 m^2 in 2010. The crop-based industrial footprint increased by 14% since 1995. A major supplying country for 10% of non-food cropland footprint for the EU is China. As an exporter of maize for industrial uses, North America plays an important role for the EU. It adds up to 10% of the non-food cropland footprint from the EU. Africa and Middle East took about 7% (Fischer et al., 2017).

EU food consumptions put a lot of pressure on agricultural land in Europe but also globally.

Unsustainable soil use and management due to agricultural land use intensification threatens both the quality and quantity of European and global soil stocks (GSP et al., 2015). According to the FAO, 32% of global soils are estimated to be moderately to severely degraded due to natural and anthropogenic factors, in particular unsustainable soil management (FAO, 2016a). Soil erosion, loss of organic matter, salinization, soil pollution and compaction (with subsequent impact on soil biodiversity) are the main forms of degradation of agricultural soils worldwide (GSP et al., 2015).

In order to increase crop yield, farmers apply mineral and/or organic fertilizers. In the northwest of Europe (in countries such as The Netherlands or Germany) there are many livestock farms with intense animal production (Deutscher Bundestag, 2013). Since the Dutch manure legislation changed in 2006, less manure can be placed on agricultural lands.

This is why manure is exported outside the Dutch agricultural sector (Figure 14). In 2016, almost 2.2 million tonnes of manure were exported to Germany. This represents 66% of the total manure exports from the Netherlands (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2017).

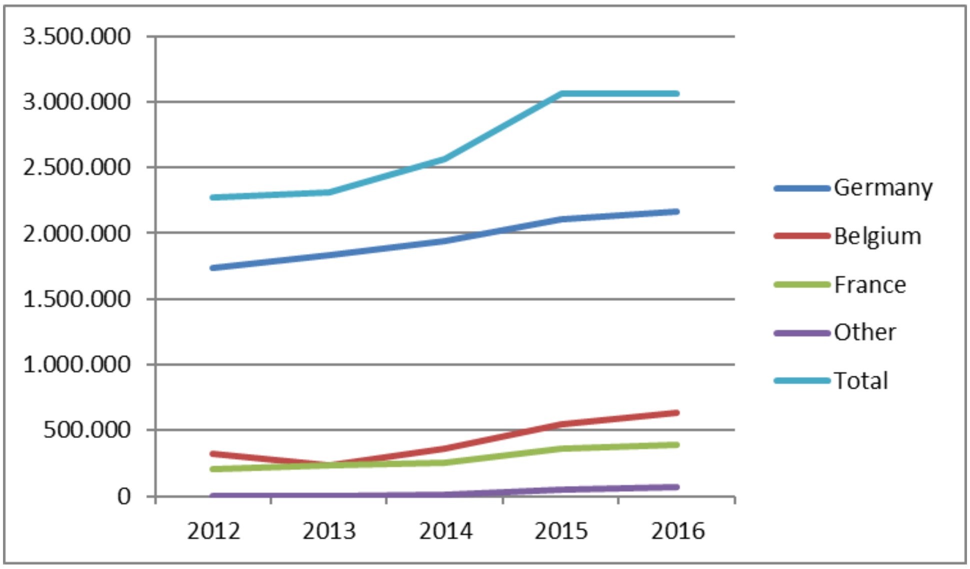

Figure 14: Export animal manure from the Netherlands (tonnes per year) (Source: https://www.rvo.nl/sites/default/files/2016/05/Overzicht%20export%20di-erlijke%20mest%20per%20jaar.pdf (29/08/2018).

Waste management

If Europe treats waste as a resource, it can secure social and economic benefits and reduce environmental pressures. One of the key aspects of resource efficiency and circular economy is to prevent and manage waste. Europe has various waste policies and targets since 1990 including legislation on waste streams, e.g. packaging, vehicles and electronic equipment, or on prevention and recycling of waste. Between 2004 and 2010 the EU, Iceland and Norway reduced their total waste deposited in landfills by about 23% (from 205 billion to 157 billion tonnes waste). In contrast to the decrease in waste deposit in landfills the export of waste from EU member states to Asia has grown. This includes the export of waste iron, steel, copper, aluminium and nickel, which has doubled from 1999 to 2011. The transboundary movements of waste have various positive impacts for the country of origin, thereunder lower financial costs for waste management and also lower environmental costs (EEA, 2015c).

Landfilling represents an enormous loss of resources in the form of both materials and energy. In addition, the management and disposal of waste can have serious environmental impacts. Landfills, take up land space and may cause air, water and soil pollution, while incineration may result in emissions of air pollutants.

The EU Waste Framework Directive[9] therefore aims to reducing the environmental and health impacts of waste and to improve the EU's resource efficiency (EC, 2008). Moreover, in 2015 the European

[9] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.

Commission adopted an action plan for the circular economy promoting the concept of recycling wastes as secondary raw material

The long-term aim of these policies is to reduce the amount of waste generated. When waste generation is unavoidable, the goal is to promote it as a resource and achieve higher levels of recycling and safe disposal. In 2014, 4.9 tonnes of waste were generated per EU inhabitant (Eurostat, 2017). Figure 15[10] shows an overview of the waste generation by economic activities and household.

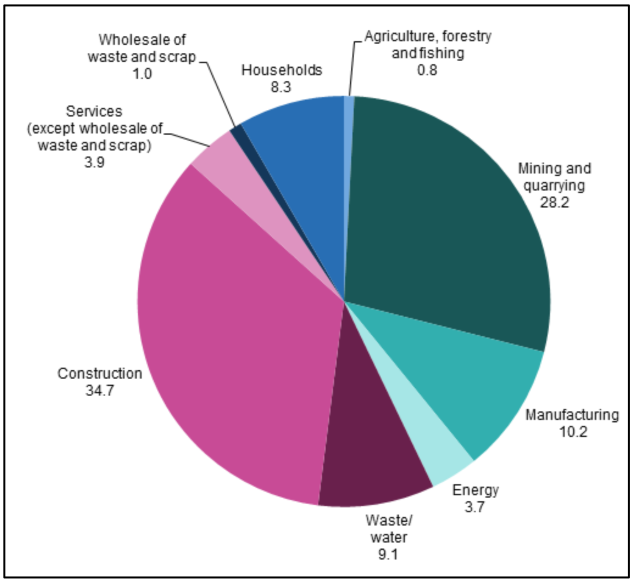

Figure 15: Waste generation by economic activities and households, EU-28, 2014 (%) (Source: see footnote 10)

The disposal of waste has transboundary effects. For example, the UK sends their waste overseas for recycling, but because of inadequate controls there is a possibility that this could be dumped or sent to a landfill instead. In 2017 the UK sent their waste to countries such as China, Turkey, Malaysia and Poland (Hughes, 2018). Strong and sufficient controls from the Environment Agency on waste dumping are required to prevent abuse of the system. Another step was taken by China in 2018 by adopting a law banning the import of waste from external countries.

Industrial activities

(Historical and current) industrial activities are a driver for pollution and waste production in different forms. With industrialization, soil contamination by heavy metals and mineral oil became a widespread problem in Europe (Science Communication Unit, 2013).

Air pollution by industry is a threat to soils not only in the regions where it occurs but also, depending on wind direction and intensity, further away. Due to EU regulations and new technologies air pollution in the EU has decreased since 1990 for all main air pollutants (EEA, 2017a). But air pollution is still significant and leads to soil and groundwater contamination. Most studies concerning transboundary impact of contamination focus on diffuse transport of contaminants between countries. Kaitala et al. (1992) presented an example of transboundary impact of soil contamination and showed that sulphur emission from the former USSR had been transported to Finland.

Energy production

[10] Source: https://ec.europa.eu/eurostat/statistics-explained/images/c/c7/Waste_generation_by_economic_ activities_and_households%2C_EU-28%2C_2014_%28%25%29_YB17.png (9/11/2918)

Energy production and distribution, energy use in industry and industrial processes and production are primarily responsible for the emission of heavy metals, e.g., cadmium (Cd), mercury (Hg) and lead (Pb) (EEA, 2017b). Germany, Poland, Italy and Spain were the countries with the highest emissions of Pb and Cd in 2015. Energy production and land management can be influenced by socio-economic and political factors (e.g. policies conditioning the choice of land use and crops; adoption of control measures as a function of crop economic margins) (Borrelli et al., 2016). The energy production from biomass and renewable waste increased in the EU territory by 302% between 1990 and 2015 (Eurostat, 2016). Agricultural biofuel production is in potential competition with agricultural food production and might also induce unsustainable land use changes and inappropriate soil management. According to De Schutter and Giljum (2014), in order to meet the National Renewable Energy Action Plans of EU member states, biomass for energy generation should occupy 10.9% of the cultivated land and 31.6% of the forested area in the EU in 2020, when making the assumption that all required biomass is produced in the EU. This is also related to the EU's land footprint.

With the revised Renewables Energy Directive[11] the EU established a new binding renewable energy target for 2030 of at least 32%. However, the legislation for energy production differs widely across Europe, with countries such as Romania having no specific legislation on where to build solar panels, so that solar energy panels are placed on fertile soils. However, policy impacts are to be assessed not only in relation to the objectives of the specific policy. For example, in Slovakia land is bought by German and Austrian companies. This issue known as land grabbing is a concern at EU level in particular in Eastern countries such as Romania, Slovakia and others and was already addressed by the European Parliament in 2017.[12]

These companies often get a subsidy from the EU, e.g. for the production of biofuels, but the local ecosystem functions are distorted. Unsustainable land use changes stimulated by energy production involve not only transitions between broad groups of land use type but also changes in intensification of arable land use or simplification of cropping structure (e.g. monocultures for biofuel production).

