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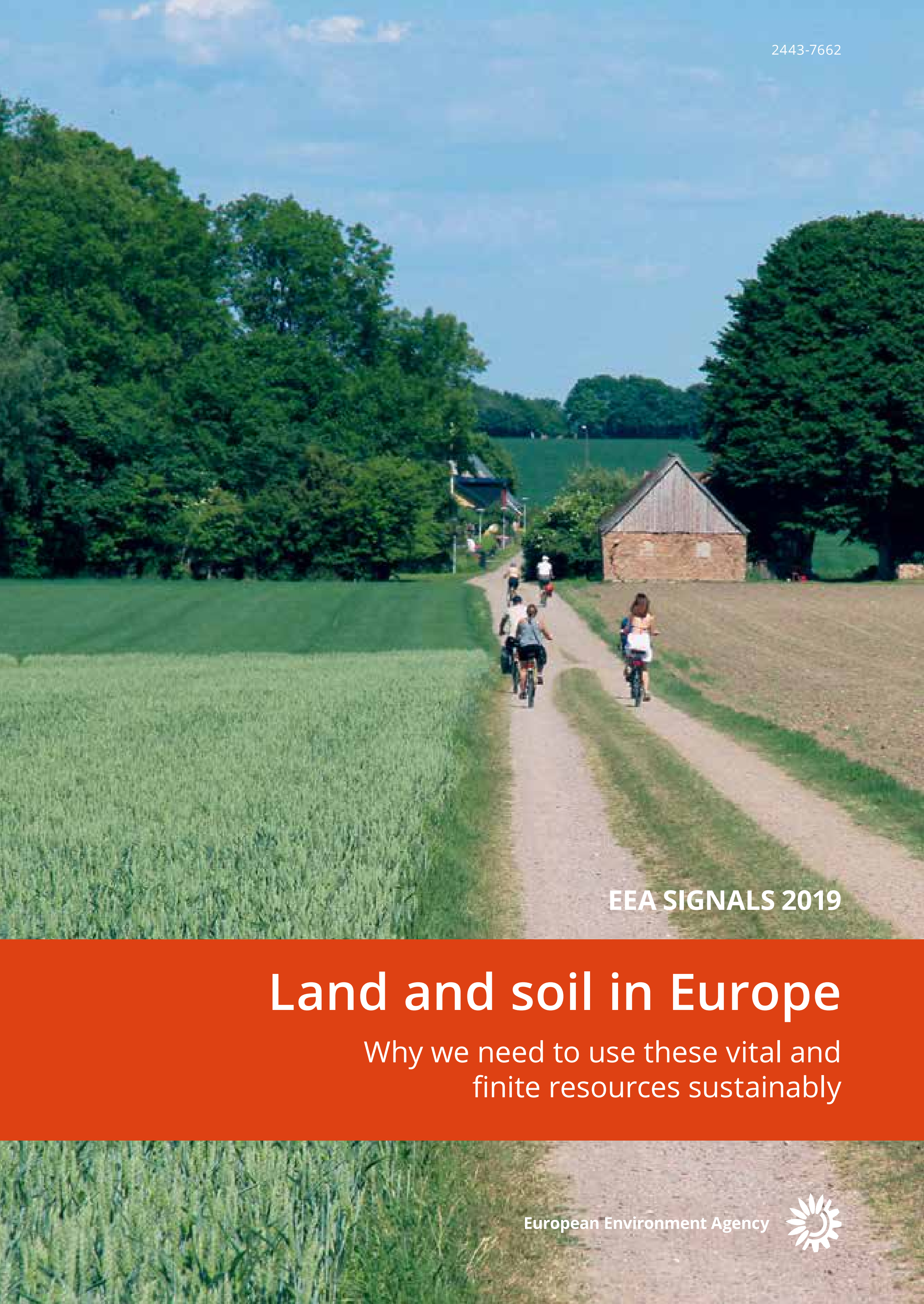

EEA SIGNALS 2019

Land and soil in Europe

Why we need to use these vital and finite resources sustainably

European Environment Agency

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SUSTAINABLE DEVELOPMENT GOALS

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Editorial

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EEA Executive Director

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Land and soil: towards the sustainable use and management of these vital resources

We cannot live without healthy land and soil. It is on land that we produce most of our food and we build our homes. For all species — animals and plants living on land or water — land is vital. Soil — one of the essential components of land — is a very complex and often undervalued element, teeming with life. Unfortunately, the way we currently use land and soil in Europe and in the world[1] is not sustainable. This has significant impacts on life on land[2].

Throughout history, landscapes have always been subject to change, as a result of forces of nature and human activities. Mountains rise and sink, rocks erode, rivers dry up or change their course, floodplains appear and disappear. Humankind has flattened hills, landfilled coastlines, dried wetlands, removed mountain tops for mining, created artificial lakes and dams, cut forests to create fields and grazing land, and created new landscapes. An increasing share of our planet's landscapes and land cover has in some way been modified by human activities. Today, around 80 % of Europe's surface area is shaped by cities, agriculture and forestry.

Pressures on land and soil are growing

Europe's urban areas are growing, often at the expense of fertile agricultural land. Concrete and asphalt surfaces **seal the soil**, preventing it from performing its functions such as storing water, producing food and biomass, regulating climate, buffering harmful chemicals and providing habitats. Rain on sealed surfaces runs off rather than seeping into the soil where it can be filtered and can replenish the groundwater. Roads, railways, canals and cities **fragment the landscape**, confining species to increasingly smaller areas and thus harming biodiversity. The way we use land in Europe is one of the reasons why the EU is not on track to achieve its target of halting biodiversity loss.

Europe is also not on track to achieve its policy target of 'no net land take by 2050'. Farmland and semi-natural land continue to be taken by cities and by commercial and industrial sites. Many sectors — industry, agriculture, households and even waste water treatment — also **release pollutants to land and soil**. These pollutants can accumulate in soil and then enter groundwater, rivers and seas. Even pollutants initially released into the atmosphere can later be deposited on land surfaces. Today, traces of different contaminants are found even in the most remote parts of our continent.

Land and soil terms at a glance

'Land' commonly refers to the planet's surface not covered by seas, lakes or rivers. It includes the total land mass including continents and islands. In more daily use and legal texts, 'land' often refers to a designated piece of land. It consists of rocks, stones, soil, vegetation, animals, ponds, buildings, etc.

Land can be covered by different types of vegetation (e.g. natural or managed grassland, cropland and wetlands) and artificial surfaces (e.g. roads and buildings).

Soil is one of the essential components of land. It consists of particles of rock, sand and clay as well as organic material such as plant residues, soil-dwelling animals and organisms such as bacteria and fungi, along with the air and water in soil pores. Soil properties (e.g. texture, colour and carbon content) can vary from one area to another as well as across layers at the same site. Soil plays a crucial role in nature's cycles, particularly the water cycle and the nutrient cycles (carbon, nitrogen and phosphorus).

Topsoil is the layer closest to the surface (usually the densely rooted zone or plough layer, down to 20-30 cm). It contains the highest amount of organic carbon and, given this, it is the most productive layer. One centimetre of topsoil can take from a few hundred to thousands of years to form. Given this, it is considered a non-renewable resource.

Deeper layers in the crust can contain other natural resources, including groundwater, minerals and fossil fuels.

In recent decades, Europe has decreased the total area used for agriculture while increasing yields. Intensification of agriculture has enabled us to produce food for a growing population. **Intensive agriculture**, which relies mainly on synthetic fertilisers and plant protection measures, is also putting pressure on the very resource that sustains it: healthy and productive soil. At the same time, we also see some agricultural land being abandoned in remote regions. **Land abandonment** affects, in particular, rural communities where local economies rely mainly on small farm holdings with limited economic prospects and low productivity, with younger generations tending to move to urban areas.

Global consumption and global impacts require global action

Land use has a global dimension. Many of the activities linked to land and its resources, in particular food production and resource extraction, are subject to global market forces. For example, **global demand** for fodder, food and bioenergy affect local agricultural production in many parts of the world, including Europe. Droughts and production shortages in exporting countries affect the global prices of, for instance, rice — a staple food for billions of people. Multinational companies can buy productive agricultural land in Africa and South America with a view to selling their products throughout the world.

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The way we use land and soil is also directly linked to **climate change**. Soil contains significant amounts of carbon and nitrogen, which can be released into the atmosphere depending on how we use the land. Clearing tropical forests for cattle grazing or planting forests in Europe can tilt the global greenhouse gas emission balance one way or the other. The melting of permafrost due to rising average global temperatures can release significant amounts of greenhouse gases, methane in particular, and accelerate temperature rise. Climate change can also substantially alter what European farmers[3] can produce and where.

Given this, many global policy frameworks, including the United Nations **Sustainable Development Goals**, directly and indirectly address land and soil. European policies aim to tackle land take, reduce landscape fragmentation, pollutant emissions and greenhouse gas emissions, and protect biodiversity and soil. However, in some of these policy domains, protecting the condition of soil in particular, European and global policies fall short of setting targets and commitments — let alone binding ones. In other areas, where targets do exist, including those related to protecting nature and biodiversity, we are not achieving our policy goals.

Knowledge is needed for action on the ground

One of the challenges in setting and meeting targets is overcoming **knowledge gaps**. Monitoring progress towards a specific target needs to be backed by knowledge, agreed methods and tools. Thanks to Copernicus[4] — the EU's Earth observation programme — we now have a much more accurate and detailed picture of Europe's land cover and how it is changing. For example, we can add different information layers to this picture to assess the potential impacts of climate change on soil moisture and hence agricultural productivity. This enhanced knowledge offers us new opportunities to take more targeted action on the ground.

At the same time, there are many aspects of land and soil that we need to understand better to address specific problems, in particular with regard to biodiversity. To be effective, actions will also need to take into account information on, for instance, the composition of the soil and how much carbon and nutrients the soil contains in a given area. This kind of information requires a **better monitoring system**.

Steps towards sustainable land management

The way forward is clear: we urgently need to change the way we use and manage land and the resources it provides. This will require looking at the landscape as a whole, with all its activities and elements.

The way we build and connect cities should not entail covering surrounding areas with concrete and asphalt but should be based on **reusing and re-purposing** land already taken. In fact, a report by IPBES[5] (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) asserts that it is cheaper to preserve land and soil resources than to restore or remediate them (e.g. by cleaning contaminated land at old industrial facilities). Moreover, compact cities with well-connected mobility options often provide the highest quality of urban life with fewer direct environmental impacts. The EU's cohesion and regional policies aim to support not only economic and social cohesion but also territorial cohesion[6], which aims to contribute to the balanced development of the EU as a whole.

