SOIL AS NATURAL CAPITAL

KVAB Thinkers' report

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0 Executive summary

We, the Thinkers of the programme on Soil as Natural Capital, organized by the Royal Flemish Academy of Belgium for Science and the Arts (KVAB), have encountered a large number of Flemish scientists and other experts in the field of Soils as Natural Capital. The information provided by these experts was presented in three sessions, entitled: (1) healthy soils for sustainable land management in the 21st century; (2) the importance of soils in a changing climate; and (3) appropriation of soils as a natural capital. We also visited the Institute for Agricultural, Fisheries and Food Research (ILVO) and Flanders Environment Agency (VMM) to learn from experts on their research and governmental programmes related to soil as natural capital.

There is growing awareness worldwide that healthy soils provide a huge natural capital that is essential for our well-being, and which is reflected in global initiatives to protect soils for climate change mitigation, food production and biodiversity conservation. During our discussions, most scientist and experts expressed concern about the loss of soil natural capital in Flanders. The reasons for this loss of soil natural capital are manifold, but major drivers are soil degradation by intensive agricultural practices, climate change, sealing of soils by buildings and infrastructure, and pollution.

We also noted that there is a scarcity of information on soil biodiversity in Flanders, the role of soils in supporting ecosystem multifunctionality, and the resilience of soils of Flanders to climate change, especially extreme weather events, which are expected to increase in severity and frequency.

We also learned that Flanders has yet no integrated action to monitor and report on soil health, for example to detect trends in soil organic carbon or in diffuse soil pollution. This is surprising given that Flanders will need to report changes in soil carbon following the COP 21 Paris agreement and will need robust soil information across land uses to comply with EU and international policy.

The concern for soil health is not unique to Flanders, although we see some issues of particular concern in Flanders:

- Land tenure creates particular problems for soils of Flanders, in that long-term stewardship for soils is currently absent, leading to degradation of agricultural soils, including soil carbon loss, erosion and compaction, due to inappropriate land management. Further, while the value of the natural capital of Flanders' agricultural soil is declining, there is no concerted action to monitor and report on soil health, and it is therefore not possible to track local soil change against regional norms.

- The sealing of soils by buildings and infrastructure is posing a major threat to soil as natural capital, and projected rates of soil sealing paint a worrying picture for Flanders' soils. Land take in Flanders is occurring at a rate of ~6 hectares per day, with about half being sealed by impervious material, thereby putting a halt to many critical ecosystem functions that soils perform. Furthermore, land is often taken from areas where natural capital of soils is high, thereby contributing disproportionally to a loss of natural capital of soils in Flanders.

  The loss of the natural capital of soils in Flanders is a threat to human well-being and risks the ability of Flanders to comply to international agreements and laws, such as "4 per 1000", launched at the COP 21, the "no debit" rule of the EU regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry (LULUCF), the Water Framework Directive, and the Convention on Biological Diversity.

- The capacity to protect soil in Flanders is compounded by the absence of an organization that has the overall responsibility for the monitoring and protection of soil

natural capital, and the fragmentation of soil protection issues within a wide range of policies.

We learned from the sessions, and especially from the session on "appropriation of soils as natural capital", that there are many instruments and initiatives to make people aware of the value of soils and how to manage soils more sustainably, although soil protection is fragmented within policy and there is a lack overall coordination. Further, most instruments are voluntary or based on agreements between stakeholders, so the options for enforcement are limited. To better protect and restore the natural capital provided by soils of Flanders and comply with EU and international (e.g. SDG 15.3 on land degradation neutrality) policy we recommend the following:

- To consider all soils, regardless of their ownership, as a common good that provides well-being for everyone in Flanders, thereby obliging every landowner, from farmer to hobby farm, to household gardener, to value and take care of the soils beneath their feet. There is an opportunity to use legislative options and incentives to reward farmers and other land users for protecting and restoring soil health, but also there is a need for measures to raise awareness among all sectors of society about the importance of soil natural capital.

- To develop a holistic soil monitoring programme based on multiple dimensions of soil health, including chemical, physical and biological properties, and soil functions, to monitor the current status and development of natural capital provided by soils across all land uses.

- To protect open land and soils by more compact building and bundling of infrastructure and ensure full consideration of soil natural capital within planning decisions. The recent published spatial policy plan should apply to all still unused building land and finances should be made available for municipalities to deal with 'planschade'. De-sealing should be considered as a compensation method for new buildings and infrastructure.

- To strive for a circular agriculture (kringlooplandbouw), thereby limiting management practices in agriculture and other land uses that damage soil natural capital. This can be achieved using methods that have been developed for sustainable agricultural land use, including compensation for the societal services provided by farmland, and by adopting longer and better land lease contracts.

- To commit to protecting and increasing the climate resilience of soils and the contribution of soils to climate mitigation through protecting and building soil organic carbon and maintaining healthy, biodiverse soils.

- To establish a committee on integrated soil policy involving different government organizations, scientists and stakeholders concerned with soil health, and pro-actively cooperate with and profit from the international efforts to combat land degradation, climate change and biodiversity loss.

1 Thinkers Programme 'soil as natural capital'

In 2020 the Royal Flemish Academy of Belgium for Science and the Arts (KVAB) ran a Thinkers Programme, entitled 'Soil as Natural Capital'. For this programme, the Academy invites one or two highly regarded scholars (called 'thinkers') to come to Flanders on several occasions during the year. The thinkers are introduced to the specifics of a particular challenge Flanders is facing and are given the opportunity to discuss the topic with scientific researchers, opinion-makers, politicians, industrial managers, and other stakeholders. The overall quintessence of the 'thinkers' experience is consolidated in a short report that holds wisdom and guidance on soil as natural capital for the Flemish Government.

The Class of Technical Sciences of KVAB took the initiative for this Thinkers Programme on 'Challenges and opportunities for preservation and strengthening soils as natural capital in the 21st century'. Supported by a steering committee chaired by Willy Verstraete the general coordination was led by a core committee consisting of Kris Verheyen (UGent), Steven Sleutel (UGent), Anne Gobin (VITO) and Erik Smolders (KU Leuven).

Two Thinkers-in-Residence were invited for this programme:

- Richard Bardgett, a British ecologist and professor of ecology at The University of Manchester, UK, and past President of the British Ecological Society, providing an academic perspective on soils as natural capital.
- Joke Van Wensem, specialist advisor of the Ministry of Infrastructure and Water Management in the Netherlands and vice chair of the Dutch Soil Science Society, providing a policy-oriented perspective on soils as natural capital.

To get an overview and discuss the topic 'Soil as Natural Capital' with scientists and other experts from NGO's and (agro-)businesses[1] three fact finding sessions were organized:

- Healthy soils for sustainable land management in the 21st century
- The importance of soils in a changing climate
- Appropriation of soils as a natural capital

Through the fact finding sessions, discussions and debriefing with the core committee, meetings with representatives at the Institute for Agricultural, Fisheries and Food Research (ILVO) and Flanders Environment Agency (VMM), and with cabinet members of the Flemish Ministers of Environment and Agriculture, the Thinkers Programme strived to establish the current status of soils in Flanders from a natural capital perspective and identify current and future threats to soil health, and consider whether the present soil related policies are sufficient to preserve and enhance the natural capital provided by soils.

The thinkers have now consolidated their findings in this report. With this report the thinkers hope to inspire policy makers, industrialists, farmers and citizens to use Flanders' soils in a more sustainable way, by recognizing that healthy soils provide essential common goods and services that are crucial for addressing urgent societal challenges faced by Flanders, such as adaptation to and mitigation of climate change, the protection of biodiversity, and maintaining a healthy living environment in a densely populated region.

[1] See appendix 1 for list of session participants and other consulted experts.

Reading Guide

Chapter 2 explains why soil represents valuable natural capital. Chapter 3 gives a short overview of targets set by international initiatives that need soils in order to be achieved. Chapters 4 -6 summarise the main findings of the three sessions, and are structured by context, current and future risks and opportunities to address them. Finally, Chapter 7 summarises the main findings of this Thinkers Programme on 'Soil as Natural Capital' and provides recommendations for Government of Flanders, soil experts and citizens.

2 Why 'soil as natural capital'?

To understand the value of soil it is important to first remind ourselves about the origin of soils. Soil formation is a very slow process, taking hundreds to thousands of years, that needs to be considered on a geological time scale. Soil formation is influenced by five soil-forming factors: parent material, climate, topography (relief), organisms, and time. The mineral material from which a soil forms is called parent material. Rock is the source of all soil mineral materials and the origin of all plant nutrients with the exceptions of nitrogen, hydrogen and carbon. As the parent material is chemically and physically weathered, transported, deposited and precipitated, and influenced by plants and other organisms, it is slowly transformed to soil.

Soil is a complex system at the interface between atmosphere, lithosphere, hydrosphere and biosphere, which sustains plant, microbial, animal and human life. Soil connects to water and air, and natural biogeochemical and hydrological cycles, and is a major global reservoir of biodiversity. By interacting with all these components, soils represent a natural capital that provides services of fundamental importance for human well-being (Figure 1).