[11] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

[12] European Parliament 2017. Motion for a European Parliament Resolution on the state of play of farmland concentration in the EU: how to facilitate the access to land for farmers (2016/2141(INI)).

2.3.2 Transboundary impacts of land use management, waste management, industrial activities and energy production

Endangering water quality

More and more concerns are expressed about the impact of soil degradation on environmental and human health. Soil degradation can lead to water contamination when the filtering capacity of the soil is not sufficient to neutralise contaminants. Soil erosion that washes away sediments in one country can block dams or damage infrastructure such as harbours in other countries; contaminated soil can also pollute the groundwater in a neighbouring country. Loss of land capacity to fulfil production, ecosystem or recreation functions due to soil and groundwater contamination in post-industrial regions might have socio-economic transboundary consequences, such as land abandonment, loss of income or deterioration of public health. Nutrient leaching due to over-fertilisation and pollution (of water and soil) from the overuse of pesticides is another example of degradation with impact on human health.

The reports from the Baltic Marine Environment Protection Commission (HELCOM) under the Helsinki Convention illustrate the transboundary effects of soil contamination on surface water. The Baltic Sea is enclosed by Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. Eutrophication caused by oversupply of nutrients in agricultural land around the Baltic Sea is the major environmental pressure on the marine ecosystem. Harmful chemicals and heavy metals enter the Baltic Sea via numerous sources, including from waste water treatment plants, leaching from landfills and filling material, spreading of sewage sludge, atmospheric deposition of industrial emissions, and agricultural use of fertilisers and pesticides (HELCOM, 2018).

The disposal of waste outside the EU leads to waste not being recycled according to EU standards. This creates landfills and contributes to pollution (Hughes, 2018). The waste receiving countries have no possibilities to safely dispose of it, and pollution increases.

Boosting climate change

Soils can be a source or a sink of carbon and greenhouse gasses depending on their properties and state. Soil is the world’s largest terrestrial pool of carbon (Scharlemann et al., 2014; IPCC, 2000) and plays a crucial role in the global carbon balance (Lal, 2013). At a global level, the soil organic carbon (SOC) pool stores more carbon than is contained in the atmosphere and terrestrial vegetation combined (GSP et al., 2015). Climate conditions, soil characteristics and the management and land-use practices determine the potential of soils to offset atmospheric CO_2 levels through carbon sequestration.

Assessments of future SOC change for Europe have concluded that northern (versus southern) European countries will have the greatest (versus the lowest) potential for SOC sequestration by 2050 under different management scenarios (Lugato et al., 2015). Soil carbon stocks in the EU are estimated between 73 and 79 billion tonnes, of which about 50% are stored in peatlands in the UK, Finland and Sweden (Schils et al., 2008).

Transforming peatlands into croplands for bioenergy production entails soil subsidence, loss of water holding capacity, rapid organic matter degradation and CO_2 emissions. Some land use changes strongly affect the soil C stock. However, conversion back to grassland increases the C stock, as documented in a long term study in Sweden (Kätterer et al., 2008). The degradation of peatlands caused by peat extraction and drainage for agriculture or forestry is estimated to affect 49% of peatlands in the EU (Schils et al., 2008) and has a huge impact on carbon emission at continental and global scale. Furthermore, mineralisation of peat soils limits water retention at landscape level, which in consequence might change local climate and resilience of the ecosystem to droughts.

This transboundary responsibility to use soil as a carbon sink has been emphasized by the call of the "4‰ Initiative. Soils for food security and climate" by the French Ministry of Agriculture, Agrifood, and Forestry (2017). This initiative promotes locally adapted agricultural practises such as conservation agriculture to increase soil organic matter content and support carbon sequestration. The initiative combines a voluntary action plan with a research program that governments, farmers, NGOs and research institutes can join. They are asked to set-up training programmes, create policies and provide financial support for development projects to support the aims of the initiative.

Losing biodiversity and ecosystem functions

The future value of ecosystem services (ESS) has been estimated under various scenarios by the Economics of Land Degradation (ELD) initiative (UNCCD, 2017). Through government interventions and effective land policies, the value of ESS could be increased by about 3.2 trillion US Dollar per year. A promotion of adequate policy measures is needed for a sustainable socio-economic value of land (Kubiszewski et al., 2017).

In rural areas soil compaction is accelerated by heavy agricultural machinery and frequent vehicle traffic or intensive trampling by animals. Reducing farming labour leads to the use of larger and more effective machinery (Schjønning et al., 2015). The expectation of increased agricultural biomass production for energy purposes might induce recovery of marginal lands for cropping. However, use of certain types of marginal land for biomass production shall be avoided as it can be a biodiversity hotspot.

Threatening human health

Another example of health threat is the transport of Saharan sands to countries in Europe. This is a well-observed phenomenon – so it is no wonder that wind erodes and transports soil particles also between European countries. However, the actual evidence-base and data on the extent is by far smaller than for water transported soil fragments. Illegal waste dumping abroad has negative healthy effects on the local people that receive the waste (EEA, 2015c).

Related to land use management, local **contamination of agricultural soils** can lead to transboundary risks when resulting in food contamination that subsequently circulates freely in the EU internal market. In the past, EFSA (2012) has provided scientific evidence that the actual dietary exposure to cadmium exceeds the tolerable dietary exposure more than twice for a significant number of Europeans, including children. Food from agricultural products is the main source of cadmium exposure for the general, non-smoking population in the EU, and fertilisation with phosphate fertilisers is by far the main cause of cadmium contamination of European agricultural soils.

3. Current responses

The assessment of the significance of drivers and severity of transboundary impacts of soil degradation obviously requires political actions based on a rigor scientific understanding of the processes and actual data of the extent of the effects. As long as general basic information on soils and socio-economic information linked to soil degradation are missing, the transboundary impacts are difficult to estimate and policies are difficult to design and to enforce. Therefore, this chapter presents the actions that are already taken at supranational level and also in data provision and monitoring.

3.1 Political strategies

3.1.1 Global level

At the global level several prominent political strategies such as the Sustainable Development Goals (SDGs), the United Nations Framework Convention on Climate Change (UNFCCC) or the Convention on Biological Diversity (CBD) address soil protection among others. In addition, to date 122 countries have engaged with the **Land Degradation Neutrality** (LDN)[13] Target Setting programme. The LDN approach requires measures to sustainably conserve, restore and manage land. In 2017 FAO published the **Voluntary Guidelines for Sustainable Soil Management** (FAO, 2017). The document detailed several measures for soil protection from a number of threats. Even though these guidelines are not binding, they provide knowledge to farmers and other stakeholders and could have a transboundary effect when they, for example, lead to the increase of SOC stocks.

The importance of soils to help offsetting atmospheric CO_2 levels increase is reflected in several international initiatives. For example, during the last COP21 conference in Paris, the **4 per 1000 initiative** was launched to promote the adoption of agricultural management practices, such as no-tillage, organic fertilization or crop diversification that are aimed at increasing SOC sequestration. In terms of transboundary effects, the initiative pursues an annual target of 0.4% increase in SOC stocks in agricultural soils to compensate the yearly increase in atmospheric CO_2 concentration.

3.1.2 European level

The **European Water Framework Directive (WFD)**[14] is the best examples of a policy that addresses transboundary drivers as well as impacts of (soil) degradation. The aim of the WFD is to protect and improve the quality and quantity of water bodies across the EU which requires that waters are addressed from a hydrological and not from an administrative perspective. The WFD considers transboundary effects within river basins by requesting that "[…] all programmes of measures, should be coordinated for the whole of the river basin district" (EC, 2000: 7). In terms of soils the WFD covers soil erosion by water, floods, soil contamination and soil sealing.

[13] LDN was defined by the UNCCD (2017: 274) as "a state whereby the amount and quality of land resources, necessary to support ecosystem functions and services and enhanced food security, remains stable or increases within specified temporal and spatial scales and ecosystems".

[14] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

Member states are requested to cooperate with each other in a river basin including the development of cross-border monitoring programs, the coordination of comparable assessment procedures, the definition of common water management issues and the implementation of measures. International river basin commissions have been established for many transboundary river basins, such as the International Commissions for the Protection of the rivers such as the Rhine (ICPR), the Elbe (IKSE) or the Danube (ICPDR). The close cooperation between the member states in the river basin also harmonise data collection and presentation.

The WFD is linked with other policy measures, such as agri-environment-climate measures (AECM)[15]. For example, specific AECM can focus on the reduction of nutrient pollution along water courses. Moreover, in the Netherlands farmers need to cooperate to be eligible for AECM funding. This could be an interesting approach for soil threat sensitive transboundary regions, where AECM, e.g. on reducing erosion, could be designed that require the cooperation of farmers across national borders.