We also need to step up our efforts to protect land ecosystems better. We can connect natural areas and create corridors for wildlife by investing in **green infrastructure**. Healthy and resilient soil ecosystems are also essential to help mitigate and adapt to climate change.

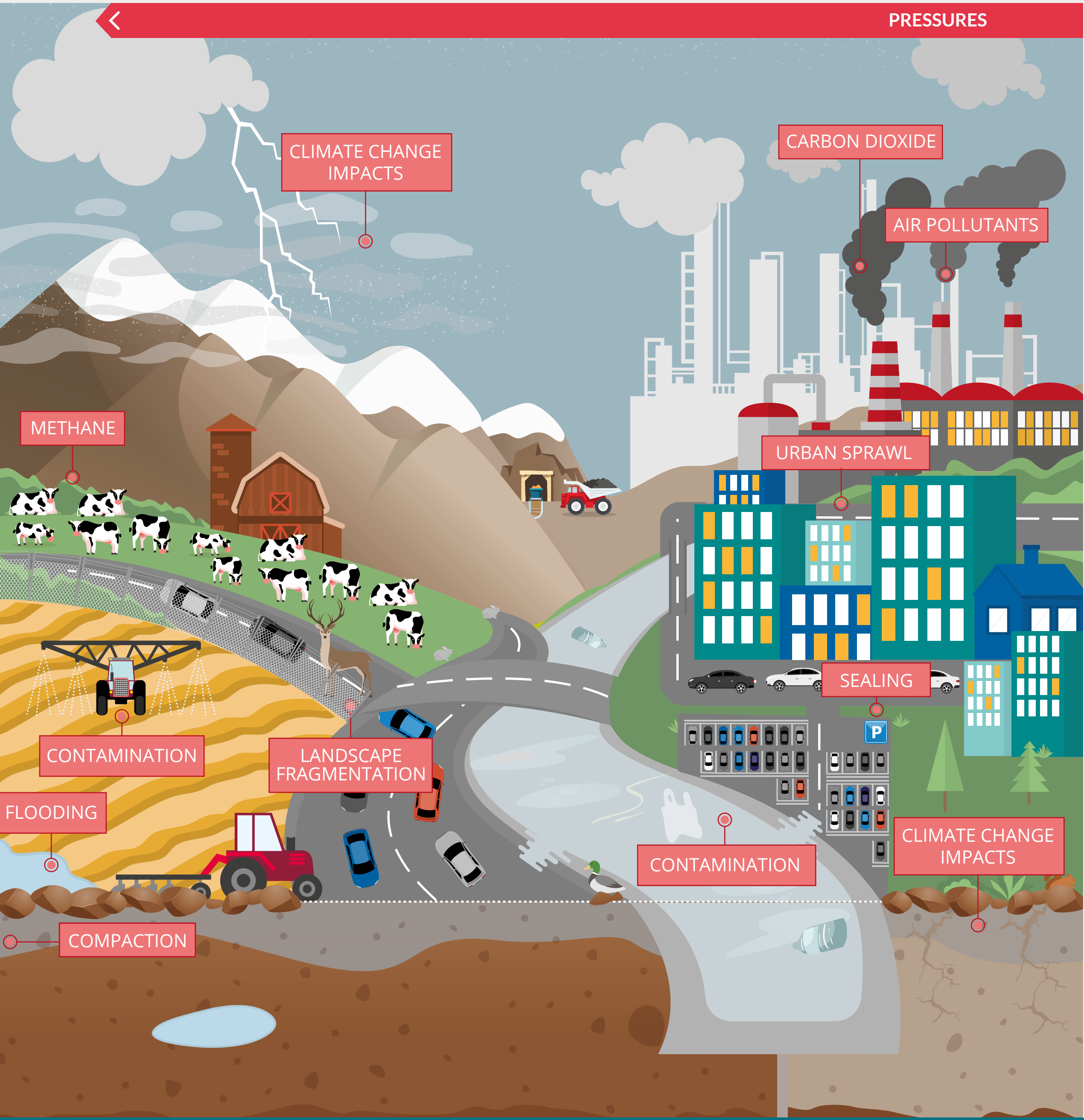
To achieve the sustainable management of our land resources, we need to significantly **reduce pressure from economic activities**, especially agriculture. To ensure sustainable and productive agriculture, we must tackle pollution and find new solutions for using land efficiently. We will also need to take into account livelihoods and the quality of life of rural communities. We need to rely on and work with farmers to take care of the land and rural biodiversity. Sustainable agriculture cannot be achieved without significant **changes in diets** and **reductions in food waste** in Europe and globally.

Land governance is complex but we all benefit from the services that healthy land and soil provide — be it nutritious food or clean water, protection against diseases or construction materials. To ensure that future generations continue to benefit from these services, we need to take decisive action today. The responsibility to protect these vital resources lies with us all — from consumers to farmers, and from local to European and global policymakers. This can only be achieved by acting together today towards a common goal.

Hans Bruyninckx
EEA Executive Director

Towards sustainable management of land and soil

Europe's land and soil face a number of pressures, including urban expansion, contamination from agriculture and industry, soil sealing, landscape fragmentation, low crop diversity, soil erosion and extreme weather events linked to climate change.



Source: EEA Signals 2019.

Greener cities with cleaner energy and transport systems, a green infrastructure connecting green areas, less intensive sustainable agricultural practices can help make Europe's land use more sustainable and soils healthier.

Land and soil in Europe — Ever-sprawling urban concrete?

Europe's landscape is changing. Cities and their infrastructures are expanding into productive agricultural land, cutting the landscape into smaller patches, affecting wildlife and ecosystems. In addition to landscape fragmentation, soil and land face a number of other threats: contamination, erosion, compaction, sealing, degradation and even abandonment. What if we could recycle the land already taken by cities and urban infrastructure instead of taking agricultural land?

In 2018, the EU's Earth observation programme, Copernicus, completed another round of a Europe-wide mapping exercise, which formed the basis of a detailed analysis by the EEA of land cover and, partly, land use in EEA member and cooperating countries[7]. According to these Corine (Coordination of information on the environment) monitoring results[8], Europe's **land cover** has remained relatively stable since 2000, with about 25 % covered by arable land and permanent crops, 17 % by pastures and 34 % by forests. However, on closer inspection of recent land cover changes, two noteworthy trends emerge.

First, cities and concrete infrastructures continue to expand. Although **artificial surfaces** cover less than 5 % of the wider EEA territory, a sizeable area — slightly smaller than Slovenia — still became sealed (covered by concrete or asphalt) between 2000 and 2018. The good news is that the rate of increase in artificial surface areas has slowed down, from 1 086 km^2 per year between 2000 and 2006 to 711 km^2 per year between 2012 and 2018.

Second, the largest losses were observed in **agricultural land**, due mainly to urban expansion and farming withdrawal, while the total forest area remained stable. The area of cropland, pastureland and natural grasslands lost was similar in size to the increase in area of artificial surfaces. And, as most of Europe's cities were built on and surrounded by fertile land, it is often productive agricultural land that gets taken and covered by artificial surfaces. Fortunately, the loss of agricultural land appears to have slowed down significantly and came close to halting in the period 2012-2018.

Urban population and cities continue to grow

Today, almost three quarters of Europeans live in urban areas. Europe's urban population is expected to continue to grow by up to 30 million additional people[9] by 2050. Additional housing and infrastructure (e.g. roads, schools, water treatment networks and waste facilities) will need to be built to accommodate Europe's growing total population as well as its urban population.

Population growth is not the only driver behind urban expansion and the **land take** and soil degradation associated with it. Rising income levels also play a role, as they often translate into bigger houses, more holiday homes and resorts along the coast, and more commercial and industrial facilities to meet rising consumer demand. In many ways, the **expansion of urban areas** and their infrastructure extensions go hand in hand with the increasing number of socio-economic benefits that many Europeans have been able to enjoy in recent decades. But some of these lifestyle changes have long-lasting negative impacts not only on the countryside and natural landscapes but also on urban landscapes.

Increasingly fragmented landscapes

Despite slowing down between 2012 and 2015, **landscape fragmentation** is still increasing[10] across the 39 EEA countries, affecting rural and sparsely populated areas in particular.

Roads and railways connect people, and urban and rural areas, but they often constitute real barriers for wildlife and plant dispersal. As urban areas and their supporting infrastructures expand across the landscape, they fragment habitats into smaller patches. Species living in these increasingly smaller areas may be forced to live with fewer resources and a more limited gene pool. When the size of an animal population falls below a critical level, species can become extinct in that particular area. This is why many species are found only in rural or protected areas. Many wild animals are also injured or killed trying to cross barriers such as motorways.

Landscape fragmentation is addressed by a number of EU policies, including the overarching EU biodiversity strategy to 2020[11] aimed at halting the decline in biodiversity. On the ground, this strategy is supported by tangible measures, such as establishing a green infrastructure[12] — a strategically planned **network of natural and semi-natural areas** to help species move and spread across the landscape. In this context, many European countries are building wildlife crossings — tunnels or bridges enabling species to move across motorways and canals. Depending on the location of the crossing and the species in the area, these crossings can make a real difference locally. Hedges and rows of trees in open landscapes also promote habitat connectivity, while reducing other threats such as soil erosion by wind.

Landscape fragmentation occurs even in **protected areas**. However, compared with unprotected areas, the increase in fragmentation appears to be noticeably lower in protected areas that are part of the EU's Natura 2000 network, indicating that well-implemented nature protection measures have positive impacts.

When farmland is abandoned

Like many other environmental policy questions, landscape fragmentation presents a dilemma. On the one hand, the expansion of transport networks fragments the landscape and introduces additional pressures on ecosystems, including pollution. On the other hand, transport networks also bring economic opportunities (e.g. jobs in tourism, industry or the bioeconomy) to rural communities, often heavily dependent on agriculture and affected by land abandonment.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For some rural communities, **land abandonment** is a pertinent concern, especially in remote regions where the local economy relies heavily on the agricultural activities of often small-scale farms with low agricultural productivity. In such communities, younger generations also tend to move to cities and small-scale farming struggles to compete economically with a more structured, intensive agricultural market. In the next 20 to 30 years, significant areas of agricultural land are expected to be abandoned[13] in parts of Europe.