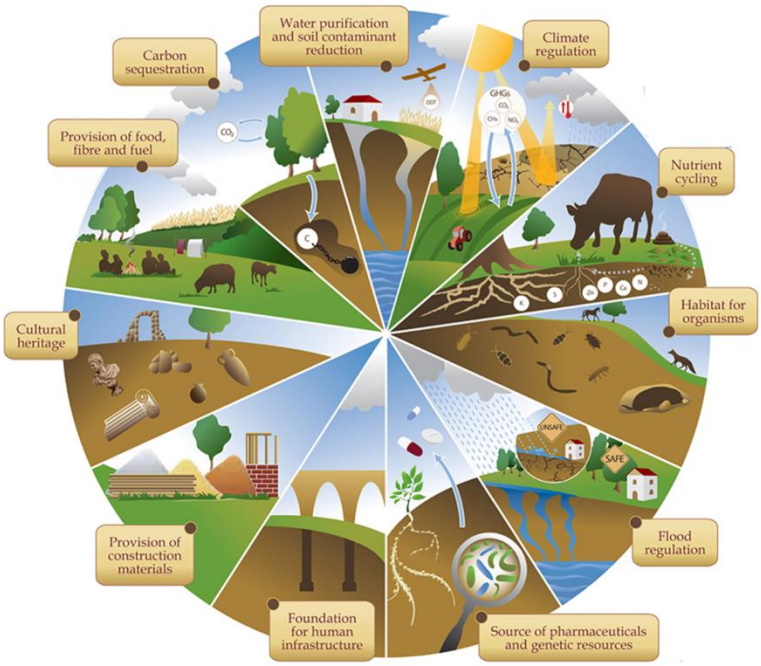

Figure 1. Schematic of ecosystem services delivered by soil (From Bayeve et al. 2016, adapted from http://www.fao.org/resources/infographics/infographics-details/en/c/284478/)

These ecosystem services include food, feed, filtered water, carbon storage, pest control, and habitat for a vast diversity of microbes, animals and plants that in turn supports these services. Soils also degrade waste and detoxify compounds, and support many recreational activities and cultural services, and a myriad of ecological interactions that shape aboveground biodiversity and the functioning of terrestrial ecosystems.

The services provided by soils have been important throughout human history. There is a famous saying by former US President Franklin Roosevelt: "A nation that destroys its soil, destroys itself". Nations with vast areas of suitable soils for providing food, feed, materials and solid foundation for

infrastructure may be considered as wealthy countries, provided the soils are maintained in a sustainable way.
The urgency to protect and take better care of soils comes mainly from the fact that they are under persistent and increasing threat from many pressures, including diffuse pollution, soil sealing, and unsustainable land uses, such as intensification of agriculture, which leads to soil erosion, compaction and loss of key components of soil functioning: organic carbon and biodiversity (Orgiazzi et al. 2016). On top of this, the climate is changing fast: on one hand climate change directly threatens soil health, while on the other hand, soils provide services that are of central importance for climate adaptation and mitigation.

The concept of soil health is still evolving, but it can be described as the continued capacity of soil to perform multiple functions (i.e. multifunctionality) and sustain plants, animals and humans (Lehmann et al. 2020). Soil health is also an overarching principle contributing to sustainability and the "One Health" concept, which recognizes that the health of humans, animals and ecosystems are strongly interconnected. To protect and improve soil health it is necessary to monitor the status of soils and to take measures where and when needed.

3 International call for action

The need for healthy soils has been recognized by supranational organizations, including the United Nations (UN) and the European Commission. Here we list a number of recent reports and initiatives that ask for action on soil protection (Box 1).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2018) and assessment report on land degradation and restoration highlight the pivotal importance of healthy soils for avoiding land degradation and restoring degraded lands, which is central to the United Nations Decade on Ecosystem Restoration (2021-2030). In 2019 the Intergovernmental Panel on Climate Change (IPCC 2019) reported that: "Land is already under growing human pressure and climate change is adding to these pressures. At the same time, keeping global warming to well below 2 degrees Celsius can be achieved only by reducing greenhouse gas emissions from all sectors including land and food". The 2030 Agenda for Sustainable Development, adopted by all UN Member States in 2015, "provides a blueprint for peace and prosperity for people and the planet, now and into the future".

The EU considers soil as an essential ecosystem that delivers valuable services such as the provision of food, energy and raw materials, carbon sequestration, water purification, nutrient regulation, pest control, and support for biodiversity and recreation. In the EU, land and soil continue to be degraded by a wide range of human activities, often combined with other factors. In the absence of a dedicated legislative framework, EU soil protection policy is shaped by the EU Soil Thematic Strategy and provisions in a number of other policy instruments, such as the Industrial Emissions Directive, the Environmental Liability Directive, the EU Biodiversity Strategy, the EU forest strategy and the Common Agricultural Policy (CAP).

The international initiative "4 per 1000", that aims for an annual growth rate of 0,4% in the soil organic carbon (SOC) stocks in the first 30-40 cm of soil, demonstrates that agricultural soils can play a crucial role in food security and climate mitigation (Box 1). The initiative was launched by France on 1 December 2015 at COP 21 and consists of federating all voluntary stakeholders of the public and private sectors. Supported by solid scientific documentation, the initiative invites all partners to state or implement some practical actions on soil carbon storage and the type of practices to achieve this (e.g. agroecology, agroforestry, conservation agriculture, landscape management). The ambition of the initiative is to encourage stakeholders to transition towards a productive and resilient agriculture, based on the appropriate management of lands and soils, creating jobs and incomes, and hence ensuring sustainable development. At present neither Belgium nor Flanders is a consortium partner of this initiative.

Recently the EU Soil Observatory was launched, which targets at an operational EU soil monitoring system supporting soil related EU policies fully integrated with national soil monitoring systems in the member states. Belgium, and therefore Flanders, will need to comply with the monitoring demands set by the EU Soil observatory.

Box 1: Intergovernmental initiatives that demand action on soils

IPBES: The report recognizes that combatting land degradation, which is a pervasive, systemic phenomenon occurring in all parts of the world, is an urgent priority to protect the biodiversity and ecosystem services that are vital to all life on Earth and to ensure human well-being. Land degradation negatively impacts 3.2 billion people and represents an economic loss in the order of 10% of annual global gross product. The report concludes that avoiding land degradation and restoring degraded lands makes sound economic sense, resulting in, inter-alia, increased food and

water security, and employment, improved gender equality, and avoidance of conflict and migration. Avoiding land degradation and restoring degraded lands are essential for meeting the United Nations Decade on Ecosystem Restoration (2021– 2030), where the restoration of healthy soil is pivotal for its success.

IPCC, from the Headline Statements from the Summary for Policymakers: Sustainable land management, including sustainable forest management, can prevent and reduce land degradation, maintain land productivity, and sometimes reverse the adverse impacts of climate change on land degradation (very high confidence). It can also contribute to mitigation and adaptation (high confidence). Reducing and reversing land degradation, at scales from individual farms to entire watersheds, can provide cost effective, immediate, and long-term benefits to communities and support Sustainable Development Goals (SDGs) with co-benefits for adaptation (very high confidence) and mitigation (high confidence). Even with implementation of sustainable land management, limits to adaptation can be exceeded in some situations (medium confidence). Response options throughout the food system, from production to consumption, including food loss and waste, can be deployed and scaled up to advance adaptation and mitigation (high confidence).

UN Sustainable development Goals: The 17 Sustainable Development Goals (SDGs) are an urgent call for action by all countries in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests. Goal 15 is dedicated to life on land and the call for action is: "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss".

4 pour 1000 initiative: An annual growth rate of 0.4% in the soil carbon stocks, or 4‰ per year, in the surface 30-40 cm of soil, would significantly reduce the CO^2 concentration in the atmosphere. This growth rate is not a normative target for each country, but is intended to show that even a small increase in the soil carbon stock (agricultural soils, notably grasslands and pastures, and forest soils) is crucial to improve soil fertility and agricultural production and to contribute to achieving the long-term objective of limiting the temperature increase to the +2°C threshold, beyond which the IPCC indicates that the effects of climate change are significant. The "4 per 1000" initiative is intended to complement those necessary efforts to reduce greenhouse gas emissions, globally and generally in the economy. It is voluntary and each member defines how they want to contribute.

4 Healthy soils for sustainable land management

4.1 Context

The soils of Flanders are diverse and cover a variety of soil types, reflecting variation in geology, a relatively flat topography, and a maritime temperate climate. Soils of northern Flanders are mostly sand and loamy sands, which are free draining and subject to leaching and podzolization processes. To the south, silty loam and sandy loam soils are common, whereas coastal areas of Flanders are mostly clay soils, with heavy clays in the polders (Figure 2). Soils of Flanders are strongly modified by human activity. Based on the Spatial Model Flanders of VITO, cropland is the most common land use (29%), followed by grassland (19%), residential (18%) and sealed land (12%), forest (10%) and nature conservation (3%). A particular feature of Flanders is the high proportion of anthropogenic soils that are typically not captured in soil surveys. A recent reclassification of land cover in Flanders estimated that 16.3% and 16.7% of the total area corresponds with a high and intermediate likelihood for anthropogenic urban soil respectively (Van de Vijver et al. 2020). Buildings, roads and other sealed surfaces are the main contributors to "high likelihood of anthropogenic soils", whereas "intermediate likelihood" land is mostly residential, parkland, and privately-owned pastures and orchards. This highlights the prevalence of anthropogenic urban soils in Flanders and hence their importance as natural capital.

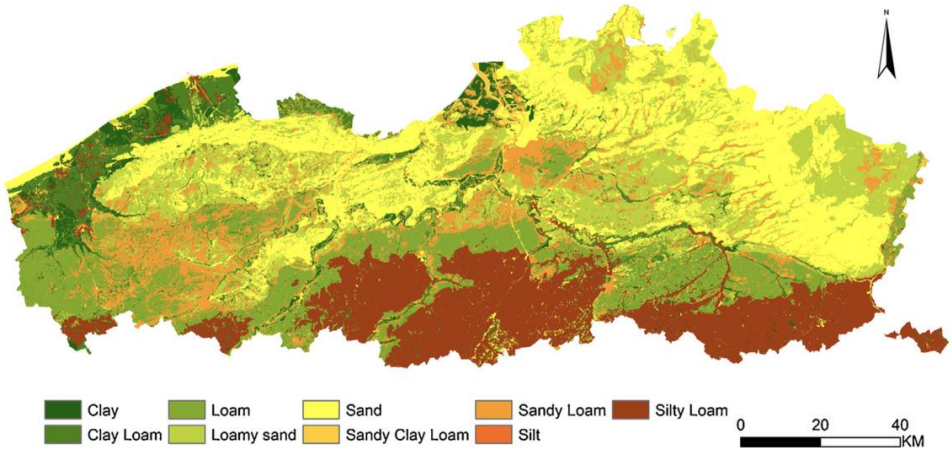

Figure 2. Soil textures of Flanders (from Zomlot et al. 2015).