The **Floods Directive**[16] is also linked to the WFD and aims to manage and reduce "[…] the impacts of flooding on people (including health and life), the economy, cultural heritage, and the environment" (Priest et al., 2016: 50). The Floods Directive shall be implemented together with the WFD and requests the development of a common framework in order to manage transboundary flood risks (Frelih-Larsen et al., 2016). It includes the coordination between member states on flood prevention and mitigation and for establishing flood risk management plans. Likewise, member states shall not undertake measures that would have negative impacts or increase the flood risk in neighbouring countries. Thus, the Floods Directive considers transboundary effects of measures for preventing floods and their impacts and also with the cooperation across borders (Priest et al., 2016).

Another positive effect of the WFD is spill-over effects as countries outside the EU also adopt WFD mechanisms: For example, the Sava river (tributary of the Danube) runs through Slovenia, Croatia, Bosnia and Herzegovina, and Serbia, with part of its catchment in Montenegro and Albania. The International Sava River Commission is working together with these countries on the development of the Sava River Basin Management Plan, in line with the Water Framework Directive. Switzerland cooperates with neighbouring states in the context of water protection, adopting certain principles of the Water Framework Directive.

The **Thematic Strategy for Soil Protection** is the only policy instrument at EU level, which exclusively addresses soil protection. It is a strategic framework for action such as awareness raising, policy integration and research which requires the sustainable use of soils to prevent further degradation, to preserve soil functions and to restore degraded soils (EC, 2012a). The Thematic Strategy for Soil Protection explicitly states that soil degradation can have transboundary consequences and gives particular consideration to the loss of organic matter, sediment transport and contamination as transboundary effects.

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[15] The Rural Development Programme (Regulation (EU) No 1305/2013) requires the design and implementation of AECM of the EU MS focus on the protection of agricultural soils.

[16] Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks

Figure 16 presents an overview of all existing EU directives or strategies addressing soil protection and considering soil threats directly or indirectly. The ones coloured in red mention transboundary effects or require transboundary cooperation, even though only few of these red coloureds actually have a transboundary effect. Examples of directives that mention transboundary effects or require transboundary cooperation are:

- The **Environmental Liability Directive**[17] requests that if environmental degradation affects several member states they shall cooperate to take action.
- The **Habitats Directive**[18] encourages transboundary cooperative research between member states.
- The **Birds Directive**[19] requests that the habitats of wild birds have to be declared as special protection areas. These special protection areas are often transboundary (especially because they affect to migratory birds) and require measures to be implemented in cooperation between member states.
- The **National Emission Ceilings Directive**[20] considers air pollution as a transboundary problem.
- The **Environmental Impact Assessment (EIA) Directive**[21] explicitly takes account of transboundary impacts of soil degradation. Examples are impacts of long-distance railway lines, motorways or waste water treatment plants (EC, 2013a: 3). Assessments consider transboundary effects of projects, which can have impacts on the environment across borders, and requires that the authorities and the public of the affected neighbouring countries have to be involved.
- The **Strategic Environmental Assessment Directive**[22] explicitly refers to transboundary effects in the case when plans or programmes might have a significant environmental effect in another member state.

[17] Directive of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage - 2004/35/EC

[18] Council Directive of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora - 92/43/EEC

[19] Directive of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds - 2009/147/EC

[20] Directive of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC (Text with EEA relevance) - 2016/2284/EU

[21] Directive of the European Parliament and of the Council of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment Text with EEA relevance - 2014/52/EU

[22] Report from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions on the application and effectiveness of the Directive on Strategic Environmental Assessment (Directive 2001/42/EC) - COM/2009/0469 final

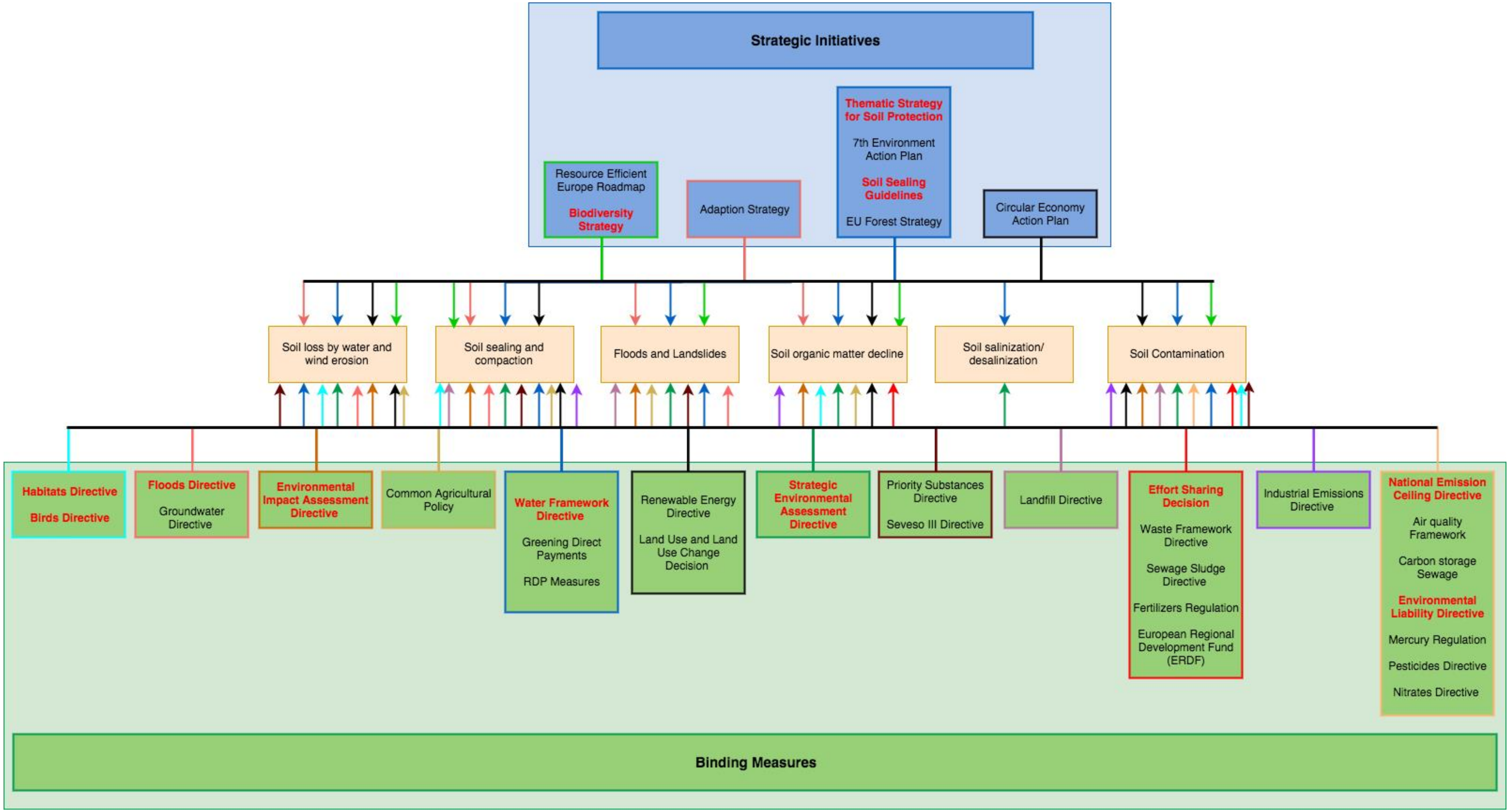

Figure 16: European policy instruments related to soil protection (Source: Own composition based on Frelih-Larsen et al., 2016)

3.2 Data provision and monitoring

The provision of permanently available quality-proven data (scenarios) and technologies is crucial for land users, planners and decision makers. Limitations in harmonized soil data throughout the EU have hampered the adoption of soil protection policy instruments (Montanarella, 2006). That is one of the reasons why **data, data availability and harmonisation** are most relevant also for the transboundary dimension of soil degradation. For example, there is a lack of data about the emission for all pollutants because EU member states did not report the data for each year (EEA, 2017c). Without such data, initiating agenda setting for a policy process is difficult.

Soil scientists succeeded to provide information on the degradation effects on soil natural capital and the flow of soil services. Computational modelling has proven to be a key tool for integrated assessments and mitigation strategies in the field of soil erosion (Bosco et al., 2015). However, scientists are being criticised for focussing too much on modelling and neglecting the more expensive approach of field work (Bouma et al., 2012). Yet, recent research also emphasizes the remaining gaps in knowledge about soil processes and that **new approaches to modelling** are needed (Vereecken et al., 2016 and Vogel et al., 2017).

The heterogeneity of national systems for the study of soils resulted in difficulties for the **homogenization of available national maps** and related soil data. Additionally, a number of European countries have not yet systematically produced sufficiently detailed soils maps. Parts of the required data and information on soil degradation are provided by the **COPERNICUS** programme, using remote sensing techniques. Copernicus provides information on land cover and land degradation. Information on soil is derived from LUCAS soil which is the first European scale soil surface monitoring programme covering all EU countries. Most of EU countries have already been surveyed three times (in 2009/2012, 2015 and 2018). Each campaign covers approximately 27 thousand soil samples out of 270,000 field sites at the same georeferenced locations. The field work, besides soil sampling, involves the collection of information on land cover (crop) and land use type. From the first LUCAS edition, soil analysis includes texture, pH, soil organic carbon, total nitrogen, available phosphorus and potassium, calcium carbonate, cation exchange capacity, spectral data. Subsequently, trace elements have been included.