When left uncultivated, vegetation — including forests — will grow and take over the abandoned area. However, after centuries of extensive land management, such as grazing by sheep or goats, **natural revegetation** often results in ecosystems with fewer species. To preserve EU habitats and species, it is often better, therefore, to support farmers to practise extensive, high-nature-value agriculture. New incentives, such as diversification of income sources (e.g. tourism) or premium prices for high-quality food products, can help change these trends.

Intensive land use affects soil and its functions

Urbanisation, a growing population and a growing economy on the one hand and land abandonment on the other have resulted in more people living and relying on a smaller area in Europe. While some areas face depopulation and a decline in agricultural and economic activities, other areas — urban and agricultural alike — are subject to increasingly intensive use.

Soil represents an almost invisible interaction between a huge diversity of soil-dwelling organisms, organic matter from plants and roots, and material from weathered rock and sediments. This sensitive biomineral layer on top of the Earth's crust can be viewed as an ecosystem of its own. Intensive use of land can affect soil and its functions significantly and in several ways, including through soil sealing, erosion, compaction and contamination.

When **sealed** — covered by buildings, asphalt or concrete — soil loses, among others, its ability to absorb and retain water or to produce food. Use of heavy machinery can change soil structure and make it more **compact**, reducing air and water in the parts of the soil where plant roots take up water and nutrients and where soil animals and microorganisms decompose organic material. Sealed or heavily compacted soil absorbs less rain water, which in turn increases surface run-off, soil erosion and the risk of flooding.

Higher productivity often relies on synthetic fertilisers and crop protection products, as well as certain agricultural practices, which may lead to **erosion** and **contamination**. For example, maize monocropping tends to increase erosion. The erosion of topsoil reduces yields and, hence, can affect farmers' incomes. Erosion can also affect biodiversity as top soils tend to shelter the highest diversity and density of soil organisms. According to some estimates[14], the current mean soil erosion rate by water is 1.6 times higher than the average rate of soil formation in the EU. Wind and harvest losses are also major sources of soil erosion.

Similarly, the excessive use of mineral **fertilisers** can contaminate the soil with cadmium (see Interview — Soil contamination: the unsettling legacy of industrialisation) and affect the way soil ecosystems function (see Interview — Soil: the living treasure under our feet). Through soil erosion or flooding, pollutants can enter water streams, leach into groundwater and spread farther. Or, waste management practices — such as landfilling or spreading waste water on land — can **introduce contaminants**, including microplastics, to soil. In Europe, pollution from industry is regulated by EU legislation and as a result has been declining significantly. Despite this, industrial facilities also release some of their pollutant emissions to land. For the 30 000 facilities and 91 pollutants included, all information on how much and what pollutants each facility releases is made public through a web portal (European Pollutant Release and Transfer Register[15]) managed by the EEA and the European Commission. In addition to known and regulated pollutants, in recent years there has been a growing concern of new pollutants, such as persistent organic chemicals used in plant protection, contaminating in Europe's soils. Depending on their potential impacts, new measures are very likely to be needed to protect the environment and human health.

Contamination is not always linked to local sources of pollution. Wind and rain can transport and deposit **air pollutants** even in the most inaccessible parts of the world. Similar to what happens in lakes and oceans, once they enter soil, pollutants can accumulate over time and affect these ecosystems.

Preserve and connect natural areas, reuse and recycle urban areas

With resources as valuable and limited as land and soil, the only viable option is to prevent their degradation and use them sustainably.

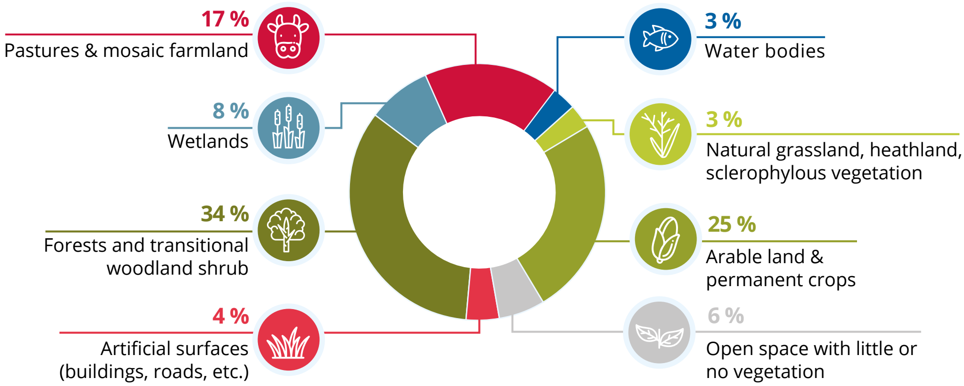
The EU aims to achieve '**no net land take by 2050**' in line with the global Sustainable Development Goals. One clear way of limiting urban expansion is to make better use of the existing urban space. Today, **land recycling** and densification (e.g. using an old industrial site for infrastructure or urban expansion) account for only a fraction — 13 % — of new developments (see EEA indicator[16] and land recycling viewer[17]), and land take continues to be a problem (see the land take data viewer[18]). Europe's spatial, especially urban, planners will need to play a key role in limiting urban expansion by designing compact but green cities, with key amenities within walkable distances or mobility systems designed to reduce travel distances and times, or an extensive green infrastructure network that connects all natural areas across the continent.

To turn such plans into reality, a wide range of stakeholders needs to be involved and key governance questions need to be addressed (see Governance — Acting together for sustainable land management).

State of play

Europe's land cover has remained relatively stable since 2000, with about 25 % covered by arable land and permanent crops, 17 % by pastures and 34 % by forests. At the same time, cities and concrete infrastructures continue to expand and the total area used for agriculture decreased.

Land cover in Europe (1)



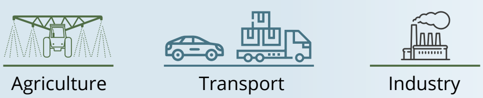
Soil contamination

Local contamination

Polluting activities (2)

- Industrial production and commercial services
- Power plants
- Storage of polluting substances
- Municipal waste treatment and disposal
- Industrial waste treatment and disposal
- Oil industry
- Other, including transport spills, mining and military

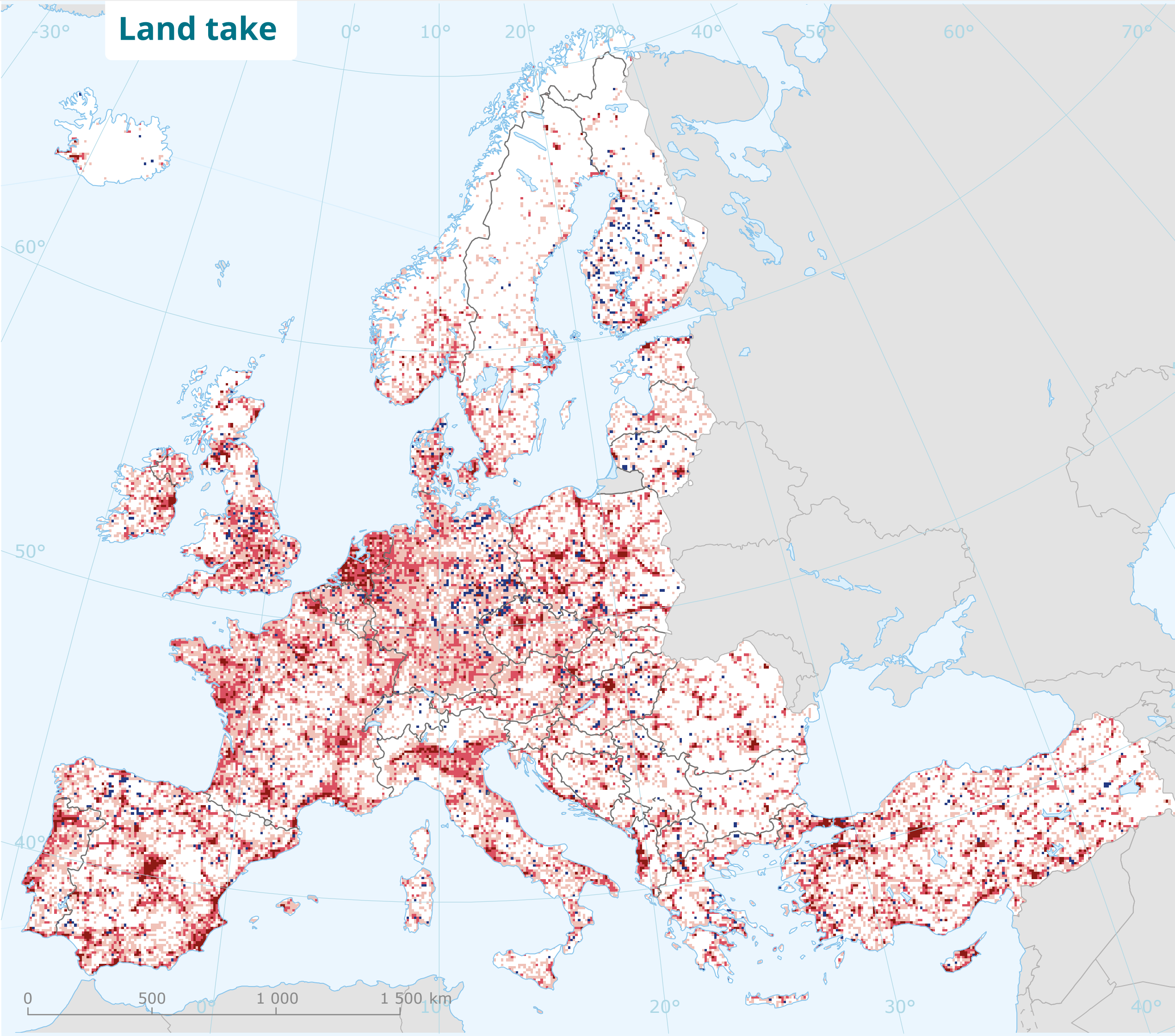
Diffuse contamination



Note: (1) According to Copernicus Corine Land Cover classification; (2) Based on 2.8 million potentially contaminated sites in EU-28. Sizes of boxes are proportionate to the importance of local sources. (Estimated by Eionet National Reference Centres Soil, 2006); (3) Land take indicators monitor how much land is taken for urban and other artificial development from agricultural, forest and other natural land use.

Although artificial surfaces cover less than 5 % of the wider EEA territory, a sizeable area still became sealed (covered by concrete or asphalt) between 2000 and 2018. The good news is that the rate of increase in artificial surface areas has slowed down in recent years.