No single organisation is responsible for promoting and protecting soil health in Flanders. Rather, soil falls within the remit of several organisations of the policy domains of 'Environment' and 'Agriculture and Fisheries'. These include the Department of Environment and Spatial Development, Public Waste Agency of Flanders (OVAM), Flemish Land Agency (VLM), Research Institute for Nature and Forestry (INBO), Agency for Nature and Forestry (ANB) and VMM within the 'Environment' policy domain, and the Department of Agriculture and Fisheries and ILVO of the 'Agriculture and Fisheries' policy domain. Soil protection is indirectly considered within legislation on issues such as ground and surface water quality targets and CAP, but it is not protected by any stand-alone legislation, except for the Decree on soil remediation and soil protection (2006) which focuses on soil contamination and erosion control. Several governmental organisations, however, recently joined forces in the Grondzaken Programme of the 'Open Ruimte Platform' to exchange knowledge and experiences, and work with local actors to promote soil health protection.

4.2 Risks to Flemish soils

Across Europe, soils are threatened by numerous interacting pressures related to human activity, including unsustainable land management, soil carbon loss, desertification, environmental pollution, and the sealing of soil by impervious materials. These pressures are exacerbated by climate change, which is considered in the Chapter 5 and represents a significant threat to soil health in Flanders. In addition to SOC loss, which is also considered in Chapter 5, particular threats to Flemish soils are soil sealing, soil erosion and compaction, over-fertilization leading to surplus soil phosphate and N, and contamination from known point sources and diffuse pollutants, including emerging contaminants like micro- and nanoplastics, antibiotics and per- and polyfluoroalkyl substances (PFAS). Salinization also presents a threat to soil health in Flanders, but only in coastal areas and the polders where salt content of groundwater is high.

Key threats for soil health include:

- The sealing of ground by an impermeable material related to urban development and infrastructure construction is one of the main causes of soil degradation across Europe. Sealing effectively suffocates the soil and abruptly ends the many critical ecosystem functions that soils perform. It takes land out of agricultural production, puts soil biodiversity at risk, and dramatically increases surface run off, thereby placing considerable pressure on sewerage systems and causing flooding in areas where runoff water collects. Flanders is a hotspot for soil sealing: the overall sealed surface cover of Flanders and Brussels Capital Region was 19.5% in 2013 (Vanderhaegen & Canters 2016). Current land take in Flanders is ~6 hectares per day, with about half being sealed by impervious material. This high rate of land take and soil sealing is mostly attributed to rapid expansion of settlements on the edge of cites and in rural areas, which has created a landscape characterized by a highly fragmented and complex mosaic of urban land and open space (Poelmans & Van Rompaey 2010). Currently, some 33% of Flanders land area is classified as settlement (Pisman et al. 2018), and if business continues as usual, the area of built-up land is expected to increase to 41-50% by 2050 (Poelmans et al. 2010). The strategic vision of the Spatial Policy Plan of Flanders aims to cut land take by new settlements by half by 2025 and to zero by 2040, but at present no instruments are in place to achieve this. As such, soil sealing represents a major threat to soil as natural capital in Flanders.

- Soil erosion associated with intensive agriculture is a widespread form of soil degradation in Flanders with significant environmental, social and economic impacts. Soil erosion by water on loamy and sandy loam soils is a particular risk and in many agricultural catchments, total water erosion soil loss rates can be > 10 tonnes soil ha-1 per year, representing a significant loss of soil and sediment input to watercourses. There are multiple causes of accelerated soil erosion, but of upmost importance are frequent soil tillage, the growing of crops on inappropriate land, overstocking, and bad timing of agricultural practices, such as harvesting crops when soils are wet. Costs of soil erosion can be considerable due to decreased crop yields, but also from declining water quality from sediments and sediment-borne contaminants, and damage to property from flooding and landslides. Wind erosion is also a problem in parts of Flanders as is soil loss from harvesting crops, such as sugar beet, potato, leeks and carrots, with soil losses of a similar order of magnitude to those caused by water erosion: average sediment export from cropland in Flanders is estimated to be 3.7 Mg ha−1 year−1, of which 46% is due to crop harvesting and 54% to water erosion (Ruysschaert et al. 2008). The soil erosion risk map of Flanders identifies 7.2% of agricultural land as high/very high erosion risk and 77% at very low to negligible risk. Soil erosion regulation is already well developed in Flanders through the Flemish Governments soil erosion policy as well as CAP-cross compliance,

which became stricter in 2016 and requires farmers with field parcels of high or very high erosion risk to take measures to mitigate soil erosion.

- Soil compaction is major a threat to soil health in Flanders. Some 20-50% of Flemish agricultural soils are considered vulnerable to soil compaction and many farmers report that it has negative impacts on crop yields and income. Soil compaction is also a problem in forests, where it can negatively affect tree growth and survival. Subsoil compaction is a particular concern due to its persistence and because it increases the risk of flooding. A particular issue in Flanders is the widespread occurrence of subsoil compaction in field-grown vegetable plots caused by ill-timed tillage and harvesting forced by strict contracts with the processing industry. Current Flemish legislation grants much freedom in terms of choice of crop rotation and producer-processing industry contracts, and contractors are often under time pressure to harvest as many land parcels as possible during a limited time period, irrespective of weather circumstances. This poses a significant problem towards the end of the growing season when soils are often moist or even saturated.

- Soil pollution has long been recognised as a major soil health issue in Flanders. From the late 19th century to the 1970's, zinc smelters produced emissions containing heavy metals that caused diffuse soil contamination of large areas of Flanders, as did fall-out of airborne pollutants during the industrial revolution. Soils of Flanders have also been affected by historic atmospheric deposition of nitrogen and sulphur (S), causing acidification and N saturation of forest soils with harmful effects on soil biodiversity and increased leaching of aluminium and nitrate. Nitrogen and S deposition has decreased, but many forest soils are still in an unfavourable condition (Verstraeten et al. 2012). Localised sources of soil pollution include mineral oil, chlorinated solvents, heavy metals, BTEX chemicals and PAHs. The Decree on soil remediation and soil protection (2006) provides a legal framework to regulate the identification and remediation of contaminated soils. The Decree states that an exploratory soil examination is required prior to the transfer of land or closure of an establishment on sites where a risk activity takes place or has taken place.

4.3 Opportunities for protecting and promoting soil health

Some mandatory and voluntary measures currently exist to protect soils from particular threats, especially soil pollution and erosion, and measures are embedded in other legislation, for instance on water quality targets and common agricultural policy. But there is currently no stand-alone framework for the protection of soil health and awareness of the importance of soils in policy and society is still relatively low. An innovative soil health framework is therefore needed that considers soils "holistically" and transforms the way that soils are managed in Flanders to protect and promote healthy soils and the services they provide.

A number of opportunities have been identified to protect and promote healthy soils for sustainable management, as summarised below:

- There is an urgent need for a visionary legislative platform to prevent soil sealing. Opportunities exist to increase public awareness of the importance of "unsealed land" and green space in urban areas, to build societal support for de-sealing soils, and to incorporate soil health management and assessment into spatial planning. Opportunities also exist for increased focus on green infrastructure and local sustainable food production in cities with benefits for soil health, environmental quality, and human wellbeing.

- Soil management focussed on multifunctionality offers potential to reap multiple benefits for biodiversity and ecosystem services without compromising yield. There is mounting evidence that agricultural management based on diversification practices, including organic amendments, reduced tillage, and crop diversification, can enhance biodiversity, nutrient cycling, water regulation, and improve soil structure and health without compromising yield (e.g. Tamburini et al. 2020).

- Opportunities exist to reduce soil erosion and compaction through revising the Belgian land leasing system, which currently promotes exploitative farm practices through short-term leases, and by allowing flexibility in the timing of harvests in contract farming to consider soil conditions. Sustainable soil management practices, such as controlled traffic, minimal tillage, and engineering developments (e.g. low compaction tractor tyres), should be promoted, along with incentives to maintain optimal levels of soil organic matter content and soil pH to promote good soil structure, thereby reducing erosion risk.

- A revised system for monitoring diffuse soil pollutants is needed, involving regular analysis of soils across Flanders and land uses, and using state of the art methods. This would provide a baseline to assess trends in the occurrence of traditional and novel diffuse pollutants in soil.

- The effectiveness of different policy and management interventions to improve soil health can only be assessed by a holistic soil monitoring scheme across a range of land uses. Engagement with stakeholders would enable the development of comprehensive soil health indices for the assessment of soil multifunctionality and trade-offs of soil functions, rather than focussing on single indicators or functions. Several exemplar initiatives exist in The Netherlands for assessing soil health, such as the Bodemindicatoren voor Landbouwgronden in Nederland (Hanegraaf et al. 2019) and Open Bodem-index (OBI) (Ros 2020), and in Flanders the project Leven(de) bodem has developed BodemIdee for farmers to assess soil health. However, a holistic and systematic monitoring scheme that covers soil physical, chemical and biological properties and soil functions is needed to asses soil health in Flanders.

- Valuation of soil natural capital provides an opportunity to improve soil health, promote sustainable soil management and deter unsustainable practices. Healthy soil should have a high "prijzij" that is rewarded via advantageous tax benefits. The valuation of soil natural capital could promote sustainable soil management and help achieve sustainable food supply chains.