The European Commission together with the European Environment Agency (EEA) established the **European Soil Data Centre (ESDAC)** that is hosted by the Joint Research Centre (JRC). Modelling, such as for erosion or soil organic carbon, is also carried out by the JRC. In addition, the EEA defines indicators and provides information on the state of soil, as reported in the State of the Environment reports. Another data source at European level is the **Geochemical Mapping of Agricultural and Grazing Land Soil (GEMAS)**.

Since decades, many **EU funded projects** within different programmes such as **Horizon**, **LIFE**, **Cohesion Policy** or the trans-national network for programming and funding **BiodivERsA**, to mention only a few, involve not only partners from different countries but work on topics related to investigating and solving soil related questions of European and even global relevance. Besides, at European level many networks and working groups are active, such as the EIONET NRC Soil or the European Soil Partnership, and share knowledge and experience not only between scientists but also between science, practice and policy makers. Additional examples are the NICOLE network and the Common Forum (CF) on Contaminated Land. The CF is a platform linking policy makers, environmental agencies, administration representatives and scientists to exchange knowledge and stimulate discussion on managing contamination and other soil threats. It contributes to discussions and analyses of EU directives and their implementation, e.g. Environmental Liability Directive[23] or Industrial Emission Directive[24].

[23] Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage.

[24] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).

4. Recommendations for future action

This report illustrates examples of how (often global) drivers lead to rather local or regional pressures that have off-site and even transboundary impacts. The DPSIR framework was applied to make these links explicit because so far there has not been any analysis of the transboundary impacts of soil degradation even though it is highly required. The severity of transboundary impacts of soil degradation obviously requires political actions based on a rigorous scientific understanding of the processes and actual data of the extent of the effects. However, as long as general basic information on soils and socio-economic information linked to soil degradation are missing, the transboundary impacts are difficult to quantify and policies are difficult to design and to enforce.

4.1 Political action needed from global to local level

To address drivers of soil degradation that have a transboundary dimension (impacts) such as lifestyle preferences, **political actions at different levels are required**. But also policies that lead to pressure on soils by land use and waste management or energy production need to be addressed. **Global action** is urgently needed for adapting and mitigating climate change to reduce impacts such as flood events, migration, increasing food insecurity or impacts on human health. Especially climate change needs to be addressed at global level aiming at sustainable solutions for reducing environmental impact of human activities. Also trade negotiations can contribute, e.g. global environmental and socio-economic impacts of imports in the EU, in particular the land footprint, are not yet considered in trade policies (Würtenberger et al., 2006), but also need to be analysed and addressed in future policies. There is already an increasing awareness of the global land footprint of EU's consumption and land grabbing within the EU, as for example shown by the European Parliament resolution on violation of the rights of indigenous peoples in the world, including land grabbing (2017/2206(INI))[25] or by reports (for example De Schutter and Lutter, 2016; Kay, 2016), but it requires further follow-up.

The consequences of land degradation for ecosystem functioning are still not specified in global assessments, especially due to the uncertainty about the long-term consequences of unsustainable land management practices: “The question is to what extent land degradation will compromise agriculture, water availability and flows, and other ecosystem functions over the longer-term future.” (Van der Esch et al., 2017: 58).

Discussion needs to be initiated at **European level** on who bears the costs of degradation, as this would also increase the awareness about the transboundary dimension. But prior to this discussion, **costs need to be assessed**. So far, many direct and indirect costs are linked to transboundary impacts of soil degradation, but they have been assessed in only a few cases. The Economics of Land Degradation (ELD) initiative already approaches costs of land degradation, but for Europe it has to be specified and extended. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) points out that “[o]n average, the benefits of restoration are 10 times higher than the costs, estimated across nine different biomes” (IPBES, 2018: 10).

[25] European Parliament resolution of 3 July 2018 on violation of the rights of indigenous peoples in the world, including land grabbing (2017/2206(INI)).

A respective initiative is required to assess these costs in a comprehensive manner, e.g. through research funding for identifying suitable assessment methods and funding to support the data collation and assessment of costs (e.g. by EEA or EU member states).

Finally, **communication** and collaboration between different policies and disciplines is required to reduce trade-offs between policies such as energy and soil or nature protection policies. In this regard it is important to understand the increased diversity and extent of transaction costs of policy measures (design and implementation) at a transboundary level as compared to a national or regional level, to keep them low and select most efficient measures.

Many **initiatives at local, regional and national levels** exist that can be **enhanced** and **linked** to the transboundary impact. An example from the Netherlands is the paradigm of not building against nature but with nature (e.g. EcoShape project). Another is the 100 Resilient Cities Initiative, where municipalities are working with spatial planning for climate change preparedness and mitigation: e.g. infrastructures to protect against floods. Another example is brownfield regeneration. Industrial areas are often built on greenfields. It has been argued that increased re-use of developed land that lost its original function is required, reducing, for example, the pressures on agricultural and grasslands. Such brownfield regeneration is increasingly understood as a local and regional effort, which supports ecological, social and economic status of (also transboundary) regions (Limasset et al., 2018; Bartke and Schwarze, 2015).

Despite the fact that soil protection is subject to the shared competence between the EU and its member states, which means that the EU can only act when the policy objectives cannot be achieved sufficiently by the member states themselves, an EU action on soil protection would have an added value compared to actions only by the member states:

1. The impact of degradation is not limited to the area of degradation but increases the pressure on soils elsewhere, e.g. for food or energy production. European policy needs to ensure the protection of citizens of a given country from the impact of soil degradation in another country.
2. The EU and its member states are subject to international treaties and commitments that need to be fulfilled, including efforts to address land and soil degradation.
3. In the medium term the loss of soil functions and services across the EU will impact on the EU´s overall competitiveness and as such the welfare and quality of life of EU citizens.

4.2 Increased understanding of processes through data collection and monitoring

A key challenge that has been outlined in previous chapters is that the **evidence base** for the exact extent of the impact effects is still scattered. This is partly due to a lack of land use and soil degradation data in some member states and partly due to lacking awareness for the transboundary dimension of soil degradation. An assessment of drivers and transboundary impacts of soil degradation needs to address a range of topics concerning the collection and processing of data, harmonizing data and linking and managing data.

Knowledge gaps about soil parameters and indicators still represent a significant knowledge gap demanding further research, as was found by the EU project INSPIRATION (Bartke et al., 2017). Moreover, social and economic data are required in order to assess the specific impacts (extent and costs) due to a transboundary caused loss of soil functions and the related decline of ecosystem services due to cross-border soil degradation. Such an **assessment** is needed as a basis for the provision of new and comparable data in order to understand and quantify drivers and impacts of soil degradation and, based on such evidence, to inform practical and policy response.

Data generation and processing requires harmonised **methods for data acquisition and evaluation**. In some member states, no coherent data collection methods exist. This increases the complexity of data comparability across national borders. A start has to be made at local/regional level on data and information on impacts, and then go up in scale (national/EU/global). Local and national data and thus impacts might be obtained more easily than at transboundary level. For example, check the conditions for a city to become climate proof, what will the effects of an extensive rainfall be (can the soil take up the water, where will it flood)? And subsequently, how will this affect the cross-border region?

Protecting soils to decrease transboundary effects requires a sound understanding of soil processes and gathering of input data from many different stakeholders, such as scientists and land owners, project developers, land users, planners and others. Research programs at European and national level provided already many data on soils and soil degradation from different sources. However, projects so far have focused on very specific regions or degradation types, such as cross-border pollution remediation of heavy metals or chlorinated solvents (BENEKEMPEN, Citychlor). A systematic inventory of those projects is lacking. There is a need for supporting further scientific research that aims at working on transboundary issues systematically for gathering, monitoring and evaluating data for Europe (soil functions, degradation, related costs).

Pressures on soils can be quantified with the use of models together with the support of monitoring systems but it requires harmonized data, an example is data on contaminated sites, on national as well as on EU-level. Moreover, **standards and protocols for data** in support of vulnerability and risk assessments, and decision-support systems need to be established. The INSPIRE Directive[26] supports the set-up of a spatial data infrastructure for sharing data for policy making also in transboundary contexts. Advancing the application of INSPIRE together with the PSI Directive (Public Sector Information)[27] could support free access and the right to use the spatial data generated under the INSPIRE Directive.

Research activities should be linked to the increasing integration of stakeholders in collecting and monitoring activities, as well as in assessment activities. Such a transdisciplinary process will not only increase the data base for soil information collection and monitoring activities – but it will most importantly also raise the awareness for soils, their functions and services.

[26] Directive 2007/2/EC of the European Parliament and the EU Council from March 14, 2007.

[27] Directive 2003/98/EC of the European Parliament and of the Council of 17 November 2003 on the re-use of public sector information.

Linking data is essential for all policy fields and sectors. One example is to establish a flood risk management system that links local data at national level and provides the basis for cost-effective risk mitigation measures. The **combination of different data** can serve for estimating effects. For example, (i) soil sealing, with river speed data and effects of downstream flooding; (ii) soil permeability (instead of soil sealing) with rainfall intensity; (iii) economic data on costs of prevention measures but also damage costs; (iv) data on societal impact, e.g. impact of flood protection measures on human well-being or health impacts.