Land take



Spatial pattern of net land take (3) in EEA39 between 2000-2018 (km²)

< 0 | 0 | 0.0001-0.5 | 0.5-2 | > 2 | Outside coverage

Source: EEA Signals 2019; EEA land take data viewer.

Soil, land and climate change

Climate change has a major impact on soil, and changes in land use and soil can either accelerate or slow down climate change. Without healthier soils and a sustainable land and soil management, we cannot tackle the climate crisis, produce enough food and adapt to a changing climate. The answer might lie in preserving and restoring key ecosystems and letting nature capture carbon from the atmosphere.

The Food and Agriculture Organization of the United Nations (FAO) recently released a map[19] showing that the top 30 cm of the world's soil contains about twice as much carbon as the entire atmosphere. After oceans, soil is the second largest natural **carbon sink,** surpassing forests and other vegetation in its capacity to capture carbon dioxide from air. These facts remind us how important healthy soils are, not just for our food production but also for our efforts to prevent the worst effects of climate change.

Climate change affects soil

Researchers can already see the effects of climate change globally and in European soil. For example, according to the EEA's most recent report on climate change, impacts and vulnerability in Europe[20], **soil moisture** has significantly decreased in the Mediterranean region and increased in parts of northern Europe since the 1950s. The report projects similar effects for the coming decades, as the rise in average temperatures continues and rainfall patterns change.

Continuing declines in soil moisture can increase the need for irrigation in agriculture and lead to smaller yields and even desertification, with potentially dramatic impacts on food production. A total of 13 EU Member States have declared that they are affected by **desertification**. Despite this acknowledgement, a recent report[21] by the European Court of Auditors concluded that Europe does not have a clear picture of the challenges linked to desertification and land degradation and that the steps taken to combat desertification lack coherence.

Changes in seasonal temperatures can also shift the annual cycles of plants and animals, resulting in lower yields. For example, spring can arrive earlier and trees can blossom before their pollinators have hatched. With the expected population growth, world food production needs to increase rather than decrease. This hinges largely on maintaining healthy soil and managing agricultural areas sustainably. At the same time, there is a growing demand for biofuels and other plant-based products, driven by the urgent need to replace fossil fuels and prevent greenhouse gas emissions.

The EEA report on impacts and vulnerability also highlights other impacts on soil related to climate change, including **erosion**, which can be accelerated by extreme climate events, such as intense rain, drought, heat waves and storms. In addition to causing the loss of areas of land, **rising sea levels** may change soil in coastal areas or bring contaminants, including salt, from the sea. In relation to land use, climate change may make some agricultural areas, mainly in the south, unusable or less productive while possibly opening up new possibilities further north. In forestry, the decline in economically valuable tree species might cut the value of forest land in Europe by between 14 and 50 % by 2100. A recent EEA report[22] on climate change adaptation and agriculture highlights that the overall impacts of climate change could produce a significant loss for the European agricultural sector: up to 16 % loss in EU agriculture income by 2050, with large regional variations.

Yet perhaps the biggest climate concern linked to soil is the carbon dioxide and methane stored in permafrost in boreal regions, mainly in Siberia. As the global temperatures increase, the permafrost melts. This thawing causes the organic material trapped in the frozen soil to disintegrate, which can lead to the release of massive amounts of greenhouse gases into the atmosphere, which could hence lead to the accelerating of global warming far beyond people's control.

Tackling the climate crisis with soil

In April 2019, a group of highly influential scientists and activists[23] called for 'defending, restoring and re-establishing forests, peatlands, mangroves, salt

marshes, natural seabeds and other crucial ecosystems' to let nature remove carbon dioxide from the atmosphere and store it. Restoring ecosystems would also support biodiversity and enhance a wide range of ecosystem services, including cleaning air and water, and providing people with enjoyable spaces for recreation.

According to a review of the existing information on the interrelations between soil and climate change (Climsoil report[24]), around 75 billion tonnes of organic carbon is stored in EU soil. About half of these soil stocks rest in Sweden, Finland and the United Kingdom, as these countries have more forest soils, and in particular wet organic soils such as peat, than the others. To put this in some perspective, according to the EEA's most recent estimates[25], the EU's total CO_2 emissions in 2017 were about 4.5 billion tonnes.

The amount of **organic carbon** in EU soils may be slowly increasing but estimates on the pace of this change are highly uncertain. To make matters more complicated, the organic carbon stock is also constantly changing, as plants capture carbon dioxide from the air before decomposing and releasing the gases back to the atmosphere. A report[26] by Intergovernmental Panel on Climate Change (IPCC) confirms that greenhouse gas emissions from all sectors — including land and food — need to be reduced in order to achieve the target of keeping global warming to well below 2 degrees Celsius.

Despite the uncertainties, restoring ecosystems and improving soil quality could be a very cost-efficient measure in terms of **climate action** with a triple impact. First, growing plants remove carbon dioxide from the atmosphere. According to the FAO[27], restoring currently degraded soils could remove up to 63 billion tonnes of carbon, which would offset a small but important share of global greenhouse gas emissions. Second, healthy soils keep the carbon underground. Third, many natural and semi-natural areas act as powerful defences against the impacts of climate change.

The examples of benefits are many. For example, areas next to rivers (riparian zones) and green spaces in cities can act as cost-effective **protection against floods and heat waves**. Healthy land and soil can absorb and store excess water and alleviate floods. Parks and other natural areas in cities can also help with cooling down during heat waves, partly because of the water present in their soil. During dry seasons, healthy ecosystems can slowly release the water they have stored underground, mitigating the worst impacts of droughts.

Capturing the carbon in the air

There are also various methods for increasing land's capacity to **capture carbon dioxide** from air. A recent European research project (Caprese study[28]) found that the conversion of arable land to grassland is the most rapid way of increasing the amount of carbon in soil. For arable land, the use of cover crops — plants such as clover grown in between harvest and sowing the next crop mainly to increase soil fertility and avoid erosion — was the most effective way of increasing carbon stocks in soil.

In contrast, decisions to use land differently can also change areas, making them sources of emissions. Notable examples of this are draining **peatlands**, burning peat from bogs for heating, ploughing up grassland and cropland, which releases previously stored carbon. For **forests**, the dynamic is the same but with a different timescale. Like soil, forests are both carbon stocks and carbon sinks, meaning that they both store carbon and capture it from the air. In many cases, young, growing forests capture carbon more rapidly than old forests but harvesting old forests removes the carbon stock from the forest. Depending on how the wood is used, the carbon may be released sooner, such as when the wood is burned for heating, or much later, when the wood is used for building houses, for example.

Healthier soils and land ecosystems could capture and store more carbon dioxide from the atmosphere than they currently do. Green spaces and natural areas could also help people and nature to adapt to the inevitable changes in our climate. Soil alone cannot fix climate change but it needs to be factored in and could be a powerful partner in our efforts.

EU action and EEA work on soil and climate change

The EU thematic strategy for soil protection and its implementation report[29] emphasise the importance of healthy soil in both climate change mitigation and adaptation. The Paris Agreement[30] highlights the critical role of the land use sector in climate action.

Following suit, a new EU regulation[31] on land use, land use change and forestry requires that Member States, at the minimum, fully offset the sector's greenhouse gas emissions from 2021 to 2030.

The implementation of the new regulation requires **reporting and monitoring**, which the EEA will support. The EEA also continues to develop knowledge about the environmental issues associated with land use and forestry and related land management practices, including by using Earth observation data from the Copernicus Land Monitoring Service[32]. Many of the EEA's assessments, indicators and data on soil, land, ecosystems, agriculture, forestry, green infrastructure and other topics also have strong links to climate change.

A lot remains unknown, but the better we understand the dynamics between soil, land and the climate, the better are our chances of designing and implementing sustainable solutions.

Soil, land and climate change

Soil contains significant amounts of carbon and nitrogen, which can be released into the atmosphere depending on how we use the land. Clearing or planting forests, the melting of permafrost can tilt the greenhouse gas emission balance one way or the other. Climate change can also substantially alter what farmers can produce and where.

Source: EEA Signals 2019.

David Russell
Senckenberg Museum of
Natural History,
Görlitz, Germany*

(*) Photo by Senckenberg, Jaqueline Gitschmann

Soil: the living treasure under our feet

Soil is much more than inanimate sand and silt. It is full of life, from microscopic organisms to larger mammals, all interacting in an equally rich number of microhabitats. Their interactions provide us with food and fibre, clean water, clean air and industrial processes free of synthetic chemicals, and can even provide a cure for many diseases. We talked to Dr David Russell of Senckenberg Museum of Natural History, Germany, about soil biodiversity and what it means for our planet.

What is soil?

Soil is a complex, dynamic and living body, which can be seen as the living skin of Earth. It is composed of mineral and organic components, as well as air and water. In very broad terms, mineral components consist of particles such as sand, silt and clay composed of different chemical components, while organic components derive from living organisms, including plants, bacteria, fungi, fauna and their residues.

Soils are important reservoirs of biodiversity. Around a quarter to a third of all organisms occur in soil. The biodiversity of soil can include organisms ranging from microscopically small bacteria and nematodes, to springtails, mites, millipedes, earthworms, moles and mice. Each of these groups is species rich. For example, in Germany alone, there are 50 different earthworm species that we know of. In fact, the diversity of soil life is often significantly higher than above the ground in the same site. A commonly cited number is that one cubic metre of forest soil can contain up to 2 000 invertebrate species.

What happens in a soil ecosystem?

Soil ecosystems vary substantially, especially at the microhabitat level. The same block of soil contains very diverse habitats — soil surface, below ground bulk soil and pore space — each home to different organisms. For example, most organisms living in soil are very dependent on and live in soil pores. These can be filled with air or water, with different groups of organisms living in each.

There are other ways of looking at soil habitats. For example, there are microscopic boundary layers between soil particles as well as biological hotspots, including the **rhizosphere** where plant roots are or the **drilosphere** around earthworm burrows. Spatial scale is also very important.

Yet, all these species in all these microhabitats live together and interact in what we call the **soil biome**. For example, they can feed on each other or the faecal pellets of one provide nutrients for others. These interactions in the soil biome are essential for soil functions, which in turn provide ecosystem services.

What kind of services does soil provide?

Soil structure and soil organic matter are two of the best-known examples important for ecosystem services. Soil structure[33] is defined by how different particles are assembled in the soil matrix. Soil includes a combination of bigger and smaller aggregates of soil particles, air- and water-filled pores, etc. Soil species can work directly on the soil structure. For example, earthworms through their burrowing activities move things around and thus change the soil structure. Some of these changes can consist of making new pores and closing others, making some parts denser or bringing new food sources for soil organisms. Earthworms are considered ecosystem engineers, as they can really churn up the soil.