- Demonstrations of sustainable soil management serve to raise awareness among farmers, foresters, land managers, policy makers and citizens of the benefits of healthy soil. Demonstrations of successful soil management interventions in different contexts would serve to provide guidance on best practices in different land uses and highlight their socio-economic benefits. Such demonstrations need to be sustained for several years to demonstrate long-term benefits of sustainable soil management and supported by independent advisors who can help farmers adapt management to suit their farm context.

4.4 Take home messages

The soils of Flanders have a long history of human modification, but recent pressures pose a particular risk to soil health. These problems are compounded by the lack of an overarching policy framework for protecting and promoting soil health and existing planning and tenure systems, that obstruct a

long-term vision for the sustainable management of soils. Further, the lack of a systematic and holistic soil monitoring scheme means that the current status of Flanders soils is not known, and it is currently not possible to properly assess the effectiveness of interventions aimed at sustainable management of soils. There is some evidence of increasing societal and political awareness of the need to protect soils, which is a requirement of several EU and intergovernmental policies. A number of opportunities have been identified to protect and promote healthy soils for sustainable management, but ultimately to meet the requirements of EU and intergovernmental policies will require a redesign and transformation in the way that soils are valued and managed in Flanders.

5 The importance of soils in a changing climate

5.1 Context

Global climate change caused by human-induced increases in greenhouse gases represents one of the biggest scientific and political challenges of the 21st century. To ensure compliance with EU commitments to the goals of the Paris Agreement on climate change, the Belgium National Climate Committee instructed members of the federal and regional governments to prepare an adaptation strategy. In response, the Flemish climate policy has put forward the objective for the non ETS sector of a 35% reduction in greenhouse gas emissions by 2030 compared to 2005 (Figure 3) and provided guidance on how this objective and a low carbon future might be achieved, including the expectation that the Land Use, Land Use Change and Forestry (LULUCF) sector will be net zero over the period up to 2030. This chapter considers the importance of soils in a changing climate, exploring optimal ways for Flanders to enhance soil carbon sequestration and compensate greenhouse gas emissions, enhance the resilience of soils and their functions to climate change, and control climate-hazards for soils, such as soil erosion by heavy rainfall events and salinization caused by sea level rise. The ultimate aim is to identify opportunities to enhance the contribution of soils to climate mitigation and adaptation in Flanders.

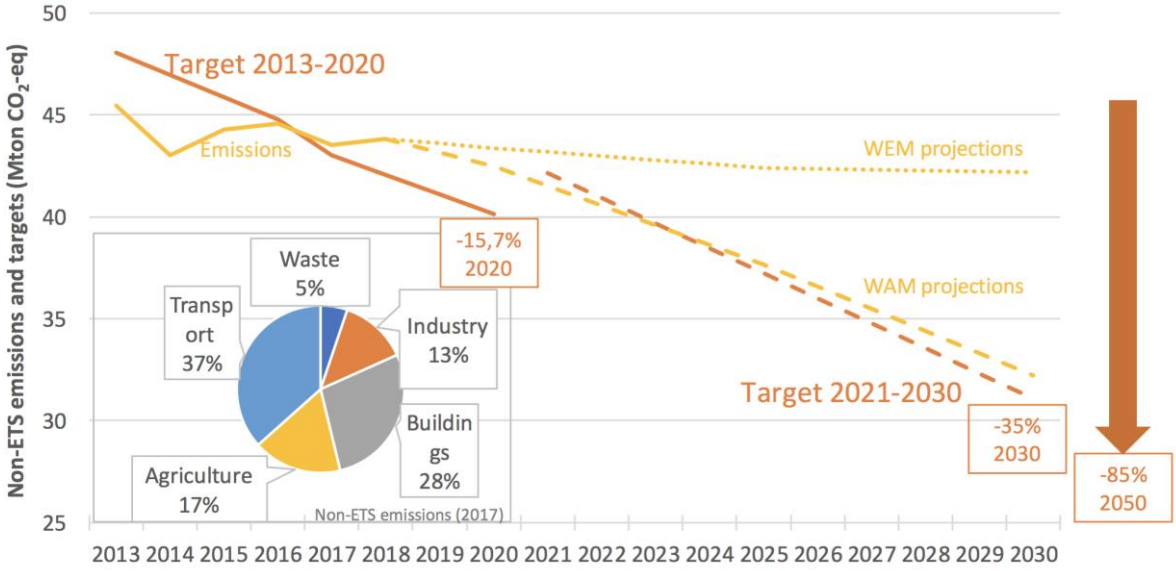

Figure 3. Flemish greenhouse gas emissions and targets from sectors not covered by the EU Emissions Trading Scheme (non-ETS) (Taken from the presentation of An Dewaele, Department of Environment and Spatial Development). [2]

Soil plays a central role in climate mitigation: it represents the largest terrestrial carbon sink and acts as both a source and sink for greenhouse gases (GHGs) such as carbon dioxide (CO^2), methane (CH4), and nitrous oxide (N_2O). However, SOC and GHG emissions are highly vulnerable to climate change and there is widespread concern that warming will stimulate carbon loss to the atmosphere as CO^2, thereby driving further climate warming (Crowther et al. 2016). Although less certain,

[2] Two types of projections are presented: projections taking into account the (current) existing domestic policies and measures (WEM, with existing measures) and projections taking also into account additional (planned) domestic policies and measures (WAM, with additional measures).

expected increases in the frequency and severity of extreme climatic events (e.g., droughts and floods) also have potential to impact SOC and GHG emissions, as do changing rainfall patterns, especially increases in winter rainfall that will also accelerate soil erosion and landslides.

Signs of climate change are already visible in Flanders. The MIRA Climate Report (2015) reports that average annual temperature in Flanders has risen by 2.4°C since the pre-industrial period and the number of days with a temperature >30°C has increased since 1968. There has also been a significant increase in winter precipitation and the number of days with heavy precipitation, and there is a trend of increasing sea level. Future climate predictions indicate further increases in temperature by 0.7 to 7.2°C over a period of 100 years, and the frequency and intensity of droughts and heat waves is also expected to increase sharply, especially in urban areas due to the urban heat island effect. Indeed, Belgium experienced the hottest week in its meteorological history during summer 2020, with an average maximum temperature of 33.5°C. Winter rainfall is also expected to increase, potentially by 38% over 100 years, and sea level will increase on average by 60-200 cm.

5.2 Climate change risks for soils in Flanders

Recent and future predicted changes in climate present considerable risks to soil health in Flanders and the potential to meet EU targets for climate mitigation. Land use and climate change impacts on SOC and GHG emissions are tightly linked, and a major hurdle for understanding the contribution of soils to climate mitigation in Flanders is a lack of reliable data on trends in SOC stocks across land uses over time. Available soil mapping data are not only outdated (1947-1974), but also suffer from low spatial density and a lack of information on soil bulk density, which precludes accurate assessment of SOC stocks. The Soil Service of Belgium has data on topsoil SOC in arable soils, but many land uses are not covered. Despite these limitations, this chapter identifies ways that ongoing climate change is affecting, and is expected to affect, soil health in Flanders, with a focus on SOC and GHG emissions, and how historic and future land use and management practices influence the climate mitigation potential of soils.

Key threats to soils from climate change identified include:

- Reliable soil data on SOC stocks in Flemish soils is not available. However, extensive measurements of topsoil SOC in croplands during (1989-2000) revealed a trend of declining SOC (Sleutel et al. 2003), as commonly found in response to intensive agriculture across Europe (EASAC 2018). Notably, the trend of declining SOC in cropland is at odds with the expansion of management practices aimed at increasing carbon input to soil (e.g. green manuring, ley farming, composting, organic farming and application of animal manures) which has been attributed to a combination of shifts in management practices, historic land transition from grassland to cropland, and enhanced organic matter decomposition and SOC loss due to climate warming (Sleutel et al. 2007).

- SOC loss poses a particular threat to the extensive sandy soils of the Campine region, which have relatively high SOC contents. Further loss of SOC from these soils due to climate warming and intensive land use will not only make them more vulnerable to soil erosion, but also it will reduce their water holding capacity and potential to support crops during drier summers. Similarly, further SOC loss from silty soils, which have inherently low SOC topsoil contents, will render these soils even more vulnerable to soil erosion and threaten their capacity to sustain crop growth during periods of drought.

- Agricultural soils represent the largest store of SOC in Flanders due to their greater spatial extent, but soils of semi-natural land use types, such as forests and low-input high-diversity systems, store more carbon per unit area. Forests represent a major carbon sink in Flanders and forest soils continue to accumulate carbon in surface soil, storing considerable amounts

of carbon to depth (~ 140 t C ha^{-1} to 1m depth in upland sites and ~200 t C ha^{-1} in poorly drained sites). Considerable carbon stocks are also concentrated in hotspots, especially wetlands (~1000 t C ha^{-1} to 1 m depth) and alluvial soils under controlled flooding (~150 t C ha^{-1} to 1 m depth), which are highly vulnerable to climate and land use change.

- Climate change effects on GHG emissions are highly variable. Higher soil temperatures will likely increase soil CO^2 emissions and potentially lead to elevated rates of denitrification and emissions of nitrous oxide (N_2O), although responses are variable and uncertain (Barnard et al. 2005). Expected increases in winter rainfall and waterlogging of soils could increase rates of denitrification and N_2O emissions, especially in fertilised, nitrogen-rich agricultural soils, and rewetting of dry soil following periods of drought induce large fluxes of both N_2O and CO^2. Changes in water table depth and drying of organic peat soils could increase GHG emissions.

- High rates of soil sealing in Flanders pose a major threat to the contribution of soils to climate mitigation and resilience. Sealing not only cuts off the exchange of GHGs between the soil and atmosphere and the capacity of soil to sequester carbon, but also it prevents the infiltration and storage of water, which increases flood risk during heavy rainfall events and impairs resilience to climate extremes. Soil sealing is also a major contributor to the urban heat island, with people in urban areas being exposed to higher temperatures and more frequent heat waves than in rural areas.