Once data are available, they need to be managed and at the same time be protected from misuse. So far data are scattered across organizations without having a pool. A **repository with all the data/reports** and information available would be an interesting tool for researchers and planners. Panagos et al. (2016) call for a pan-European soil and water conservation service that would collaborate with regional services for disaster prevention and sustainability. A data exchange platform could be established based on the ESDAC model.

Monitoring is a key component of soil protection as information is key for policy and decision making. In fact, as pointed out by the INSPIRATION project, without the information on soil properties and their trends, linking demand of soil services and natural capital is impossible. INSPIRATION illustrates that European monitoring activities exist but need to be strengthened. For example, hazardous compounds and fluxes of compounds are being monitored but cannot be harmonised easily or for all transboundary regions. So far, **soil monitoring networks** have focused on assessing the trends of hazardous compounds in soil, soil biology, and erosion, and in some intensive monitoring sites also fluxes of compounds between soil and groundwater. Such data and monitoring are a **precondition for potential warning systems** that can help prevent hazards (e.g. floods, wind erosion) and risks to soils (e.g. due to contamination).

The consequences of land degradation for ecosystem functioning are often not specified in global assessments, especially due to the uncertainty about the long-term consequences of unsustainable land management practices: “The question is to what extent land degradation will compromise agriculture, water availability and flows, and other ecosystem functions over the longer-term future.” (Van der Esch et al., 2017: 58). There is a high level of uncertainty about critical tipping points leading to ecosystem collapse.

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References

Agora Energiewende and Sandbag 2018. The European Power Sector in 2017. State of Affairs and Review of Current Developments. Available at: https://sandbag.org.uk/wp-content/uploads/2018/01/EU-power-sector-report-2017.pdf (24/10/2018).

Apap, J. 2018. The concept of 'climate refugee'. Towards a possible definition. European Parliamentary Research Service (EPRS). Available at: http://www.europarl.europa.eu/RegData/etudes/BRIE/2018/621893/EPRS_BRI(2018)621893_EN.pdf (24/10/2018).

Asselmann, N. E. M., Middelkoop, H., Van Dijk, P. M. 2003. The impact of change in climate and land use on soil erosion, transport and deposition of suspended sediment in the River Rhine. In: Hydrological Processes 17: 3225-3244.

Bakker, M. 2007. Transboundary river floods: vulnerability of continents, international river basins and countries. Oregon State University, PhD Dissertation.

Bakker, M.H.N. 2009. Transboundary river floods: examining countries, international river basins and continents. In: Water Policy 1: 269–288.

Bartke, S. and Schwarze, R. 2015. No perfect tools: Trade-offs of sustainability principles and user requirements in designing tools supporting land-use decisions between greenfields and brownfields. In: Journal of Environmental Management 153: 11 – 24.

Bartke, S., Boekhold, S., Brils, J., Grimski, D., Ferber, U., Gorgon, J., Guerin, V., Makeschin, F., Maring, L., Nathanail, C.P., Villeneuve, J., Zeyer, J. and Schröter-Schlaack, C. 2017. Soil and land management in Europe: Lessons learned from INSPIRATION bottom-up strategic research agenda setting. In: Science of the Total Environment, in press, doi: 10.1016/j.scitotenv.2017.11.335.

BBC 2018. Europe heatwave: Spain and Portugal struggle in 40C+ temperatures. Available at: https://www.bbc.co.uk/news/world-europe-45070498 (29/08/2018).

Behnisch, M., Poglitsch, H. and Krüger, T. 2016. Soil Sealing and the Complex Bundle of Influential Factors: Germany as a Case Study. ISPRS Int. J. Geo-Inf. 2016, 5, 132. DOI https://doi.org/10.3390/ijgi5080132.

Blum, W.E.H. 2005. Functions of soil for society and the environment. In: Reviews in Environmental Science and Bio/Technology 4: 75-79.

Blöschl, G., Hall, J., Parajka, J., Perdigão, R.A.P., Merz, B., Arheimer, B., Aronica, G.T., Bilibashi, A., Bonacci, O., Borga, M., Čanjevac, I., Castellarin, A., Chirico, G.B., Claps, P., Fiala, K., Frolova, N., Gorbachova, L., Gül, A., Hannaford, J., Harrigan, S., Kireeva, M., Kiss, A., Kjeldsen, T.R., Kohnová, S., Koskela, J.J., Ledvinka, O., Macdonald, N., Mavrova-Guirguinova, M., Mediero, L., Merz, R., Molnar, P., Montanari, A., Murphy, C., Osuch, M., Ovcharuk, V., Radevski, I., Rogger, M., Salinas, J.L., Sauquet, E., Šraj, M., Szolgay, J., Viglione, A., Volpi, E., Wilson, D., Zaimi, K. and Živković, N. 2017. Changing climate shifts timing of European floods. In: Science 357: 588.

Bosco, C., de Rigo, D., Dewitte, O., Poesen, J. and Panagos, P. 2015. Modelling soil erosion at European scale: towards harmonization and reproducibility. In: Natural Hazards and Earth System Sciences 15: 225-245.

Bouma, J., Broll, G., Crane, T.A., Dewitte, O., Gardi, C., Schulte, R.P.O. and Towers, W. 2012. Soil information in support of policy making and awareness raising. In: Environmental Sustainability 4: 552-558.

Bucella P. 2015. Sustainable land use in the European Union. In: Cultivar Cadernos de Análise e Prospetiva 2: 13-20.

Carlowicz, M. 2018. Saharan Dust Makes Orange Snow. Available at: https://earthobservatory.nasa.gov/images/91903/saharan-dust-makes-orange-snow (29/08/2018).

Cherlet, M., Ivits, E., Sommer, S., Tóth, G., Jones, A., Montanarella, L. and Belward, A. 2013. Land Productivity Dynamics in Europe. Towards a Valuation of Land Degradation in the EU. EUR 26500, doi: 10.2788/70673.

d'Amour, C. B., Reitsma, F., Baiocchi, G., Barthel, S., Güneralp, B., Erb, K. H., Haberl, H., Creutzig, F., and Seto, K. C. 2017. Future urban land expansion and implications for global croplands. Proceedings of the National Academy of Sciences Aug 2017, 114 (34) 8939-8944; DOI: 10.1073/pnas.1606036114.

De Schutter, L. and Lutter, S. 2016. The true cost of consumption. Brussels. Friends of the Earth Europe. Available at: https://www.foeeurope.org/sites/default/files/resource_use/2016/foee-true-cost-consumption-land-footprint.pdf (29/08/2018).

Deutscher Bundestag 2013. Nutztierhaltung in Deutschland und den Niederlanden auch unter dem Aspekt der Ansiedlung niederländischer Investoren. Wissenschaftliche Dienste, WD 5-3000-083/13. Available at: https://www.bundestag.de/blob/410156/c685dfe899289f88bb8b9035cad8be07/wd-5-083-13-pdf-data.pdf (29/08/2018).

EC 2006. Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions. Thematic Strategy for Soil Protection. Impact Assessment of the Thematic Strategy on Soil Protection. COM(2006)231 final. SEC(2006)1165. Available at: http://ec.europa.eu/environment/archives/soil/pdf/SEC_2006_620.pdf (09/11/2018).

EC 2008. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. L 312/3. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&from=EN (09/11/2018).

EC 2012a. Commission staff working document. Guidelines on best practice to limit, mitigate or compensate soil sealing. SWD (2012) 101 final. Available at: http://ec.europa.eu/environment/soil/pdf/soil_sealing_guidelines_en.pdf (27/11.2017).

EC 2012b. Innovating for A Bioeconomy for Europe. Brussels. European Commission.

EC 2013a. Hard surfaces, hidden costs. Searching for alternatives to land take and soil sealing. Available at: http://ec.europa.eu/environment/soil/pdf/SoilSealing-Brochure_en.pdf (27/11/2017).

EC 2013b. Hard surfaces, hidden costs. Searching for alternatives to land take and soil sealing. Available at: http://ec.europa.eu/environment/soil/pdf/SoilSealing-Brochure_en.pdf (30/08/2018).

EC 2016. Soil. Soil sealing. Available at: http://ec.europa.eu/environment/soil/ sealing_guidelines.htm (08/05/2018).

EC 2017. Agriculture and food trade. Available at: https://ec.europa.eu/ agriculture/sites/agriculture/files/statistics/facts-figures/agricultural-food-trade.pdf (27/11/2017).

European Court of Auditors (ECA) 2018. Combating desertification in the EU: a growing threat in need of more action. ECA Special Report 33/2018. Available at: https://www.eca.europa.eu/Lists/ECADocuments/SR18_33/SR_DESERTIFICATION_EN.pdf (18/01/2019).

Environmental Protection Agency (EPA) 2018. What is climate change? Environmental Protection Agency. Available at: http://www.epa.ie/climate/communicatingclimatescience/whatisclimatechange/ (29/08/2018).

ESA 2018. From Green to Brown in a Month. Available at: http://www.esa.int/spaceinvideos/Videos/2018/07/From_green_to_brown_in_a_month (30/08/2018).

ESPON n.d. Environmental challenges. ESPON. Available at: https://www.espon.eu/environmental-challenges (24/10/2018).

European Environment Agency (EEA). 2011. Urban soil sealing in Europe. Available at: https://www.eea.europa.eu/articles/urban-soil-sealing-in-europe (08/05/2018).

European Environment Agency (EEA) 2015a. The European Environment. State and Outlook 2015. Available at: https://www.eea.europa.eu/soer (27/11/2017).