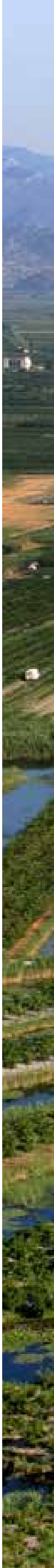
The structure of the soil is also a key factor in the **water cycle**. It plays a role in determining how much water soil can take up and retain, how it purifies it and how this water can feed plants and so on. Imagine if soil could not retain or purify water, what that would mean for agriculture, flooding or our health.

The other example is the **nutrient cycle** involving how much **soil organic matter** — i.e. carbon, nitrogen and phosphorus — is taken up and stored in soil. Carbon inputs to soil are all organic and are the basis of the soil food web. Organic compounds, such as leaves and root tips, have to be broken down to simpler compounds by organisms living in soil before they can be used by plants. In a quite complex multi-step process, one after another, different organisms degrade what used to be dead leaves or branches and turn them into inorganic compounds that are suitable to be taken up/used by plants. About 90 % of forest leaf litter is processed by millipedes, earthworms and woodlice. Without these organisms, we would be suffocating in leaf litter.

There are soil bacteria that convert atmospheric **nitrogen** into mineral nitrogen, which is essential for plant growth. Fungi transport nutrients through the soil from one location to another. All these microbial processes are regulated by the grazing of larger animals feeding on these microbes. We need to see these **rich and complex interactions** as the essence of a well-functioning system, which then provides us with the ecosystem services mentioned above.

In fact, healthy soils provide us with a wide range of benefits. For example, the nutrient cycle is key to food and fibre production. There are also clear links with the water cycle. When the soil structure is altered or destroyed, the ability of soil to purify, take up and hold water is affected. Compaction or soil sealing, for example, can lead to more flooding.

Soil microbial enzymes are being isolated in laboratories to see how they can be used for industry. For example, these enzymes can replace chemicals in, for example, the paper industry. Similarly, the pharmaceutical industry uses soil bacteria in developing medicines, including penicillin[34] and streptomycin[35].

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Do we know enough about soil biodiversity?

Soil biology is a fairly young field of research. Moreover, soil is a cryptic environment, difficult to observe. Despite this, we tend to underestimate what we know. In Europe, we have a good general understanding of which groups of organisms occur in and which are the main constituent species of soil. We have a fair understanding of what drives biodiversity as well as a basic understanding of how human soil use will affect soil biodiversity. There are many sources of information on soil, including the European Atlas of Soil Biodiversity[36] by the Joint Research Centre and the French Atlas of Soil Bacteria[37].

However, to monitor change over time, we need time series for soil biodiversity. The time series we have are often for protected natural sites, and there we can see that soil biodiversity is usually maintained and preserved. Furthermore, most of the soil monitoring done at the moment looks only at chemical compounds. Along with contaminants, we also need to monitor other parameters and understand how climate change or different agricultural methods affect soil biodiversity and the various soil functions they drive. There have been many studies across Europe, but knowledge has not been compiled in a way that enables us to establish baselines across Europe.

Soil in general and soil biodiversity in particular are very site specific. Effective measures often need more detailed and site-specific information, not only on biodiversity and species distribution and interactions at a given site, but also on, for instance, the impacts of human activities and climate change at that site.

What are the main threats soil biodiversity faces today?

There are many threats, including contamination linked to our land use practices. For example, pesticides, herbicides and other chemicals linked to agricultural intensification impact species distribution and harm soil biodiversity. Other threats include physical changes such as compaction and soil sealing — covering the soil with artificial surfaces such as concrete or asphalt. Compaction reduces pore space, affecting the species living in pores, while soil sealing cuts off carbon and water input into soil and also reduces the dispersal of species.

Because of its small scale and because it is a relatively slow process, soil species' dispersal is often ignored. Over longer time-frames, there is actually very active dispersal across the landscape, enabling high levels of soil biodiversity. By reducing landscape-level biodiversity above the ground through monocultures and landscape homogenisation, we also risk losing biodiversity in soil.

Climate change impacts, such as significant changes in precipitation (drought or floods), could also affect soil biodiversity. 2018 was so warm and dry that we observed a 90-95 % reduction in soil invertebrates at some of our field sites. If we consistently reduce species diversity, all these soil activities can be impacted.

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What is being done to protect soil in Europe?

There are global and European efforts and initiatives aimed at protecting soil, such as the Global Soil Partnership[38], as well as EU policies and directives — at least 18 directives by my own estimate, including the common agricultural policy. They address a wide range of areas from reducing pollutant emissions and sustainable land use to awareness raising. The better implementation of these policies and directives would certainly also be a good way forward for soil biodiversity. On the ground, there are many actions that can be taken, such as reducing fertiliser and pesticide use and adopting precision farming for agricultural soil.

Nearly half of the Sustainable Development Goals (SDGs) are linked to soil — from clean water and climate change mitigation to zero hunger — without healthy soil these SGDs will not be achieved.

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Copernicus — Monitoring Earth from space and the ground

Known as Europe's eyes on Earth, the EU's Earth observation and monitoring programme, Copernicus, is revolutionising the way we understand and plan for the more sustainable use of our valuable land and soil resources. From urban planning, transport routes and green spaces to precision farming and forest management, Copernicus provides detailed and timely land monitoring information to support decision-making.

Europe is one of the most intensively used land masses in the world, with the highest share of landscape fragmentation due to settlements and infrastructure, such as highways and railways. The way we use land has substantial impacts on the environment — species, ecosystems and habitats. Europe's land resources are also facing increased pressure due to the impacts of climate change, including more frequent extreme weather events, forest fires, droughts and flooding.

From patchy aerial photographs to high-resolution imagery

European national authorities have collected information on land cover and use at local, regional or national level for a long time. As the demand and competition for land resources grew during the second half of the 20th century, it became clear that a better and broader understanding of the links between land use and its impacts was essential to better protect land and soil resources. To this end, the EU decided, together with national authorities, in the mid-1980s to coordinate tracking and monitoring of land cover and use across borders.

In 1985, EU Member States initiated the Corine[39] (Coordination of information on the environment) programme, which saw the first joint effort by EU Member States to map land cover across Europe. In these initial days, land management experts relied on a mix of ground measurements and aerial photos, complemented by often expensive, low-resolution imagery from only a handful of satellites. As the data were fragmented, it was difficult to get a comparable Europe-wide picture of the threats to Europe's land resources. The first mapping took 10 years to complete.

High in the sky and down on the ground

The idea behind the Copernicus programme[40] was developed in the late 1990s ([i]) and its first satellite was put into orbit in 2014. The programme is run by the European Commission in close collaboration with the

(i) The Copernicus programme started in 2014. It was called GMES (Global Monitoring of Environment and Security) before 2014.

European Space Agency and is supported by Member States and various European organisations and agencies. Copernicus operates in six thematic areas: the atmosphere, marine, climate change, security, emergency management and land.

Today, two out of the seven Copernicus satellites in orbit — Sentinels 2A and 2B — are specifically tasked with land monitoring. They provide high-spatial- and high-temporal-resolution imagery every 5 days with a wall-to-wall coverage of the entire EEA-39 region ([ii]) and beyond, and support the monitoring of agriculture, forestry, land use and land cover change, and coastal and inland waters. They even provide biophysical data, such as on the level of chlorophyll in and the water content of leaves.

These two satellites are supported by data gathered from more than 100 contributing missions, both commercial and public, plus data from a large number of existing ground and air monitoring stations and sensors. Now, thanks to Copernicus, it takes only about a year to complete fully detailed and accurate mapping of Europe's land resources.

Copernicus land monitoring

The EEA manages the Copernicus Land Monitoring Service's pan-European and local components. In practice, the EEA makes sure that the imagery and data sets derived are easily accessible by the public and free to use. This service is becoming an increasingly essential knowledge tool for national environment agencies, city planners and others involved in managing the use and preservation of land resources, from the European to the local level.

The EEA uses Copernicus data to assess some aspects of the health of Europe's ecosystems and how land is used. The results are presented in various EEA assessments, including state of the environment reports, and key indicators. A first indicator — on land take[41] — looks at how much land is taken for urban and other artificial development from agricultural, forest and other natural land use (see the land take data viewer[42]). The second EEA indicator assesses the level of soil sealing and imperviousness[43] across Europe, monitoring the extent to which soil is covered by buildings, concrete, roads or other constructions (see the imperviousness data viewer[44]).

The EEA and other institutions can use these findings and data in a wide range of thematic or systemic assessments. For instance, based on Copernicus data and products, land managers can identify areas where urban sprawl, agriculture, highways and construction are splitting up key habitats and propose location-specific solutions. Similarly, Copernicus imagery helps to monitor habitat change and changes in land cover in the EU's Natura 2000[45] network of protected sites, which covers over 18 % of the EU's land area and 7 % of its marine territory (see the Natura 2000 data viewer[46]).

(ii) The 28 EU Member States plus Albania, Bosnia and Herzegovina, Iceland, Kosovo (under UN Security Resolution 1244/99), Lichtenstein, North Macedonia, Norway, Serbia, Switzerland and Turkey.

The geospatial data collected by Copernicus also form the basis of what is known as Urban Atlas[47]. Experts can study and compare the detailed make-up of almost 800 urban areas across Europe with more than 50 000 inhabitants. Detailed layers of information show where industrial, commercial and residential areas and parks are located. Data also include information on population density, building height and transport corridors, and pastures, wetlands and forests located in or near these urban areas.

Towards more knowledge and more sustainable choices

Supported by a dedicated set of satellites and advances in technology, land monitoring data and knowledge on Europe's landscape are set to improve further in the years ahead. With expected improvements in resolution, including millimetre precise ground movement, and thematic details, such as vegetation phenology and productivity, the potential uses of the imagery offer numerous opportunities. Ongoing plans for Copernicus envisage the placing of almost 20 more satellites in orbit before 2030, further expanding the level and detail of information collected.

Data taken from Copernicus and the EU's satellite navigation programme, Galileo[48], are already helping farmers to introduce precision farming techniques when growing crops, reducing the amount of irrigation and pesticides needed during growing seasons. City planners are also tapping into the increasing sets of data available on urban landscapes, to monitor housing dynamics, which can, for example, help in managing and improving access to public transport.