- Projected increases in winter rainfall and heavy rainfall events will increase rates of soil water erosion and risk of landslides. Changes in land use due to climate change, such as the adoption of new crops (e.g. warm-tolerant crops), could also increase soil erosion on erosion-prone soils (Mullan 2013), and increased summer drying of soils will likely increase dust production from cultivated soil, thereby causing soil loss and a threat to human health. More intense and recurring droughts will cause shrinking and swelling in clay-rich soils, causing damage to buildings and infrastructure on clay soil.

- Projected rise in sea level will increase the risk of soil salinization in coastal areas and the polders due to increased salinity of groundwaters and intrusion of saline waters. The threat of soil salinization will be exacerbated by increases in crop water demand and associated lowering of the groundwater table, and irrigation with salt-rich waters during periods of drought.

- Increases in the intensity and frequency of climate extremes, especially drought, will negatively impact soil biodiversity with negative consequences for the resilience of soil functions to climate change. Coupled with pressures from intensive management, recurring droughts could trigger soil-system transitions to alternative, deleterious functional states, thereby damaging soil health.

5.3 Opportunities for soils in a changing climate

Both climate and land use change present many threats to soils of Flanders that hamper soils contribution to climate mitigation and compliance with climate policy. A number of opportunities exist to address these threats and meet climate policy including adoption of sustainable soil management practices in agriculture to increase SOC and reduce GHG emissions, improved spatial planning and focus on green infrastructure in urban areas, and adoption of nature-based solutions for climate mitigation in forestry and other land use sectors. Technological solutions exit to address challenges of water supply, including irrigation and storage of excess winter rainfall, and for monitoring of SOC via the use of sensor technology. Importantly, increasing SOC also benefits soil

structure, soil biological activity, the retention of water and nutrients, and renders soils and their functions more resilient to erosion and climate extremes.

Opportunities for enhancing the role of soils in climate mitigation include:

- Improved agricultural management can increase SOC and be an effective tool to mitigate climate change with added benefits for soil health. Several options are available to increase SOC in agricultural soils, such as improved crop rotations, expansion of the use of cover crops and deep-rooted crops, and no/reduced tillage, although benefits of no-till may not be as large as expected because surface SOC accrual can be offset by carbon loss at depth (Powlson et al. 2014). Crops with well-developed, dense root systems are especially effective for increasing SOC and forming stable carbon (Sokol & Bradford 2019) and have additional benefits for efficient nutrient capture and water use. In grassland, a key priority should be to protect existing SOC stocks, but options for increasing grassland SOC also exist. These include optimal grazing and fertiliser management, and the restoration of high-diversity grassland (De Deyn et al. 2011; Yang et al. 2019). While agricultural soils are responsive to measures to increase SOC, rates of SOC accumulation decrease as a new equilibrium is reached, meaning that net CO^2 removals are of limited duration (West and Six 2007).

- Degradation of soil carbon hotspots, such as forests, wetlands and nature conservation land, should be prevented and the use of nature-based approaches to restore degraded land (e.g., afforestation and active restoration of species-rich grassland (Yang et al. 2019) offer a way to increase SOC with additional benefits for biodiversity, although divergent responses are often reported (Hong et al. 2020). Soil amendment with biochar has also been proposed as a way to increase soil carbon and soil productivity due to its long residence time (Kerré et al. 2017), although benefits for soil health are variable and biochar addition can also stimulate SOC decomposition and introduce contaminants into soil (Jeffery et al. 2013). Soil amendment with crushed, fast-reacting silicate rocks has also been proposed as a CO^2 removal strategy, but field tests are still needed to test its efficacy (Beerling et al. 2018).

- Opportunities for reducing soil N_2O emission from agricultural soils include more efficient N management to minimise excess soil N, which can be achieved by improved matching of fertiliser application to crop needs and soil nutrient balance, and adoption of precision farming for spatial planning of fertiliser use. No-till and reduced tillage can be an effective strategy for reducing N_2O emissions when combined with deep placement of fertiliser N under humid conditions (van Kessel et al 2013). Land use can also impact resistance of soil food webs to climate change, with low-input system with minimal disturbance promoting more resistant fungal-based food webs associated with reduced GHG and leaching losses of N from soil following drought (De Vries et al. 2012).

- Legislative frameworks for smarter spatial planning should incorporate "weather-proofed soils" and green space as critical components of climate mitigation in urbanised areas. Increased awareness of the importance of "unsealed soil" and green space in urban areas among policy makers and citizens will help build support for de-sealing soils and use of permeable materials and ensure effective use of urban soils for green infrastructure and local sustainable food production with multiple benefits for soil health, environmental quality, and human wellbeing in urban areas.

- Policy for erosion control requires mix of mandatory and voluntary schemes. Mandatory measures, which are costly to farmers, require governmental control and should be supported by demonstrations that show-case effective control measures for different locations. Current schemes for erosion control may become outdated with ongoing climate change and hence need to be revised based on scenarios of climate and land change. Effective erosion control requires improved linking of optimal counter-measures to digital maps of erosion risk, and increased awareness of the benefits of erosion control for climate

mitigation. Although soil erosion regulation is well developed in Flanders, continuous efforts are required to raise awareness of soil erosion control and to work with farmers to create management practices tailored to the individual farm context.

- A focus on soil resilience to climate extremes enables more effective planning and control of water storage and supply during periods of drought. Technological developments offer potential for more efficient irrigation, climate adaptive drainage, and water storage, combined with nature-based solutions for improving water quality and availability, and reducing risks to water-related extreme events, such increasing biodiversity of buffer zones. Opportunities for taking soil salinization include improved mapping of saline topsoil, water level management, and adoption of salt tolerant crop varieties.

5.4 Take home messages

A wide range of management practices are available to increase soil carbon sequestration and reduce GHG emissions, thereby increasing the climate mitigation potential of soils. Measures also exist for improved management of water reserves to buffer climate extremes and to enhance the contribution of urban soils to climate mitigation. Importantly, the climate mitigation potential of soils goes hand in hand with soil health: healthy soils with greater SOC content and reduced GHG emissions are also more biologically diverse, better structured, and have an enhanced ability to store water, recycle nutrients, resist erosion and support ecosystem services in a changing environment. Further, nature-based solutions targeted at increasing biodiversity, both above and belowground, also reap benefits for both climate mitigation and soil health, including increased resilience to climate extremes. As noted by Paustian et al. (2016), however, that while there are many benefits of "climate-smart soil management" there are also many economic, cultural and scientific challenges that need to be overcome to realise its potential as a large-scale mitigation strategy.

6 Appropriation of soils as natural capital

6.1 Context

Urgent calls at a European and global level to combat and to adapt to climate change, to halt biodiversity loss and combat desertification, and to realize the Sustainable Development Goals, has reinforced the need for healthy soils. In the two previous chapters, risks and opportunities for healthy soils in Flanders were identified in the context of sustainable management and climate mitigation. In this chapter, we identify relevant instruments to protect and promote soil health in Flanders and to comply with the international calls for action. A broad scope was chosen for this investigation: regulatory, risk-based, cultural, social, economic and financial instruments were considered with respect to their suitability to better appropriate soil as a valuable natural capital.

For Flanders, both European and regional instruments are relevant. At European level there is currently no overarching legislation on soils. However, several European legislation and regulatory instruments indirectly address soils, such as the Environmental Liability Directive, Industrial Emissions Directive, Environmental Impact Assessment Directive, Sewage Sludge Directive, Regulation on fertilizers, Mercury Regulation, Land use, land use change and forestry Regulation, Common Agriculture Policy (EC 2020a). In addition, legislation and regulations for nitrates, plant protection products, and registration of chemicals also implicitly protect soils against adverse effects (Table 1).

Table 1. Detailed overview of European policies in relation to adaptation, biodiversity, circular economy and forest strategy, with links to soils (Peeters 2020)

Adaptation Strategy	Biodiversity Strategy	Circular Economy Action Plan	EU Forrest Strategy
Drinking Water Directive	Effort Sharing Decision	Environmental Impact Assessment Directive	Renewable Energy Directive
Resource Efficiency Roadmap	Soil Sealing Guidelines	Waste Framework Directive	Cohesion Fund
Water Framework Directive	Environmental Liability Directive	Strategic Environmental Assessment Directive	Nitrates Directive
Birds and Habitat Directive	Common Agricultural Policy	Landfill Directive	Groundwater Directive
Pesticides Directive	Fertilizer Regulation	European Regional Development Fund	Mercury Regulation
LULUCF Decision	Floods Directive	National Emission Ceiling Directive	Sewage Sludge Directive
Industrial Emissions Directive	European Social Fund	Horizon 2020	LIFE

In the context of the upcoming Green Deal and the European research and innovation programme Horizon Europe, the European Commission decided to launch missions for five big societal challenges, one being on soil health and food (EC 2020b). The main goal of the mission is that by 2030 at least 75% of the soils of the European Union (EU) should be healthy and able to provide essential ecosystem services that we depend on. The mission describes ways how to reach this goal, making use of existing legislation, regulation, monitoring, and raising awareness of the importance of soil health among all stakeholders.

At the level of Flanders, there is no stand-alone legislation or regulation on soils. However, of importance for healthy soils in Flanders are the regional zoning plans, the building permit system, the upcoming spatial policy plan and Blue Deal, the new version of the Soil Decree, the manure action plan, the Flemish Energy and Climate Plan 2021-2030, and CAP-cross compliance. The Flemish Government included four focus points for soils in the Flemish coalition agreement of September 2019:

- We don't want to lose any net carbon from our soil for the next ten years. In addition to efforts to capture more carbon in agricultural soils, we must store more carbon in forests, wetlands and (semi) natural grasslands. To this end, we invest in additional forests and wetlands, and manage (semi) natural grasslands, forests and wetlands in a more targeted manner. We are working on soil carbon monitoring.