European Environment Agency (EEA) 2015b. Air quality in Europe – 2015 report. EEA Report/ No 5/2015. Available at: https://www.eea.europa.eu/publications/air-quality-in-europe-2015/ at_download/file (10/01/2018).

European Environment Agency (EEA) 2015c. European briefings. Waste. Available at: https://www.eea.europa.eu/soer-2015/europe/waste#tab-based-on-indicators (29/08/2018).

European Environment Agency (EEA) 2017a. European Union emission inventory report 1990-2015 under UNECE Convention on Long-range Transboundary Air Pollution (LRTAP). Luxembourg. Publications Office of the European Union.

European Environment Agency (EEA) 2017b. Heavy metal emissions. Indicator Assesment, Data and maps. Available at: https://www.eea.europa.eu/data-and-maps/indicators/eea32-heavy-metal-hm-emissions-1/assessment-8 (10/01/2018).

European Environment Agency (EEA) 2017c. European Union emission inventory report 1990-2015 under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP). EEA Report, No 9/2017.

European Food Safety Authority (EFSA) 2012. Cadmium dietary exposure in the European population. EFSA Journal 10(1): 2551.

Eurostat 2016b. Land cover, land use and landscape. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Land_cover,_land_use_and_land scape#Database (27/11/2017).

Eurostat 2017. Waste statistic. Waste generation, 2014, kg per inhabitant. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics (25/10/2018).

FAO 2009. Global agriculture towards 2050. Available at: http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf (27/11/2017).

FAO 2015. Healthy soils are the basis for healthy food production. Fact Sheet. FAO, Rome. Available at: http://www.fao.org/3/a-i4405e.pdf (27/11/2017).

FAO 2016a. Food outlook. Biannual Report on Global Food Markets. Available at: http://www.fao.org/3/a-I5703E.pdf (27/11/2017).

FAO 2017. FAO Soils Portal. Soil degradation. Available at: http://www.fao.org/soils-portal/soil-degradation-restoration/en (27/11/2017).

Fenn, T., Fleet, D., Garrett, L., Daly, E., Elding, C., Hartman, M. and Udo, J. 2014. Study on Economic and Social Benefits of Environmental Protection and Resource Efficiency Related to the European Semester. Final Report to DG Environment.

Fischer, G., Tramberend, S., Bruckner, M. and Lieber, M. 2017. Quantifying the land footprint of Germany and the EU using a hybrid accounting model. Umweltbundesamt, Dessau. Available at: https://www.umweltbundesamt.de/en/publikationen/quantifying-the-land-footprint-of-germany-the-eu (27/11/2017).

Foresight 2011. Migration and Global Environmental Change 2011. Final Project Report. The Government Office for Science, London.

French Ministry of Agriculture, Agrifood and Forestry. 2017. Join the 4‰ Initiative Soils for food security and climate. Available at: http://agriculture.gouv.fr/join-40-initiative-soils-food-security-and-climate (03/01/2018).

Frelih-Larsen, A., C. Bowyer, S. Albrecht, C. Keenleyside, M. Kemper, S. Nanni, S. Naumann, R., D. Mottershead, R. Landgrebe, E. Andersen, P. Banfi, S. Bell, I. Brémere, J. Cools, S. Herbert, A. Iles, E. Kampa, M. Kettunen, Z. Lukacova, G. Moreira, Z. Kiresiewa, J. Rouillard, J. Okx, M. Pantzar, K. Paquel, R. Pederson, A. Peepson, F. Pelsy, D. Petrovic, E. Psaila, B. Šarapatka, J. Sobocka, A.-C. Stan, J. Tarpey and R. Vidaurre 2016. Updated Inventory and Assessment of Soil Protection Policy Instruments in EU Member States. Final Report to DG Environment. Berlin: Ecologic Institute.

George, R., Joy, V., Aiswarya, S., Jacob, P. A. 2014. Treatment Methods for Contaminated Soils – Translating Science into Practice. In: International Journal of Education and Applied Research 4 (1): 17-19.

Global Soil Partnership (GSP), FAO and ITPS 2015. Status of the World´s Soil Resources. Available at: http://www.fao.org/3/a-i5199e.pdf (27/11/2017).

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M. and Toulmin, C. 2010. Food Security: The Challenge of Feeding 9 Billion People. In: Science 327 (5967): 812-818.

Hatfield, J. L., Sauer, T. J., Cruse, R. M. 2017. Soil: The Forgotten Piece of the Water, Food, Energy Nexus. In: Advances in Agronomy 143: 1-46. Available at: http://dx.doi.org/10.1016/bs.agron.2017.02.001 (08/05/2017).

Haque, U., Blum, P., da Silva, P.F. et al. 2016. Fatal landslides in Europe. In: Landslides 13: 1545-15154.

HELCOM 2018. State of the Baltic Sea – Second HELCOM holistic assessment 2011-2016. Baltic Sea Environment Proceedings 155.

Hervas, J. 2003. Lessons learnt from landslide disasters in Europe. EC JRC, NEDIES PROJECT, EUR 20558 EN.

Huber, S., Prokop, G., Arrouays, D., Banko, G., Bispo, A., Jones, R.J.A., Kibblewhite, M.G., Lexer, W., Möller, A., Rickson, R.J., Shishkov, T., Stephens, M., Toth, G., Van den Akker, J.J.H., Varallyay, G., Verheijen, F.G.A. and Jones, A.R. 2008. Environmental Assessment of Soil for Monitoring. Volume I: Indicators & Criteria. Pub: Joint Research Centre of the European Commission.

Hughes, D. 2018. UK waste sent overseas for recycling could end up in landfill instead, says watchdog. Independent. Available at: https://www.independent.co.uk/news/uk/home-news/recycling-waste-uk-overseas-landfill-pollution-nao-environment-defra-a8458991.html (29/08/2018).

IPBES 2018. Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Scholes, R., Montanarella, L., Brainich, A., Barger, N., ten Brink, B., Cantele, M., Erasmus, B., Fisher, J., Gardner, T., Holland, T.G., Kohler, F., Kotiaho, J.S., Von Maltitz, G., Nangendo, G., Pandit, R., Parrotta, J., Potts, M.D., Prince, S., Sankaran, M. and Willemen, L. (eds.). Bonn. IPBES secretariat.

IPCC 2000. Land use, land use change, and Forestry. Summary for Policymakers. Available at: https://www.ipcc.ch/pdf/special-reports/spm/srl-en.pdf (27/11/2017).

Kaitala, V., Pohjola, M. and Tahvonen, O. 1992. Transboundary air pollution and soil acidification: A dynamic analysis of an acid rain game between Finland and the USSR. In: Environmental and Ressource Economics 2(2): 161-181.

Kay, S. 2016. Land grabbing and land concentration in Europe. A Research Brief. Available at: https://www.tni.org/files/publication-downloads/landgrabbingeurope_a5-2.pdf (18/01/2019).

KNMI – the Royal Dutch Meteorological Institute 2018. Rainfall surplus in the Netherlands between 1 april 2018-7 august 2018. Available at: https://www.knmi.nl/nederland-nu/klimatologie/geografische-overzichten/neerslagoverschot (29/08/2018).

Kokkindis, T. 2018. Athens' Acropolis Covered in African Dust. Available at: https://greece.greekreporter.com/2018/03/26/athens-acropolis-covered-in-african-dust-photos/ (29/08/2018).

Kommission Bodenschutz beim Umweltbundesamt (KBU) (ed.) 2017. Urbanisierung und Bodenschutz : Warum zwei Prozent für den Boden die Welt bedeuten, UBA Position // August 2017, Dessau Rosslau. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/421/publikationen/kbu_urbanisierung_und_bodenschutz_august_2017.pdf (29/08/2018).

Kubiszewski, I., Costanza, R., Anderson, S. and Sutton, P. 2017. The future value of ecosystem services: Global scenarios and national implications. In: Ecosystem Services 26 part A: 289-301.

Lal, R. 2013. Soil carbon management and climate change. In: Carbon Management 4(4): 439-462.

Limasset, E., Pizzol, L., Merly, C., Gatchett, A.M., Le Guern, C., Martinát, S., Klusáček, P. and Bartke, S. 2018. Points of attention in designing tools for regional brownfield prioritization. In: Science of the Total Environment: 622–623: 997-1008.

Lugato, E., Bampa, F., Panagos, P., Montanarella, L. and Jones, A. 2015. Potential carbon sequestration of European arable soils estimated by modeling a comprehensive set of management practices. In: Global Change Biology 20: 3557-3567.

Ministerie van Landbouw, Natuur en Voedselkwaliteit 2017. Mestexport naar Duitsland biedt kansen. Available at: https://www.agroberichtenbuitenland.nl/landeninformatie/duitsland/achtergrond/ agrologistiek_sp (29/08/2018).

Montanarella, L. 2006. Policies for a sustainable use of soil resources. Joint Research Centre, Institute for Environment and Sustainability, Italy: Ispra.

Mullan D. 2013. Soil erosion under the impacts of future climate change: Assessing the statistical significance of future changes and the potential on-site and off-site problems. In: Catena 109: 234–246.