Similarly, monitoring urban heat islands and access to green spaces, including parks, gardens and forests, for city dwellers can help city planners in improving well-being and making sure cities are better prepared for climate change.

A recent EEA report on natural capital accounting in support of policymaking[49] discusses how to build better knowledge on using our natural resources, including land and soil, sustainably. The Copernicus satellite data will play an important role in this regard, in combination with direct monitoring of biodiversity and ecosystems through other programmes.

Changing menus, changing landscapes — Agriculture and food in Europe

Most of the food we eat is produced on land and in soil. What we eat and how we produce it have changed significantly in the last century along with the European landscape and society. The intensification of agriculture has enabled Europe to produce more food and at more affordable prices but at the expense of the environment and traditional farming. It is now time to rethink our relationship with the food we put on our plates and with the land and communities that produce it.

Agriculture has always been more than food production. Over centuries, farming shaped the European landscape, local communities, economy and cultures. A hundred years ago, the countryside was dotted with small farms, and many houses in urban areas had small vegetable gardens. Markets offered local, seasonal produce, and meat was a special treat for most Europeans. In the last 70 years, however, agricultural food production has increasingly evolved from a local activity to a global industry aimed at feeding growing populations with globalised tastes in Europe and around the world. Today, Europeans can enjoy lamb from New Zealand next to rice from India, along with Californian wine and Brazilian coffee. Fresh tomatoes cultivated in Dutch or Spanish greenhouses can be bought all year round.

In an increasingly urbanised and globalised world, farmers need to be able to produce ever-increasing amounts of food. Growing competition called for economies of scale — intensive agricultural production — favouring larger corporations, often specialised in cultivating a few types of crops or livestock in larger areas with secured access to markets across the globe. European agriculture was no exception.

Agriculture in Europe: a focus on producing more

Just like air and water, food is a basic human need. Whether it is due to natural disaster or bad policies, not having access to enough food could result in the starvation of entire communities. Given this, food production has always been seen not only as an activity carried out by individual farmers but also as a national policy and security issue, including an economic security issue. In the 1800s, the majority of Europeans worked in agriculture; however, the share of the workforce accounted for by farmers has been declining since, mainly because of the increased use of agricultural machinery and better incomes from urban jobs.

It was in this context that the EU Member States agreed on a common agricultural policy[50] initially aimed at ensuring that there was enough food at affordable prices in Europe. This also implied that enough farmers would have to stay on and cultivate their land. Global competition can drive prices down and only a small fraction of the final sale price ever reaches the farmer. Over time, the common agricultural policy integrated measures to help the rural economy in general and to reduce the environmental impacts of agriculture and protect soils[51].

In recent decades, the land area used for agriculture in Europe has decreased in size due to expanding urban areas and, to a lesser extent, expanding forests and woodlands. Today, over 40 % of Europe's land area is used for agricultural activities. In 2016, there were more than 10 million farms[52] (agricultural holdings) in the EU and about 3 % of these used more than half of the agricultural land[53]. In fact, about two thirds of Europe's farms are smaller than 5 hectares (50 000 m^2, roughly equivalent to seven football pitches) and they largely consist of hobby and subsistence farms, which consume more than half of their outputs. Many farming communities, especially in areas with lower agricultural productivity, face land abandonment, and shrinking and ageing populations, putting additional pressure on smallholdings.

Europe's agricultural landscapes are increasingly characterised by **low crop diversity** with vast areas and increasingly larger fields where only a few crops such as wheat or maize are grown. In such intensive-agriculture landscapes, biodiversity is significantly reduced compared with landscapes characterised by smaller fields of different crops, separated by lines of shrubs and small woodlands.

Intensive agriculture: higher outputs but higher impacts

Higher productivity was also achieved partly thanks to the increased use of synthetic chemicals, such as fertilisers and pesticides. Throughout history, farmers have used manure or minerals to fertilise soil and increase productivity. Fertilisers work by adding nutrients to soil, which are essential for plant growth.

Nitrogen: the key to plant growth

A plant is made mainly of hydrogen, oxygen, carbon and nitrogen. Plants can easily obtain carbon, hydrogen and oxygen from water and carbon dioxide from the atmosphere, but this is not the case for nitrogen. Soil can be depleted of its nitrogen after a couple of harvests.

Nitrogen makes up more than 70 % of our atmosphere, but plants cannot use the nitrogen in the form it is found in the atmosphere. Only some free-living and plant symbiotic bacteria (notably legume symbionts) can transform atmospheric nitrogen into a form that plants can use. To allow the soil to replenish its nitrogen stocks, traditional farming practices let land go fallow or plant legumes between harvest and sowing the next crop.

Synthetic fertilisers were invented in the early 1900s and widely commercialised from the 1950s onwards to solve the problem of 'nitrogen depletion in soil' and thus increase productivity. Synthetic fertilisers contain mainly nitrogen, phosphorus and potassium, followed to a lesser extent by other elements such as calcium, magnesium, sulphur, copper and iron. Farming also relies on plant protection products — a wide range of mostly chemical substances aimed at eliminating unwanted weeds, insects and fungi that harm plants and restrain plant growth.

On the one hand, synthetic fertilisers and pesticides secured a higher amount of harvests from a given field, enabling the growing populations both in Europe and in the world to be fed. Growth in output has also made food more affordable.

On the other hand, not all the nitrogen applied is taken up by plants. The excessive use of synthetic chemicals can contaminate the land, rivers, lakes and groundwater in a wider area, and they even enter the atmosphere as nitrous oxide — one of the main greenhouse gases after carbon dioxide and methane. Some pesticides harm pollinators, including bees. Without pollinators, we simply cannot produce enough food.

European countries produce significantly more meat than in the 1960s. And meat, beef in particular, requires significantly more land and water than plant-based food products. At the same time, cattle raising produces methane[54] and nitrous oxide, both very powerful greenhouse gases. Livestock is estimated to contribute to more than 10 % of total greenhouse gas emissions.

Unsustainable use harms soil and land productivity

The long-term agricultural productivity of soil depends on its overall health. Unfortunately, if we continue using this resource as we currently do, we will also reduce soil's ability, among others, to produce enough feed and food fit for human consumption.

There are many pressures that intensive agriculture exerts on land and soil, including contamination, erosion and compaction due to heavy agricultural machinery. An increasing number of studies highlight how widespread the residues of chemicals[55] used in pesticides and fertilisers are across Europe ([iii]). For some chemicals, such as copper and cadmium, soil samples from some areas indicate critically high levels. Excess nutrients (nitrogen and phosphorus) have altered life in lakes, rivers and seas, and recent EEA recent assessments ([iv]) on water call for urgent reductions in nutrients to prevent further harm to these ecosystems.

In addition to affecting land resources and soil biodiversity, this increased food production has also influenced our diets in unplanned ways.

(iii) See SOER 2020, Chapter on Soil and land use

(iv) EEA Reports No 7/2018, 11/2018, 18/2018, 23/2018; see Key EEA sources.

Changes in eating habits come with new problems

Five of the seven biggest health risk factors today (high blood pressure, high cholesterol levels, obesity, alcohol abuse and insufficient consumption of fruit and vegetables) causing premature death are linked to what we eat and drink. More than half of Europe's adult population[56] is classified as overweight, including over 20 % that is classified as obese. Child obesity is also a growing concern.

Compared with 50 years ago, Europeans consume more food per person. The intake of animal proteins, mainly meat and dairy products, has doubled in this period and is currently double the global average. Every year, on average, European adults eat, for instance, 101 kg of cereal and 64 kg of meat per person — which has been slightly declining in recent years but is still well above the global average. We also consume more sugar and sugar products (13 kg) than fish and seafood (10 kg).

At the same time, 88 million tonnes of food are wasted[57] in Europe every year, corresponding to 178 kg per person. Food waste means that all the resources used to produce food — water, soil and energy — are also wasted. And, the pollutants and greenhouse gases released during production, transport and marketing contribute to environmental degradation and climate change.

However, there are millions of people across the world who do not have enough nutritious food to eat. According to the

United Nations Food and Agriculture Organization, more than 820 million people[58] in the world were undernourished in 2017. According to Eurostat, 12 % of Europeans were unable to afford[59] a good-quality meal every second day in 2017.

It is clear that increased food production does not always mean better nutrition for everyone. This is a widely recognised problem and there are European and global measures aimed at addressing food waste[60] and malnutrition, including Sustainable Development Goal 2: Zero Hunger[61] and Goal 12: Responsible Consumption and Production[62]. Healthier diets, and minimising food waste, including through a more even distribution of healthy and nutritious food across society and the world, could reduce some of the impacts on health, the environment and the climate linked to food produced on land.

Competing demands for agricultural land

The EU common agricultural policy and the single market make food products produced across the EU in accordance with high safety standards a common feature of our daily lives. Along with this intra-EU trade in food products, the EU imports and exports[63] agricultural products from and to the rest of the world, which accounted for 7 % of all extra-EU trade in 2018. The EU is a large importer of fresh fruits and vegetables, while exporting beverages and spirits and meat. Indirectly, food trade means that the EU imports and exports land resources. Along with palm oil production, growing global meat consumption is one of the drivers of deforestation in tropical forests, which are often converted to pastureland for cattle or palm plantations.

But land is not only cultivated to produce food or animal feed. An increasing share of Europe's agricultural land is used to grow crops, such as rapeseed, sugar beet and maize, for biofuel production. Competing demands exert additional pressure on land in general and on agricultural land in particular when it comes to cultivating **biofuel crops**. Biofuels are seen as a tool to reduce greenhouse gases but this depends on the way they are produced and what plant material they use. Various biofuels have unintended negative consequences for the environment. To prevent such outcomes, the EU adopted a number of sustainability criteria[64] to limit biofuels' harmful impact on the environment, including land resources.

The EU's environmental impact on land and soil resources is not limited to the EU territory. Europeans consume agricultural products imported from the rest of the world. Land and soil, along with other resources such as water and energy, in the countries exporting to the EU are affected by Europe's high consumption levels. To ensure a regular supply, multinational corporations might also opt to buy large swathes of land in third countries to cater to European consumers.

According to a recent report[65] by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, the productivity of about one quarter of the global land surface has been reduced because of land degradation. Declining pollinator populations can result in crop losses worth up to EUR 500 billion every year.

What the future holds

According to United Nations projections[66], in the next 30 years, the global population will increase by 2 billion to reach 9.7 billion in 2050. This increase in itself means that we must change the way we grow, produce and consume food. Food production will need to increase, while factoring in climate change.