- Soil remediation ensures that we can safely use contaminated old business locations or landfills again, thus reducing our pressure on the open space.
- We adjust the erosion policy, based on the principle "the polluter pays". This is good for the soil, good for the quality of the surface water and saves on the costs of clearing the waterways.
- We optimize the enforcement of the fertilizer policy. Flanders considers information and guidance on integrated soil management (including carbon storage) and judicious fertilization important.

In general, three environmental compartments are considered in environmental policy: air, water and land (land as the spatial dimension including soils). Unlike water and air, land is mostly privately owned and not considered as a common good. However, the services that land and soils provide are of common interest to everyone, which implies that policies that consider soil as a common good might be instrumental in resolving conflicts between property rights and the need for sustainable land management (Jacobs 2020). Awareness raising is also very important for securing soil health given that it varies among land users and wider society. This can be done at many levels, for instance by improving education about soils in primary and secondary schools, by promoting public awareness of the importance of soils for society through storytelling, exhibitions, and through citizen science projects targeted at soil health issues. For farmers, awareness raising in the group of advisors that farmers trust will be important for encouraging sustainable soil management, as will instruments that highlight the consequences of management practices for soil health, such as soil footprints, benchmarking, scoring systems, and monitoring with open access to data. Economic and financial instruments can express the true economic value of healthy soils for society and provide incentives to land owners to take better care of their soils.

6.2 Policy instruments to secure soil health in Flanders

6.2.1 Compliance with international and EU policy

An obvious way forward to secure soil health in Flanders is to cooperate with the European Commission, because the European Green Deal (Figure 4) and the upcoming research programme Horizon Europe have similar goals. Under the goal "Preserving and restoring ecosystems and biodiversity", the EU lists the following in the Green Deal:

- **EU Biodiversity Strategy** for 2030 (20/05/2020)
- Address **soil and land** degradation in a comprehensive way
- Achieve **land degradation neutrality** by 2030
- Protecting **soil fertility**
- Reducing **erosion** and **sealing**
- Increasing **organic matter**
- Identifying and remediating **contaminated sites**
- **Restoring** degraded soils
- Defining their **good ecological status**
- Improving **monitoring**

The Green Deal may provide accessible instruments, guidance and funding to help protect and increase the extent of healthy soils and their contribution to climate mitigation in Flanders. It is not yet known how the Green Deal will operate, but member states can be pro-active in reaching goals through close cooperation with EU programmes.

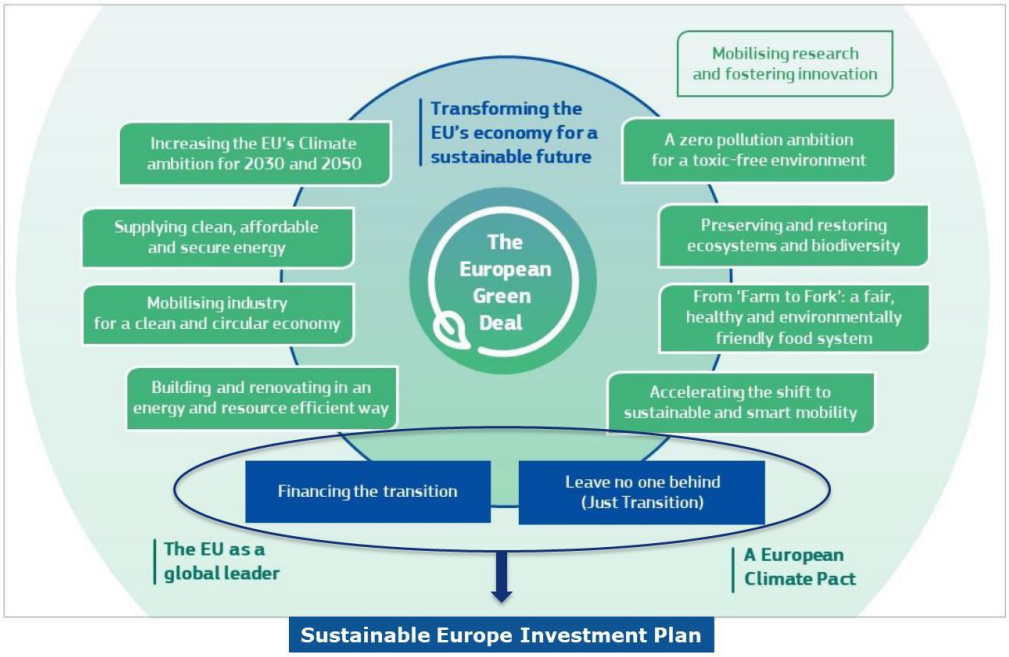

Figure 4. The European Green Deal

6.2.2 Prevention of soil degradation by intensive agriculture

A number of instruments are available to prevent further degradation of soil health by intensive agriculture, which is currently exacerbated by short land tenures and lack of incentives to better manage the soil. Fundamental to a policy for soil protection should be the notion that although privately owned, agricultural soil provides many common services that benefit everyone. Based on this, farmers could be compensated for achieving a better balance between food and feed production and the other ecosystem services provided by the soils on their land. This is what the EU's common agricultural policy hopes to achieve, by shifting subsidies from production to the provision of other ecosystem services, including those provided by soil. Specific regional problems might be tackled by Payments for Ecosystem Services (PES) systems.

The issue of short land leases might be approached by introducing instruments that compare the status of the soils at the beginning and end of a lease, such as the "Prijzij" system. If the condition of soil at the end of the lease is worse, the user should pay for the damage, or when it is better, the user should be rewarded via advantageous tax benefits. A problem with such a system, however, is that soils react slowly to different management systems, especially if there is a legacy of intensive management. It is therefore questionable whether differences in measures of soil health will be detected in the short term, whatever indicators are used. Alternatively, and as recently announced by the Dutch Minister of Agriculture in reaction to a report of the Council for the Environment and Infrastructure "De bodem bereikt" (RLI 2020), lease legislation should change to encourage long-term lease contracts including sustainability conditions (LNV 2020). For such instruments to be successful, however, it will be important to provide farmers with a means to evaluate changes in soil health and the benefits of sustainable soil management. The Open Soil Index (in Dutch Open Bodem Index, OBI,) is one such measure for the quality of agricultural soils (Box 2), as is the BodemIdee, which is a result of a Interreg Project Leve(n)de Bodem (https://levendebodem.eu/BodemIDee).

During the first fact finding session the difficulty to reward or penalize soil users based on slowly changing soil health indicators was discussed. A general stance was taken that in some cases not 'effects from' but 'efforts towards' sustainable soil management should to be rewarded, much like existing 'beheersovereenkomsten'. In the Netherlands, the same discussion is taking place and the idea to reward farmers based on compliance with 'Kritische Prestatie Indicatoren (KPI)' (Erisman et al. 2020), rather than based on indicators of soil health, has been forwarded. Examples of such KPIs

proven beneficial to soil health are: the number of cover crops in a rotation, the soil organic matter balance, and the percentage of permanent grassland in dairy farms. Development of KPIs is being supported by the Dutch Minister of Agriculture.

6.2.3 Legislation to limit soil sealing

The lack of effective legislation to halt soil sealing in Flanders is a major risk for soil health. The Spatial Policy Plan of Flanders aims to cut land take by new settlements by half by 2025 and to zero by 2040, but at present no instruments are in place to achieve this. Opportunities to halt sealing in Flanders might be provided by the upcoming Spatial Policy Plan for Flanders, changes in the building permit system, and via using the Blue Deal to increase the amount of green space in urbanized areas. The big hurdle here is the 'planschade', for which a land owner would need to be compensated for if their land is used for a less lucrative green infrastructure purposes. However, by categorizing new land uses as urban green infrastructure or green space, the natural capital of soil becomes more evident, because urban soils contribute to biodiversity, adaptation to climate change, including flood prevention, recreation, and carbon sequestration. Indeed, it was recently reported that unsealed soils in Flemish residential areas contain a staggering SOC stock, upward of 183 t C ha^{-1} to 1 m depth on average (Sleutel et al. 2020).

All experts consulted agreed that something urgently needs to be done to address land take and soil sealing in Flanders. Recently, the Government of Flanders has approved measures to reduce the land take and bring it down to zero by 2040. The plan mainly focuses on so-called 'building expansion areas' which make up 12 000 ha of land and municipalities instruments to stop development there. However, the so called 'planschade' to be paid is high (100% of the current market value) and it is expected that local towns won't be able to pay this. Furthermore, there is no policy to stop development on the 40 000 ha of other building land. Hence, it's highly likely that there will be a lot of additional land take by 2040.

The experts agreed that interventions by the Government of Flanders is the only option to solve the land take/soil sealing problem. This can be done by extending the measures to all potential building land and to support municipalities with financial compensation to prevent sealing. In addition to these measures to prevent sealing, it is also important to prevent and de-seal land in already build-up areas by revised building permit system that fully integrates the natural capital value of green space and urban soils, and by adopting the principle that soils provide common goods for all people in Flanders. At a local scale, de-sealing plans can be stimulated by neighbourhood programmes such as the 'Ontharding' project by the Department Omgeving, or the Dutch 'Operatie Steenbreek', which is organized by a foundation in which different authorities, scientists and NGO's work together. In Flanders, 2/3rds of land classified as sealed consists of roads, driveways, terraces (Eynde 2020), in which there is ample opportunity for de-sealing. As an example, in The Netherlands, a number of NGO's organised the challenge 'Tegels wippen' between Rotterdam and Amsterdam to remove as many tiles from the ground surface as possible with a certain timeframe. Competition was fierce, Rotterdam won, and in total almost 95.000 tiles were removed (https://nk-tegelwippen.nl/organisatie/, visited at 24 November 2020).