Müller, A., Lobos Alva, I., Weigelt, J., Bossio, D., Brander, M., Ehlers, K., Götz, A., Herren, H., Louwagie, G., Lovera, S., Matuschke, I., Miggiano, L., Montanarella, L., Obaikol, E., Reeves, J., Bergöö, M., Safriel, U., Sakoh, M., Schmidt, O., Sietchiping, R., Unger, S., Vaturi, T. and Zelaya, S. 2015. Grounding the Post-2015 Development Agenda: Options for the protection of our precious soil and land resources. Policy Brief. - IASS Opinion.

Nabielek K., Hamers, D., & Evers, D. 2016. Cities in Europe. PBL Netherlands Environmental Assessment Agency, The Hague. ISBN: 978-94-91506-97-0. Available at: http://www.pbl.nl/sites/default/files/cms/publicaties/PBL-2016-Cities-in-Europe-2469.pdf (29/08/2018).

Neslen, A. 2017. Europe faces droughts, floods and storms as climate change accelerates. Available at: https://www.theguardian.com/environment/2017/jan/25/europe-faces-droughts-floods-storms-climate-change-accelerates (29/08/2018).

Neuroth, O. 2018. Waldbrände in Portugal. Kampf gegen die Flammen. Tagesschau. Available at: https://www.tagesschau.de/ausland/feuer-portugal-123.html (29/08/2018).

NSW 2017. Australia New South Wales portal webpage (Office of Environment and Heritage). Available at http://www.environment.nsw.gov.au/topics/land-and-soil/soil-degradation (04/05/2018).

Oldeman, L.R. 1991-1992.Global Extent of Soil Degradation. Published in: ISRIC Bi-Annual Report 1991-1992, pp.19-36. Available at: http://edepot.wur.nl/299739 (08/05/2018).

Orr, B.J., Cowie, A.L., Castillo Sanchez, V.M., Chasek, P., Crossman, N.D., Erlewein, A., Louwagie, G., Maron, M., Metternicht, G.I., Minelli, S., Tengberg, A.E., Walter, S. and Welton, S. 2017. Scientific Conceptual Framework for Land Degradation Neutrality. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn.

Osman, K. T. 2013. Soil Erosion by Water. In: Soil Degradation, Conservation and Remediation, Springer, Dordrecht: 69-101.

Panagos, P., Imeson, A., Meusburger, K., Borrelli, P., Poesen, J. and Alewell, C. 2016. Soil Conservation in Europe: Wish or Reality? In: Land Degradation and Development 27: 1547-1551.

Perper, R. 2018. Deadly forest fires are burning across Greece, and these photos show how 9 other European countries are battling fires amid a punishing heatwave. Business Insider. Available at: https://www.businessinsider.de/photos-greece-europe-fires-2018-7?r=US&IR=T (29/08/2018).

Priest, S.J., Suykens, C., Van Rijswick, H.F.M.W., Schellenberger, T., Goytia, S., Kundzewicz, Z.W., van Doorn-Hoekveld, W.J., Beyers, J.-C. and Homewood, S. 2016. The European Union approach to flood risk management and improving societal resilience: lessons from the implementation of the Floods Directive in six European countries. In: Ecology and Society 21 (4): 50.

Prokop, G., Jobstmann, H. and Schonbauer, A. 2011. Report on best practices for limiting soil sealing and mitigating its effects. Publisher: European Commission, Brussels, Technical Report.

Rojas, R., Feyen, L., Bianchi, A. and Dosio, A. 2012. Assessment of future flood hazard in Europe using a large ensemble of bias-corrected regional climate simulations. In: Journal of Geophysical Research Atmospheres 117. Available at: https://doi.org/10.1029/2012JD01746 (21/12/2017).

Roudier, P., Andersson, J.C.M., Donnelly, C., Feyen, L., Greuell, W. and Ludwig, F. 2016. Projections of future floods and hydrological droughts in Europe under a +2°C global warming. In: Climate Change 135: 341–355.

Scharlemann, J. PW., Tanner, E. VJ., Hiederer, R. and Kapos, V. 2014. Global soil carbon: understanding and managing the largest terrestrial carbon pool. In: Carbon Management 5 (1): 81-91.

Schils, R., Kuikman, P., Liski, J., van Oijen, M., Smith, P., Webb, J., Alm, J., Somogyi, Z., van den Akker, J., Billett, M., Evans, C., Lindner, M., Palosuo, T., Bellamy, P., Jandl, R. and Hiederer, R. 2008. Review of existing information on the iterrelations between soil and climate change. Available at: http://ec.europa.eu/environment/archives/soil/pdf/climsoil_report_dec_2008.pdf (27/11/2017).

Schjønning, P., van den Akker, J.J.H., Keller, T., Greve, M.H., Lamandé, M., Simojoki, A., Stettler, M., Arvidsson, J. and Breuning-Madsen, H. 2015. Soil compaction. In: Stolte J., Tesfai, M., Øygarden, L.,

Schlanger, Z. 2018. Every one of Europe's 571 cities is destined for worse heat waves, droughts, or floods. Available at: https://qz.com/1212443/climate-changes-impact-on-europe-all-571-cities-are-destined-for-worse-heat-waves-droughts-or-floods/ (28/08/2018).

Science Communication Unit. 2013. Science for Environment Policy In-depth Report: Soil Contamination: Impacts on Human Health. Report produced for the European Commission DG Environment, University of the West of England, Bristol. Available at: http://ec.europa.eu/science-environment-policy (03/01/2018).

Siebielec, G., Prokop, G., van Delden, H., Verzandvoort, S., Miturski, T. and Łopatka, A. 2015. Soil sealing. In: Stolte J., Tesfai, M., Øygarden, L., Kværnø, S., Keizer, J., Verheijen, F., Panagos, P., Ballabio, C. and Hessel, R., Soil threats in Europe, Status, methods, drivers and effects on ecosystem services. JRC Technical Reports: 79-91.

Silva, V., Montanarella, L., Jones, A., Fernández-Ugalde, O., Mol, H. G. J., Ritsema, C. J., and Geissen, V. 2018. Distribution of glyphosate and aminomethylphosphonic acid (AMPA) in agricultural topsoils of the European Union. Science of the Total Environment 621: 1352-1359.

Sohn, C. and Stambolic, N. 2015. The urban development of European border regions: a spatial typology. Europa Regional, 21.2013(4), 177-189.

Sojka, W. 2007. Grossraum Basel. Available at: https://de.wikipedia.org/wiki/Datei:Grossraum_Basel.png (30/08/2018).

Spiegel Online 2018. Meeresspiegelanstieg in Deutschland. Das droht Deutschlands Küsten. Available at: http://www.spiegel.de/wissenschaft/mensch/meeresspiegelanstieg-das-droht-deutschlands-kuesten-a-1231792.html (24/10/2018).

Stolte J., Tesfai, M., Øygarden, L., Kværnø, S., Keizer, J., Verheijen, F., Panagos, P., Ballabio, C. and Hessel, R. 2016. Soil threats in Europe. doi:10.2788/828742 (online).

Tal, A. 2018. Making Conventional Agriculture Environmentally Friendly: Moving beyond the Glorification of Organic Agriculture and the Demonization of Conventional Agriculture. In: Sustainability 10 (1078): 1-17.

The World Bank. 2018. Agricultural land (% of land area). Food and Agriculture Organization. Available at: https://data.worldbank.org/indicator/AG.LND.AGRI.ZS (07/05/2018).

Tittonell, P. 2016. Feeding the world with soil science: embracing sustainability, complexity and uncertainty, In: SOIL. Available at: http://doi:10.5194/soil-2016-7 (27/11/2017).

United Nations (UN) 1994. United Nations Convention to Combat Desertification in those Countries experiencing serious Droughts and / or Desertification, particularly in Africa. Available at: https://treaties.un.org/doc/Publication/MTDSG/Volume%20II/Chapter%20XXVII/XXVII-10.en.pdf (27/11/2017).

UNCCD 2017. The Global Land Outlook, United Nations Convention to Combat Desertification, Bonn, Germany. Available at: https://static1.squarespace.com/static/5694c48bd82d5e9597570999/t/59e9f992a9db090e9f51bdaa/1508506042149/GLO_Full_Report_low_res_English.pdf (27/11/2017).

United Nations Geospatial Information Section 2012. Environmental Migration Portal. Knowledge Platform on People on the Move in a Changing Climate. Available at: https://environmentalmigration.iom.int/maps (24/10/2018).

U.S. DOE. 2008. Carbon Cycling and Biosequestration: Integrating Biology and Climate Through Systems. Science. Report from the March 2008 Workshop, DOE/SC-108, U.S. Department of Energy Office of Science. Available at: http://genomicscience.energy.gov/carboncycle/report/CarbonCycle012609LR.pdf (27/11/2017).

Van den Akker, J. J. H., Berglund, K. and Berglund, Ö. 2016. Decline in soil organic matter in peatsoils. IN: Stolte J., Tesfai, M., Øygarden, L., Kværnø, S., Keizer, J., Verheijen, F., Panagos, P., Ballabio, C. and Hessel, R. Ed. Soil threats in Europe. doi:10.2788/828742 (online), 39-54.

Van der Esch, S., ten Brink, B., Stehfest, E., Bakkenes, M., Sewell, A., Bouwman, A., Meijer, J., Westhoek, H. and van den Berg, M. 2017. Exploring future changes in land use and land condition and the impacts on food, water, climate change and biodiversity: Scenarios for the Global Land Outlook. PBL Netherlands Environmental Assessment Agency, The Hague.