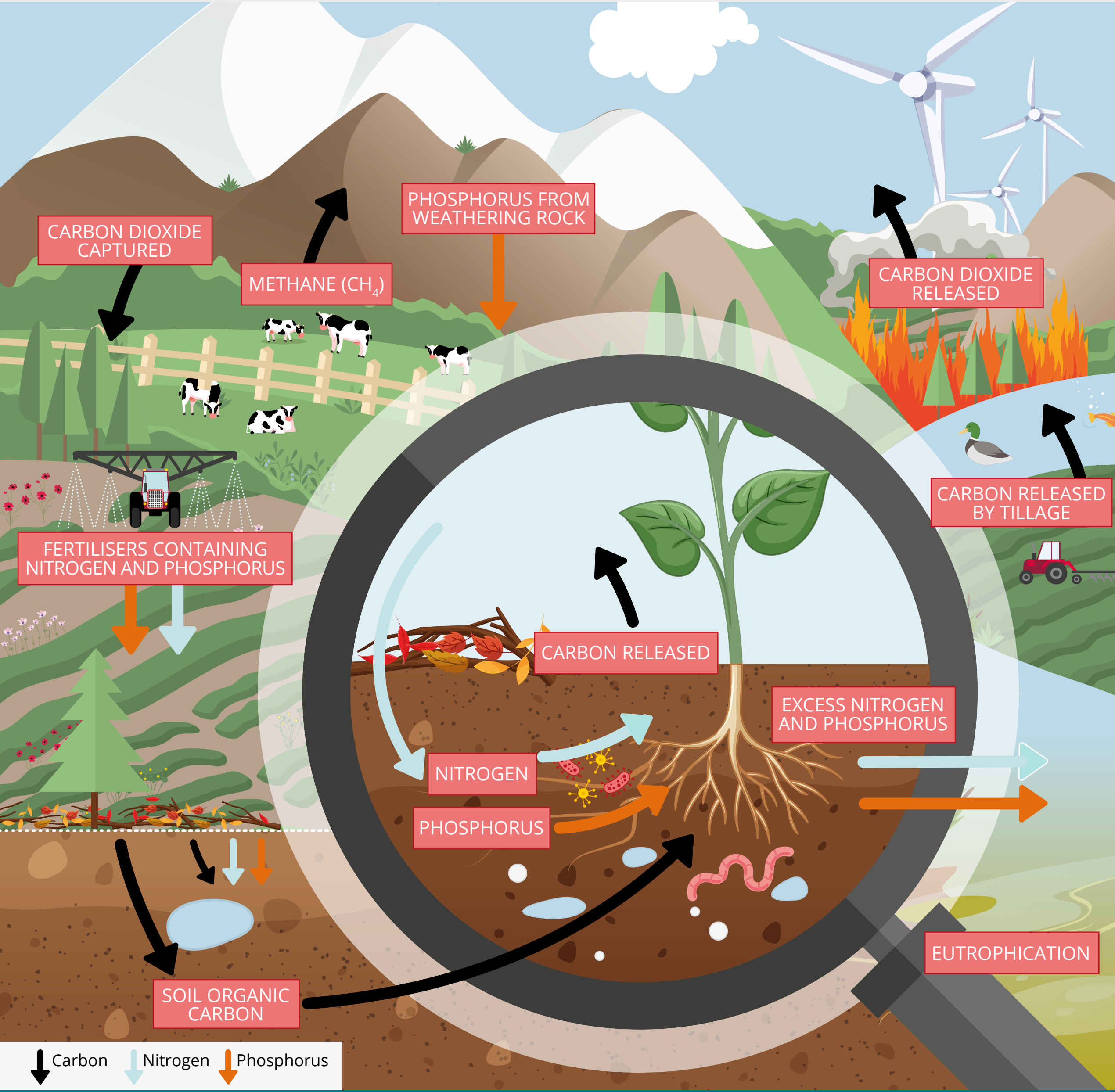
Yet, the way we currently produce food on land is already exerting too much pressure on this finite resource. At the same time, reducing the amount of food produced in Europe and meeting the domestic demand by increasing imports more can have severe impacts on global food markets, increase food prices and put vulnerable populations at risk of further undernourishment.

The urgency of this situation calls for an overhaul of our relationship with food — both what we eat and how we produce it. Most likely, this will entail eating less meat and dairy products and more seasonal fruits and vegetables. Plant-based 'meats' and 'milks' or other food products with similar nutritional values but with significantly lower inputs (including land, water and energy) are being developed and marketed. The question is whether these alternatives will become the norm in our shopping baskets, rather than the exception.

It will also require **food waste** to be minimised in the field, in the market and in homes. To meet the growing demand for food and to prevent further deforestation, intensive production in some areas will need to continue but we must stop the contamination that comes with it. For sustainable food production, depopulation will also need to be addressed in certain areas by encouraging more people to remain to take care of the land, protect local biodiversity and produce high-quality products.

Nature's nutrient cycle

Soil plays a crucial role in nature's cycles, including the nutrient cycle, which involves how much soil organic matter — i.e. carbon, nitrogen and phosphorus — is taken up and stored in soil. Organic compounds, such as leaves and root tips, are broken down to simpler compounds by organisms living in soil before they can be used by plants. Some soil bacteria convert atmospheric nitrogen into mineral nitrogen, which is essential for plant growth. Fertilisers introduce nitrogen and phosphates to induce plant growth but not all amounts are taken up by plants. The excess can enter rivers and lakes and affect life in these water ecosystems.



Source: EEA Signals 2019.

Interview

Mark Kibblewhite
Cranfield University,
Bedford, United Kingdom

Soil contamination: the unsettling legacy of industrialisation

Soil contamination is an issue that is strongly linked to our common past and part of the story of how Europe first became the industrial and later the environmental frontrunner in the world. We talked to Mark Kibblewhite, Emeritus Professor at Cranfield University, United Kingdom, and one of Europe's leading soil experts, to better understand the issue of soil contamination.

What does soil contamination mean?

In principle, soil that is contaminated is soil that has any substances added to it by human activity. This can happen directly or indirectly and it might be that the contamination took place a very long time ago or it could be happening right now. It is a serious problem when land is used for something where there is a possibility of people being exposed to soil contaminants. It is hard to remove soil contamination and the cost of this is often very high. It is very onerous for a generation to clean up the mess made by many past generations.

What are the main sources of soil contamination? What can be done to address it?

Different contaminants have different sources but probably the most important sources are former industrial activities. Their legacy is areas with serious soil contamination, mainly with metals, tars and other associated substances. Another important source is military activity, including on training grounds. For example, one of the worst examples of soil contamination in Europe is in former Yugoslavia where anti-personnel mines were deployed, which cause an extreme form of soil contamination.

The range of different types of contaminants is vast, including not just metals but a range of organic molecules, pathogens, biologically active materials, radioactive substances and so on, and all these have different sources.

Regulations and standards have been increasingly successful over the past 30-40 years in preventing soil contamination. Meanwhile, many heavily contaminated sites have been brought to safer conditions, although many remain that have not been dealt with. A very wide range of technologies can be used to reduce the risk of soil contamination, either by removing the contaminant or by containing it. The critical issue is the level of residual risk we are prepared to accept in the context of the cost of remediation.

How much of past contamination are we able to clean up? How are these sites selected?

The two big drivers for cleaning up soil contamination are risks to human health and to surface water and groundwater quality. Meeting the EU's Water Framework Directive[67] targets can require soil remediation to protect aquatic ecology. A third driver is agricultural production and ensuring plant health and food safety.

A lot depends on the end use of the land and the availability of funding from developers. In cities with a long industrial past, soil contamination in very-high-value areas, such as business districts or big developments near water, has now largely been dealt with, so risks are contained. This is good progress, but for areas without a high current economic importance, it is often not possible to secure funding for remediation.

We have made huge progress in cleaning up soils in Europe but we still have a problem. There are many places in Europe where the economic incentives and motivation to clean up soil contamination have not yet emerged. In the end, the key question is what level of risk we are prepared to accept, and where those risks are exceeded what we will do about it.

How is agriculture linked to soil contamination?

Two metals are particularly important in this context: cadmium and copper. Cadmium is an impurity in phosphate fertilisers and there is always some additional cadmium in soil where these are used. The amounts may be very small but they are cumulative. As cadmium is a carcinogen, we need to monitor this accumulation carefully. A lot of work has been and is being done to quantify this problem and explore how to reduce cadmium in fertilisers. Copper is found in areas that have vineyards and where the metal was used historically as an antifungal agent. This copper has unfortunately accumulated in soil. Once these and other metals are added to soil, they remain there and there are few realistic prospects for removing them.

Pesticides are another problem linked to agriculture. We know, for example, that organochlorine pesticides, which have long been prohibited, are still in soils across all of Europe. With current pesticides, the focus on their impact on the soil biota has been rather limited. They may create problems that we have not noticed yet. Also, our regulatory regime on agricultural chemicals' impact on soil is in my opinion rather weak.

How does soil contamination affect biodiversity?

Our understanding of the impacts of soil contamination on soil biota and soil functions is relatively poor and today there are some complications linked to soil contamination and above-ground biodiversity. Many sites across Europe have been abandoned for decades and as a consequence have become important reservoirs of species and biodiversity following natural regeneration. Cleaning them up may damage this biodiversity.

Thinking globally, we have to recognise that especially our airborne emissions may contaminate soil very far away and impact on soil biodiversity; therefore, we have a responsibility to make sure these emissions are minimised. Even in the polar regions and other very remote areas, we find contaminants that are entirely of human origin.

What other type of knowledge is missing about soil contamination? What are the emerging issues?

We may have underestimated radioactivity as a problem. It is a widespread lower-level issue but there are also some hotspots, such as cities with old jewellery and watchmaking areas. These areas can contain enhanced levels of radioactive soil contamination from luminescent and other substances that have been used in small-scale workshops.

By combining new spatial data sets and soil information, we will get a much clearer idea of where there is contamination. In parallel, epidemiological studies are getting ever more sophisticated and we have more and more information about the instances of disease that are linked to specific areas. When these two things come together, we may find that some diseases we observe in the general population can be clearly linked to soil contamination, which has been hard to demonstrate up to now.

What kind of positive progress do you see for the future?

The best thing for the future is to prevent further soil contamination. We can build on existing regulations controlling industrial soil contamination and engage citizens more directly. Plastics are a good example. We already have a citizen-driven movement to reduce the use of plastics and I'm very optimistic that as people become more aware of the impacts of their individual actions they will change behaviours and this will have a positive effect on soil management generally, including contamination.