6.2.4 Monitoring soil health

It is obvious that regular and holistic monitoring of multiple dimensions (i.e. physical, chemical and biological properties, and soil functions) of soil health is needed to know trajectories of soil change over space and time, and to know whether policies and interventions have the desired effect. A revised system for monitoring diffuse soil pollutants is also needed to assess trends in the occurrence of traditional and novel diffuse pollutants in soil. Monitoring alone, however, is not enough. The data need to be reported and there needs to be a responsible authority to act on monitoring results if necessary. Such a system is not in place in Flanders. At present, regular monitoring is done in the context of legislation for the application of manure on agricultural land and contamination of land

with well-known pollutants. The government of Flanders is also working on a soil carbon network in the context of climate mitigation, but this is not yet operationalized. EU soil monitoring programmes, such as the Land Use/Cover Area frame statistical Survey (LUCAS), also provide an effective way to detect state and change in soil (Tóth et al. 2013). Recently a soil indicator was launched for monitoring the erosion risk on agricultural land based on modelling with inputs such as topography, crop types and measures taken.

A long-standing question in soil science is what to monitor to measure soil health. Many proposals have been made for indicators of soil health, involving a range of chemical, physical and biological properties. Lehmann et al. (2020) recently published an extensive review of how soil health could be quantified (and measured) with a plea for international standards to be developed with stakeholders (Box 2). The Horizon Europe mission on soil health and food advocates using a relatively simple set of six fundamental indicators, namely: 1) presence of soil pollutants, excess nutrients and salts; 2) vegetation cover; 3) soil organic carbon; 4) soil structure including soil bulk density and absence of soil sealing and erosion; 5) soil biodiversity; and 6) soil nutrients and acidity (pH). They also recommend that improvement in one indicator should not come at a cost to another, and that measurements are soil-specific with a characteristically different range of values for different soil types. Other approaches to monitor soil health include remote sensing and citizen science, which could enable detection of trends in soils over space and time.

6.2.5 Valuation of soils as natural capital

Soils can be viewed as a natural asset because they provide many ecosystem services with business and public benefits. However, it is difficult to connect soil to natural capital that can be economically valued because soil is intimately interconnected with goods and benefits of the whole ecosystem, and few services flow directly from soil to goods or human benefits. Reflecting this, accounting for soil resources as natural capital is poorly developed, although there is growing recognition that it could better highlight the value of soils, the risks of soil degradation, and the benefits of investment and action (Janes-Bassett and Davies (2018). Nevertheless, frameworks for accounting for soil resources as natural capital, for example based on the United Nations System of Environmental Economic Accounting (SEEA) (Robinson et al. 2017), are being developed, and research programmes are underway to realise the opportunities of soil natural capital valuation. In the EU, a carbon farming initiative was launched under the Climate Pact, to promote new business models with payments either via CAP or public or private initiatives (carbon market). In Flanders, several projects, such as the Interreg Carbon Farming project are working towards the development of carbon farming business cases, but an overall framework and certification rules, agreed on by the government and largely supported by the stakeholder community, is needed.

6.2.6 Cultural values

Sustainable management of soils through better understanding of the natural capital provided by soils may be achieved by awareness raising and education, for instance by storytelling (Vancampenhout, KU Leuven) and including soils in the curriculum of primary and secondary schools. It is important that it is generally known that soils, though often privately owned, do provide common goods and services for everyone. Awareness about the meaning of open soils in urbanized areas - for biodiversity and adaptation to climate change - can be stimulated by analogues of the programme for air quality (Curieuze Neuzen), in addition to programmes and initiatives that were mentioned in the section about sealing.

Box 2: Indicators of soil health

The soil health index is a number that indicates the quality of Dutch arable soil. The index is adjusted for soil type and the purpose of use of the soil. The index provides an indication of the improvement of the soil quality that is still possible. To this end, the feasible desired situation per soil type has been determined by researchers. Based on measurements and control measures, the biological, physical and chemical indicators are identified. The various indicators ultimately determine the total score on the soil index. https://openbodemindex.nl/, last visited at November 25, 2020.

Because of soil's broad environmental and societal functions, soil health should be legally recognized as a **common good**. The development of soil health quantification standards should be spearheaded by governmental or intergovernmental organizations such as the Global Soil Partnership in consultation with a range of stakeholders. Further, international standards need to be developed for suitable types of indicators, including methodological details and their integration into indices. Such a comprehensive soil health index should then be referenced by local, regional or national jurisdictions and organizations to guide decisions that impact soil and its functioning to benefit sustainability goals.

7 Conclusions and Recommendations

The three fact finding sessions, visits to ILVO and VMM, and discussions with a large number of Flemish scientists and other experts in the field of soils as natural capital resulted in the insight that:

- The 21st century confronts us with many urgent environmental and societal challenges, including climate change, biodiversity loss and land degradation.
- Healthy soils and sustainable soil management are essential for addressing these challenges and achieving many of the Sustainable Development Goals, but it has been overlooked in agricultural and environmental policy recent decades.
- Soil health in Flanders and is threatened by a number of well-known and novel pressures, especially unsustainable agricultural practices, sealing and land take, (diffuse) pollution by known and emergent contaminants, and climate change, including extreme weather events.
- Evidence indicates that these pressures pose a serious threat to soil health in Flanders and are undermining the natural capital of Flemish soils.
- Therefore, there is an urgent need to better protect, improve and maintain soil health in Flanders and elsewhere and raise awareness of soil as an important natural capital resource.

To better protect, improve and maintain the natural capital provided by soils of Flanders in order to respond on urgent environmental and societal challenges, and thereby also to comply with relevant international and EU policy, we recommend the following:

- To consider all soils, regardless of their ownership, as a common good that provides well-being for everyone in Flanders, thereby obliging every landowner, from farmer to hobby farm, to household gardener, to value and take care of the soils beneath their feet. There is an opportunity to use legislative options and incentives to reward farmers and other land users for protecting and restoring soil health, but also there is a need for measures to raise awareness among all sectors of society about the importance of soil natural capital.
- To develop a holistic soil monitoring programme based on multiple dimensions of soil health, including chemical, physical and biological properties, and soil functions, to monitor the current status and development of natural capital provided by soils across all land uses.
- To protect open land and soils by more compact building and bundling of infrastructure and ensure full consideration of soil natural capital within planning decisions. The recent published spatial policy plan should apply to all still unused building land and finances should be made available for municipalities to deal with 'planschade'. De-sealing should be considered as a compensation method for new buildings and infrastructure.
- To strive for a circular agriculture (kringlooplandbouw), thereby limiting management practices in agriculture and other land uses that damage soil natural capital. This can be achieved using methods that have been developed for sustainable agricultural land use, including compensation for the societal services provided by farmland, and by adopting longer and better land lease contracts.

- To commit to protecting and increasing the climate resilience of soils and the contribution of soils to climate mitigation through protecting and building soil organic carbon and maintaining healthy, biodiverse soils.

- To establish a committee on integrated soil policy involving different government organizations, scientists and stakeholders concerned with soil health, and pro-actively cooperate with and profit from the international efforts to combat land degradation, climate change and biodiversity loss.

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Appendix: List of activities and meetings with stakeholders

January 14, 2019 - First brainstorm session Steering Committee
Present: Anne Gobin (VITO), Steven Sleutel (UGent), Kris Verheyen (coördinator Thinkers Programme KVAB, UGent), Willy Verstraete (member KVAB, UGent)

March 15, 2019 - Kick-off meeting with Experts Group
Present: Ann Cuyckens (OVAM), Jeroen De Waegemaeker (ILVO), Anne Gobin, Elisabeth Monard (member KVAB, Chair Class of Technical Sciences), Joost Salomez (Dep. Environment), Steven Sleutel (UGent), Martine Swerts (Planbureau Environment), Wim Verbeke (Climate Innovation), Kris Verheyen, Willy Verstraete, Inez Dua (staff member KVAB).

May 6, 2019 - Skype meeting Steering Committee
Present: Inez Dua, Anne Gobin, Steven Sleutel, Kris Verheyen

May 29, 2019 - Meeting Steering Committee
Present: Inez Dua, Freddy Dumortier (permanent secretary KVAB), Anne Gobin, Steven Sleutel, Kris Verheyen, Willy Verstraete

September 19, 2019 - Meeting Experts Group
Present: Inez Dua, Anne Gobin, Jean Poesen (member KVAB), Greet Ruysschaert (ILVO), Steven Sleutel, Kris Van Looy (OVAM), Wim Verbeke, Kris Verheyen, Willy Verstraete

FACT FINDING I - Nov 6-8, 2019

November 6, 2019 - Meeting Steering Committee + Thinkers
Present: Richard Bardgett (Thinker), Inez Dua, Anne Gobin, Steven Sleutel, Erik Smolders (KU Leuven), Joke Van Wensem (Thinker), Kris Verheyen, Willy Verstraete

November 7, 2019 - FACT FINDING SESSION ON "HEALTHY SOILS FOR SUSTAINABLE LAND MANAGEMENT IN THE 21ST CENTURY"
Participants:

Richard	Bardgett	Thinker
Nele	Cattoor	VeGeBe
Stefaan	De Neve	UGent
Koen	Desimpelaere	VLM
Bruno	Devos	INBO
Jan	Diels	KU Leuven
Annemie	Elsen	Bodemkundige Dienst België
Ruben	Fontaine	DLV
Anne	Gobin	VITO
Erik	Grietens	Bond Beter Leefmilieu
Stijn	Overloop	VMM
Jean	Poesen	KVAB
Greet	Ruysschaert	ILVO
Steven	Sleutel	UGent
Erik	Smolders	KU Leuven