Van de Meulen, S.M., Maring, L., Bartkowski, B., Hagemann, N., Arrúe, L.J., Playán, E., Castañeda, C., Herrero, J., Plaza, D., Álvaro-Fuentes, J., Faneca Sànchez, M., Lopatka, A., Siebielec, G., Verboven, J., De Cleen, M., Staes, J., Boekhold, S., Goidts, E., Salomez, J., Creamer, R., Alberico, S., Abdul Malak, D., Soraci, M., Munafo, M., Bal, N., Baritz, R., Molenaar, C., Brils, J., Akzoy, E., Cousin, I., Hessel, R., Dejonckheere, A., Bartke, S., Salata, S., Marin, A., Verzandvoort, S., Jones, A., Maes, J., Vallecillo, S., De Angelis, A., Innamorati, A., Orgiazzi, A., Bertaglia, M., Teller, A., Forlin, V., Masson, J., Delsalle, J., Olazabal, C., Peeters, B. 2018. Mapping and Assessment of Ecosystems and their Services - Soil ecosystems. Soils4EU deliverable 1.2.

Vaughan, A. 2017. Almost 90% of new power in Europe from renewable sources in 2016. Available at: https://www.theguardian.com/environment/2017/feb/09/new-energy-europe-renewable-sources-2016 (24/10/2018).

Vaughan, A. 2018. Why is Europe going through a heatwave? Available at: https://www.theguardian.com/uk-news/2018/jul/24/why-is-europe-going-through-a-heatwave (28/08/2018).

Vereecken, H., Schnepf, A., Hopmans, J. W., Javaux, M., Or, D., Roose, T., ... and Allison, S. D. 2016. Modeling soil processes: Review, key challenges, and new perspectives. In: Vadose zone journal 15(5), doi:10.2136/vzj2015.09.0131.

Vogel, H.-J., Bartke, S., Daedlow, K., Helming, K., Kögel-Knabner, I., Lang, B., Rabot, E., Russel, D., Stößel, B., Weller, U., Wiesmeier, M. and Wollschläger, U. 2017. Sustainable soil management requires a systemic approach. In: SOIL Discussion, doi: 10.5194/soil-2017-26.

Wackermann, G. 2000. Regionale Studien/ Area Studies/ Etudes régionales. Das Elsass – Wandel und Perspektiven einer europäischen Grenzregion. In: Geopgrahica Helvetica 55(1): 45-60.

Watts, J. 2018. The Swedish town on the frontline of Arctic wildfires. Available at: https://www.theguardian.com/world/2018/jul/30/the-swedish-town-on-the-frontline-of-the-arctic-wildfires (30/08/2018).

Würtenberger, L., Koellner, T. and Binder, C. R. 2006. Virtual land use and agricultural trade: Estimating environmental and socio-economic impacts. In: Ecological Economics 57: 679-697.

Annex Introduction to soil degradation

"Soil is generally defined as the top layer of the earth's crust, formed by mineral particles, organic matter, water, air and living organisms. It is the interface between earth, air and water and hosts most of the biosphere." (Soil Thematic Strategy[28])

Notably, biomass production in agriculture and forestry depends on healthy soils for the supply of water and nutrients and for root fixation. Soils interact with plants and atmosphere in the nutrients cycle including filtering, storage, buffering and transformation functions. Thus, soils are playing a central role in the protection of water and in the food chain and the exchanges of gases with the atmosphere. Moreover, soil is a biological habitat, a gene pool, an element of the landscape and cultural heritage, as well as a provider of raw materials. Soils are also the physical basis for the development of infrastructure, such as for housing, industrial production, transport, dumping of refuse, sporting grounds and others (Blum, 2005).

Tittonell (2016: 1) summarizes the societal challenges in terms of soil protection: "The design of soil management strategies to meet the SDGs requires knowledge and innovation, and embracing the dimensions that define the way we regard (agro)ecosystems nowadays: the notions of sustainability, complexity and uncertainty. These dimensions describe respectively our aspirations, our understanding, and the challenges we face towards the future management of agroecosystems."

Soil, as a natural resource and a public good, is strongly linked to the provision of ecosystem services and as such contributes to human wellbeing. Soil functions provide the basis for a number of ESS and also the variety of sectors that are linked to soils. Most soil functions have a local context but the related services already have a broader, transboundary, effect; examples are carbon storage or flood regulation. ESS are clearly linked to the SDGs, which address many societal challenges linked to soils.

The timespan of soil recovery varies depending on climate, soil type, structure and chemical as well as biological conditions. Disturbed or degraded soils may need centuries to recover, due to a very slow soil formation processes. Due to this long timespan, soils must be considered as non-renewable resource. As a consequence, Europeans are on average losing their soils. At the same time, the global population could top 9 billion people in 2050.

This means that global food production needs to increase by 70 to 100% in order to feed this predicted population (Godfray et al., 2010). The pressure on our soils will increase with the impact of climate change.

[28] COM(2006) 231.Communication from the Commission on the Thematic Strategy for Soil Protection.

Degradation, such as organic matter decline and contamination, is often not always immediately visible or takes a long time to become apparent. As a consequence, some types of degradation are not recognised in decision making. There is in many cases a considerable time lag between actions that cause degradation, noticeable impact of degradation, decisions on action to protect soils and the impact of soil protection measures. This is particularly true if decisions are to be made and implemented by several actors (e.g. by more than one member state).

"Soil degradation is defined as a change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries. Degraded soils have a health status such, that they do not provide the normal goods and services of the particular soil in its ecosystem." (FAO, 2017).

"Soil degradation is the decline in soil condition caused by its improper use or poor management, usually for agricultural, industrial or urban purposes" (NSW, 2017).

"The information on soil degradation processes does not relate to the relative fragility of the ecosystem. It describes situations where the balance between the natural Resistance of the soils (and its vegetative cover) and the climatic aggressivity has been disturbed by human intervention" (Oldeman, 1991-1992:20).

Soil degradation "can be the loss of organic matter, decline in soil fertility, and structural condition, erosion, adverse changes in salinity, acidity or alkalinity, and the effects of toxic chemicals, pollutants or excessive flooding" (NSW, 2017).

<u>*Soil erosion:*</u>
"Soil erosion […] involves detachment of soil particles from the soil surface, transport of those particles, followed by deposition […] Soil erosion is too often interpreted by the public as soil lost, but in reality, it is soil movement on (or from) a defined slope with typically a portion lost from the defined area. The quantity of lost soil depends on a myriad of factors including topography, size of the area considered, soil texture, and water runoff rate" (Hatfield et al. 2017: 12)

<u>*Soil erosion by wind:*</u>
"Wind erosion is a natural process that moves soil from one location to another by wind power. It can cause significant economic and environmental damage. Wind erosion can be caused by a light wind that rolls soil particles along the surface through to a strong wind that lifts a large volume of soil particles into the air to create dust storms" (NSW, 2017).

Soil sealing:
"Soil sealing - the covering of the ground by an impermeable material – is one of the main causes of soil degradation in the EU. Soil sealing often affects fertile agricultural land, puts biodiversity at risk, increases the risk of flooding and water scarcity and contributes to global warming" (EC, 2016).

Soil compaction
Compaction is related to the use of heavy machinery and trampling of animals in agriculture. Soil compaction seriously affects soil functions and is a persistent problem of which many stakeholders are not sufficiently aware (Stolte et al., 2016).

Soil organic matter (SOM) decline:
"A decline in organic matter is caused by the reduced presence of decaying organisms, or an increased rate of decay as a result of changes in natural or anthropogenic factors. Organic matter is regarded as a vital component of a healthy soil; its decline results in a soil that is degraded" (EC, 2009b).

Soil erosion by water:
"Detachment of soil particles from aggregates primarily by raindrops and flowing water and their transport by runoff water are involved in soil erosion by water" (Osman, 2013: 69).

Soil Salinization:
"Salinity is the accumulation of salt in land and water to a level that damages the natural and built environment […] Salinity usually occurs with other natural resource problems such as decreasing soil and water quality, erosion and loss of native vegetation" (NSW, 2017).

Soil contamination:
"Soil contamination or soil pollution is caused by the presence of xenobiotic (human-made) chemicals or other alteration in the natural soil environment. It is typically caused by industrial activity, agricultural chemicals, or improper disposal of waste […] Soil pollution can be caused by: Pesticides, herbicides and fertilizers; Mining; Oil and fuel dumping; Disposal of coal ash; Leaching from landfills; Drainage of contaminated surface water into the soil; Discharging urine and feces in the open; Electronic waste" (George et al., 2014: 17).

Loss of soil biodiversity
"Soil biodiversity is the variability of living organisms in soil and the ecological complexes of which they are part. Soils contain between a quarter to one third of all living organisms on the planet although little is known about them. Therefore it is difficult to assess the overall state of soil biodiversity. Decline in soil biodiversity is usually related to other deteriorations in soil quality and can be linked with other threats." (Stolte et al., 2016).

Floods and landslides
"Floods and landslides are major natural hazards, resulting from a complex of natural, social, economic and ecological origins. Floods and landslides can occur as a result of climate and land use change. Landslides occur in mountainous areas and on slopes." (Stolte et al., 2016).