Mark Kibblewhite
Emeritus Professor, Cranfield University, Bedford, United Kingdom

Governance — Acting together for sustainable land management

Who owns land and its resources? Who decides how they can be used? In some cases, land is private property, which can be bought and sold, and exclusively used by its owners. Often its use is governed by national or local regulations, for example to maintain forest areas. In other cases, some areas are designated for public use only. But land is not only space or a territory. When we all use land and rely on its resources, sustainable management requires owners, regulators and users from local to global level to work together.

In our daily lives, 'land' can mean many things at once. It can refer to a space on the surface of our planet's land mass. It can also mean the soil, rocks, sand or water bodies on the Earth's surface and its upper layers. In some cases, it can include all the minerals and other resources such as groundwater, oil and precious stones in the depths of an area. For rural communities or amateur urban gardeners, it can even mean a personal and cultural connection with the rural way of life or a connection with nature.

Land: commodity or public good?

The market value of land (a given area) can vary significantly depending on its use, location and the resources it holds. History is filled with stories of remote or not-so-popular areas where land prices skyrocket upon the discovery of oil or gold, or of neighbourhoods, such as Kreuzberg in Berlin which was a peripheral neighbourhood along the Berlin Wall, that quickly become central to urban life, with rising land and property prices. Productive land can also be a global commodity or an investment for multinationals buying large areas across the globe often at the expense of small-scale local production.

The concept of designating land as private property (as a commodity that can be bought and sold) varies across cultures and over time. In traditionally nomadic cultures, such as the Sami in northern Finland and Sweden, seasonal migration over vast distances and relying on natural resources along the way have been and to a lesser extent still are the norm. This way of life depends on unhindered access to the landscape and its resources. The community as a whole uses and cares for the land. In this context, the land and its resources above and below the ground are common goods.

Land can also be **a shared space** and **a shared good** assigned to a specific community's use. Many villages across Turkey have access to clearly marked pastureland, to be used by the herds of that village. Legally, the land might belong to the state or the village as a community but the village has the right to use the space and decide how to share it.

In some ways, this is similar to other public spaces. In urban areas, authorities can designate some areas, such as parks, public squares or pedestrian zones, to be used and shared by everyone. Public spaces can include land owned by the state or a public authority.

In Europe, the concept of common **public spaces** co-exists with the concept of areas that are clearly and legally defined as **private property**, belonging to individuals or legal entities such as companies or organisations. The boundaries are clearly marked, often by a fence or a wall, and registered and recognised by an official institution such as a land registry or municipality. Regardless of the type of land ownership, public authorities, through zoning laws, can also determine how specific areas are to be used, such as for residential, commercial, industrial or agricultural purposes.

Forest ownership: private or public?

The governance of land and its resources has never been straightforward. An area designated as private property managed by private entities can also function as a public space and provide public good. In some cases, the space can be considered a public space that provides a public good while its resources are commodities belonging to the legal owner, as in the example of Finnish forests.

Over 70 % of Finland is covered by forests and about 60 % of Finnish forests[68], consisting of some 440 000 holdings, are owned by almost 1 million private individuals or families. These relatively small forest patches (average of 23 hectares per holding, roughly equal to 32 football pitches) are passed on from one generation to the next. Over time, the number of forest-owner farmers has declined significantly, partly due to an ageing population and the migration of young people to cities. Today, pensioners are the largest group of forest owners and the actual management of most of these areas is run by an extensive network of owner associations across Finland. Yet, all Finns can access and enjoy these private forests.

In fact, more than 60 % of Europe's forests[69] are privately owned. Private ownership ranges from 75 % in Sweden and France to less than 25 % in Greece and Turkey. Forest management and forestry activities can then be handled by public entities or entrusted to private forestry companies.

Who has the duty of care?

To protect land and its resources and how to use them, different governance structures put in place a series of policies and measures. In Europe, these can range from local zoning regulations to European legislation aimed at reducing industrial pollutant releases to land, or from connecting green areas to reduce fragmentation to extending protected areas to preserve nature's diversity. Some of these measures are closely linked to economic sectors or specific policy areas. For example, the EU's common agricultural policy[70] requires farmers to adopt a set of practices to achieve 'good agricultural and environmental condition'. Similarly, the Seventh Environment Action Programme[71], guiding the EU's environment policy until 2020, includes a non-binding commitment of 'no net land take by 2050', with the aim of halting the spread of urban areas into often fertile agricultural land and forests. Despite such measures, there is not a coherent and comprehensive set of policies targeting land and soil. A recent report[72] by the European Court of Auditors (ECA) stresses that the risks linked to desertification and land degradation are increasing and that policy measures lack coherence. The ECA recommends, among other things, that a methodology be established to assess the extent of desertification and land degradation in the EU and that guidance be provided to Member States on preserving soil and achieving land degradation neutrality.

When it comes to taking action on the ground to achieve such policy goals, it is not down to individual stakeholders such as farmers, consumers or urban planners alone. Although our consumption choices, such as avoiding personal care products with microplastics, diets or farming practices can have an impact on the health of our soils and land, there are many factors and other stakeholders at play. Market prices for food and land, the productivity of land, climate change and pressure from urban sprawl may all force farmers to adopt monoculture or intensive farming practices to remain economically viable. It is not surprising that many farming communities across Europe face abandoned land and young people migrating to urban areas, especially in areas with low agricultural productivity. Similarly, individual urban planners may choose to limit urban sprawl by converting old industrial sites into new urban areas but authorities may lack the resources needed. In many cases, cleaning and remediating land in industrial areas may be more costly than expanding the infrastructure and building on farmland.

Who is responsible?

In some policy areas, such as soil pollution, it can be extremely difficult to attribute responsibilities. In a given field, some contamination might be due to excessive fertiliser and pesticide application by the farmer. Additional pollutants released by transport, industry or energy sectors might be transported in by wind and rain, or as a result of flooding. Ultimately, wider society benefits from the food produced in the field and its transport to cities.

Some of the land resources, including sand and gravel, are global commodities. End users might be quite far from the extraction location. According to a recent report by UN Environment[73] (the United Nations Environment Programme), the global demand for sand has trebled over the last two decades as a result of urbanisation and infrastructure developments. Extraction rules and their enforcement can vary from one country to another. Along with growing demand and illegal extraction practices, these differences in governance can result in additional pressure on already vulnerable ecosystems, such as rivers and coastal areas, where sand is extracted. Similarly, other mining activities — of coal, limestone, precious metals or gems — can have equally significant impacts (e.g. contamination or removal of topsoil layers) on ecosystems near their extraction sites.

Defining and agreeing on measurable targets can present another governance challenge. For example, we know that soil organic matter — such as plant residues — is essential for healthy and productive soil and for mitigating climate change. Given this, the EU has committed itself to increasing soil organic matter in its Roadmap to a resource efficient Europe[74]. But how can we measure change accurately when we do not know the current amount of organic matter in Europe's soil? To this end, the European Commission's Joint Research Centre initiated an initial soil survey[75] comprising about 22 000 soil samples from across the EU.

Soil and land have increasingly been recognised as vital and finite resources globally and in Europe that face increasing pressures, including those linked to climate change and biodiversity loss. For example, a recent special report[76] from the Intergovernmental Panel on Climate Change brings a global perspective to the challenges ahead by looking at land degradation, sustainable land management, food security and greenhouse gas fluxes in terrestrial ecosystems in the context of climate change. A report by the IPBES[77] (the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) highlights the scope of global land degradation and its implications. A more recent global assessment[78] by IPBES draws attention to the accelerating decline in biodiversity, including land-based species, which is caused by, among other factors, changes in land use.

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In recent years, this recognition has gradually been translated into overarching goals and structures. The United Nations Sustainable Development Goals — in particular Goal 15: Life on Land[79] and Goal 2: Zero Hunger[80] — depend on healthy soil and sustainable land use. The Global Soil Partnership[81] of the Food and Agriculture Organization of the United Nations along with its regional partnerships aim to improve the governance and promote the sustainable management of soil by bringing together all stakeholders, from land users to policymakers, to discuss soil issues. Many EU policy documents, including the EU's soil thematic strategy[82] and biodiversity strategy[83], call for protecting soil and ensuring the sustainable use of land and its resources.

Given the complexity of governance linked to soil and land, binding targets, incentives and measures for protecting soil and land resources are largely missing despite these global and European efforts.

However, various initiatives are in progress across different parts of society to better manage our land and soil. These range from improving our environmental monitoring, policy reform proposals (e.g. agriculture), research initiatives and associations that promote environmentally friendly farming, to consumers that buy sustainable food products. Ultimately, we all have a duty of care and we are all responsible, as we are the users, owners, regulators, managers and consumers of land and soil.

Soil and United Nations Sustainable Development Goals

Many global policy frameworks, including the United Nations Sustainable Development Goals (SDGs), directly and indirectly address land and soil. Many of these SGDs cannot be achieved without healthy soils and a sustainable land use. Below is an overview of the SDGs with strong links to soil.

Take urgent action to combat climate change and its impacts. Soil can play a positive role in reducing the impacts of climate change, by sequestering CO2, sustainably managing the resource and restoring degraded soils.

'Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.'

Improving the quality of land and soil to 'end hunger, achieve food security and improved nutrition and promote sustainable agriculture.'

'Ensure healthy lives and promote well-being for all at all ages' by preventing dangerous chemicals, air and water pollution from contaminating land and soil. Additionally, reducing soil degradation can help to increase food production.

'Ensure sustainable consumption and production patterns,' through making sure chemicals and waste does not make its way into the air, water and soil, which can have adverse impacts on our health and environment. That is why it is important to sustainably manage and efficiently use soil resources.

'Make cities and human settlements inclusive, safe, resilient and sustainable,' by ensuring land and soils are protected as they safeguard our cultural and natural heritage.

'Ensure availability and sustainable management of water and sanitation for all,' by preserving soil quality because of the role it plays in helping to provide clean water for drinking and agriculture.

Source: United Nations Sustainable Development Goals.

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EEA Signals 2019

Land and soil in Europe

We cannot live without healthy land and soil. It is on land that we produce most of our food and we build our homes. For all species — animals and plants living on land or water — land is vital. Soil — one of the essential components of land — is a very complex and often undervalued element, teeming with life. Unfortunately, the way we currently use land and soil in Europe and in the world is not sustainable. This has significant impacts on life on land.

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