Martine	Swerts	Planbureau Omgeving
Karen	Van Geert	Arcadis
Griet	Van Gestel	OVAM
Koen	Van Keer	Yara
Georges	Van Keerberghen	Boerenbond
Kris	Van Looy	OVAM
Joke	van Wensem	Thinker
Kris	Verheyen	UGent
Patrick	Verstegen	VLM
Willy	Verstraete	UGent
Jeroen	Watté	Wervel
Mark	Wulfrancke	ABS

November 8, 2019 - Debriefing Steering Committee + Thinkers

January 7, 2020 - Meeting Steering Committee + Thinkers
Present: Richard Bardgett (skype), Inez Dua, Anne Gobin, Steven Sleutel, Erik Smolders, Joke van Wensem (skype), Kris Verheyen, Willy Verstraete

FACT FINDING II - Feb 12-13, 2020

February 12, 2020 - Visit ILVO and farm compost pilot site
Present: Richard Bardgett, Inez Dua, Anne Gobin, Steven Sleutel, Erik Smolders, Joke van Wensem, Kris Verheyen, Willy Verstraete
From ILVO: Tom De Swaef, Sarah Garré, Els Lemeire, Joris Relaes, Bert Reubens, Isabelle Roldan-Ruiz, Greet Ruysschaert, Bart Vandecasteele, Hans Vandermaelen, Anna Verhoeve, Koen Willekens

February 12, 2020 - Visit VMM
Present: Richard Bardgett, Inez Dua, Anne Gobin, Steven Sleutel, Erik Smolders, Joke van Wensem, Kris Verheyen, Willy Verstraete
From VMM: Bernard De Potter, Willem Maetens, Dieter Vandevelde, Steven Vinckier

February 13, 2020 - FACT FINDING SESSON ON "SOILS IN A CHANGING CLIMATE"
Participants:

Richard	Bardgett	Thinker
Dave	Buchan	Bioforum
Nele	Cattoor	fvp house
Wim	Cornelis	Land-en-water.be
An	Dewaele	EKG, Dep. Omgeving
Tom	Diez	Watergroep
Ilse	Geyskens	Boerenbond
Anne	Gobin	VITO
Kevin	Grauwels	VLM
Pieter	Janssens	Bodemkundige dienst
Maayke	Keymeulen	DLV
Hans	Leinfelder	KU Leuven
Steve	Leroi	IFLUX
Suzanna	Lettens	INBO

Katrien	Oorts	Dep. Omgeving
Jean	Poesen	KU Leuven
Joost	Salomez	Dep. Omgeving
Steven	Sleutel	UGent
Erik	Smolders	KU Leuven
Marc	Sneyders	Bayer
Jan	Staes	UAntwerpen
Rhune	Van Cleemput	Watergroep
Karel	Van Daele	Land-en-water
Joke	van Wensem	Thinker
Hendrik	Vandamme	ABS
Kris	Verheyen	UGent
Inge	Vermeulen	Provincie Antwerpen
Willy	Verstraete	UGent
Patrick	Willems	KU Leuven

February 13, 2020 - Debriefing Steering Committee + Thinkers

April 28, 2020 - Skype meeting Steering Committee + Thinkers
Present: Richard Bardgett, Anne Gobin, Steven Sleutel, Erik Smolders, Joke van Wensem, Kris Verheyen, Willy Verstraete

June 24, 2020 - Skype meeting Steering Committee + Thinkers
Present: Richard Bardgett, Inez Dua, Anne Gobin, Steven Sleutel, Erik Smolders, Joke van Wensem, Kris Verheyen, Willy Verstraete

September 17, 2020 - Skype meeting Steering Committee + Thinkers
Present: Richard Bardgett, Inez Dua, Anne Gobin, Steven Sleutel, Erik Smolders, Joke van Wensem, Kris Verheyen, Willy Verstraete

FACT FINDING III - October 7-8, 2020

October 7, 2020 - FACT FINDING SESSION ON "APPROPRIATION OF SOILS AS NATURAL CAPITAL"

Richard	Bardgett	Thinker
Robin	De Smedt	Dep. OMG
Lieven	De Smet	INBO
Koen	Dhoore	Landwijzer
Anne	Gobin	VITO
Dieter	Helm	Oxford
Lars	Heyn	Wageningen University
Dirk	Holemans	Oikos
Miro	Jacob	ILVO
Sarah	Jacobs	MonardLaw
Mahmut	Kocak	Dep. OMG
Bavo	Peeters	DG environment
Marnix	Pieters	Flanders Heritage
Gerard	Ros	NMI Agro
Steven	Sleutel	UGent

Erik	Smolders	KU Leuven
Martine	Swerts	Planbureau Omgeving
Griet	Van Gestel	OVAM
Kris	Van Looy	OVAM
Joke	van Wensem	Thinker
Karen	Vancampenhout	KU Leuven
Laurens	Vanden Eynde	Dep. OMG
Hans	Vandermaelen	ILVO
Bernard	Vanheusden	UHasselt
Kris	Verheyen	UGent
Elisa	Vermeulen	Grondbank
Willy	Verstraete	UGent

October 7, 2020 - Debriefing Steering Committee + Thinkers

October 8, 2020 - Online meeting with Raf Suys, Lieven Van Waes and Wim Verrelst (Cabinet of Hilde Crevits, Flemish minister of Agriculture)

October 8, 2020 - Online meeting with Victor Dries (Cabinet of Zuhal Demir, Flemish minister of Environment)

October 23, 2020 - Skype meeting Steering Committee + Thinkers
Present: Richard Bardgett, Inez Dua, Anne Gobin, Steven Sleutel, Erik Smolders, Joke van Wensem, Kris Verheyen, Willy Verstraete

December 2, 2020 - Skype meeting Steering Committee + Thinkers
Present: Richard Bardgett, Inez Dua, Anne Gobin, Steven Sleutel, Erik Smolders, Joke van Wensem, Kris Verheyen, Willy Verstraete

January 15, 2021 - Skype meeting Steering Committee + Thinkers
Present: Richard Bardgett, Inez Dua, Anne Gobin, Steven Sleutel, Erik Smolders, Joke van Wensem, Kris Verheyen, Willy Verstraete

February 8, 2021 - SYMPOSIUM 'SOILS AS NATURAL CAPITAL'
Online public presentation of Thinkers report with reactions of policy makers.

General overview of all stakeholders involved

Richard	Bardgett	Thinker
Dave	Buchan	Bioforum
Nele	Cattoor	fvp house
Wim	Cornelis	Land-en-water.be
Ann	Cuyckens	OVAM
Stefaan	De Neve	UGent
Bernard	De Potter	VMM
Robin	De Smedt	Dep. OMG
Lieven	De Smet	INBO
Tom	De Swaef	ILVO
Jeroen	De Waegemaeker	ILVO

Koen	Desimpelaere	VLM
Bruno	Devos	INBO
An	Dewaele	EKG, Dep. Omgeving
Koen	Dhoore	Landwijzer
Jan	Diels	KU Leuven
Tom	Diez	Watergroep
Victor	Dries	Cabinet minister Demir
Inez	Dua	KVAB
Freddy	Dumortier	KVAB
Annemie	Elsen	Bodemkundige Dienst België
Ruben	Fontaine	DLV
Sarah	Garré	ILVO
Ilse	Geyskens	Boerenbond
Anne	Gobin	VITO
Kevin	Grauwels	VLM
Erik	Grietens	Bond Beter Leefmilieu
Dirk	Holemans	Oikos
Miro	Jacob	ILVO
Sarah	Jacobs	MonardLaw
Pieter	Janssens	Bodemkundige dienst
Maayke	Keymeulen	DLV
Mahmut	Kocak	Dep. OMG
Hans	Leinfelder	KU Leuven
Els	Lemeire	ILVO
Steve	Leroi	IFLUX
Suzanna	Lettens	INBO
Willem	Maetens	VMM
Elisabeth	Monard	KVAB
Katrien	Oorts	Dep. Omgeving
Stijn	Overloop	VMM
Bavo	Peeters	DG environment
Marnix	Pieters	Flanders Heritage
Jean	Poesen	KU Leuven
Joris	Relaes	ILVO
Bert	Reubens	ILVO
Isabelle	Roldan-Ruiz	ILVO
Gerard	Ros	NMI Agro
Greet	Ruysschaert	ILVO
Joost	Salomez	Dep. Omgeving
Steven	Sleutel	UGent
Erik	Smolders	KU Leuven
Marc	Sneyders	Bayer
Jan	Staes	UAntwerpen
Raf	Suys	Cabinet minister Crevits
Martine	Swerts	Planbureau Omgeving
Rhune	Van Cleemput	Watergroep

Karel	Van Daele	Land-en-water
Karen	Van Geert	Arcadis
Griet	Van Gestel	OVAM
Koen	Van Keer	Yara
Georges	Van Keerberghen	Boerenbond
Kris	Van Looy	OVAM
Lieven	Van Waes	Cabinet minister Crevits
Joke	van Wensem	Thinker
Karen	Vancampenhout	KU Leuven
Hendrik	Vandamme	ABS
Bart	Vandecasteele	ILVO
Laurens	Vanden Eynde	Dep. OMG
Hans	Vandermaelen	ILVO
Dieter	Vandevelde	VMM
Bernard	Vanheusden	UHasselt
Wim	Verbeke	Climate Innovation
Kris	Verheyen	UGent
Anna	Verhoeve	ILVO
Elisa	Vermeulen	Grondbank
Inge	Vermeulen	Provincie Antwerpen
Wim	Verrelst	Cabinet minister Crevits
Patrick	Verstegen	VLM
Willy	Verstraete	UGent
Steven	Vinckier	VMM
Jeroen	Watté	Wervel
Koen	Willekens	ILVO
Patrick	Willems	KU Leuven
Mark	Wulfrancke	ABS