TOWARDS A HOLISTIC SOIL PROTECTION IN LUXEMBOURG

A REPORT FOR THE ADMINISTRATION DE L'ENVIRONNEMENT OF THE GRAND DUCHY OF LUXEMBOURG

PROTECTION DES SOLS

D'ËMWELTVERWALTUNG
Am Déngscht vu Mënsch an Ëmwelt

LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de l'Environnement, du Climat
et du Développement durable

Administration de l'environnement

Towards a Holistic Soil Protection in Luxembourg

A report for the Administration de l'Environnement of the Grand Duchy of Luxembourg

04 November 2021

space 4 environment

«Using Space to provide Space for the Environment»

LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de l'Environnement, du Climat
et du Développement durable

Administration de l'environnement

Title:

Towards a Holistic Soil Protection for Luxembourg

Authors:

Mark Kibblewhite (MK Soil Science Ltd), Mirko Gregor (space4environment sàrl)

Acknowledgement

This report includes text and figures from M. Hümann & Wener A. (2020) "Preliminary study on the thematic complex: 'Soil Conservation in Luxembourg'. Analysis of existing instruments in terms of soil protection and interfaces to various areas of the environmental sector", Internal Report 20191458 – LP - ENV, Luxplan S.A.

Disclaimer

Place and date:

Beaminster and Niederanven, 30.09.2021

Contact information:

MK Soil Science Ltd 8 Woodswater Lane Beaminster, Dorset DT8 3DU, UK Tel: +44 1308 861391 http://www.linkedin.com/in/markkibblewhite Mark Kibblewhite - mark@mksoilscience.com	space4environment sàrl 48, rue Gabriel Lippmann L-6947 Niederanven Tel: +352 26 71 41 35 Fax: +352 26 71 45 54 http://www.space4environment.com Mirko Gregor - gregor@space4environment.com

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction

Protection of soil resources is an increasingly important focus for actions to ensure sustainable futures and a core theme within the United Nations (UN) Sustainable Development Goals (SDGs). In this context, the Government of the Grand Duchy of Luxembourg has brought forward a bill on soil protection and the management of polluted sites and anticipates its implementation will need a holistic approach as a first step towards a national Soil Protection Plan (SPP). The timeliness of these national initiatives is underlined by developments at the European level - including a consultation by the European Commission (EC) on a roadmap for drafting a Communication on a new soil strategy to be presented in 2021. The Administration de l'Environnement (AEV) will be a Luxembourgish competent authority in charge of the SPP drafting, which is the reason of this preparatory analysis of the current situation regarding soil and its protection in Luxembourg. The goal for this report is to support development of the future SPP.

In order to set the stage, the report describes briefly the soil system and the services and goods that it supports and gives a summary of the soil resources in Luxembourg and processes that contribute to their degradation. Then, it reviews existing global, European and national policies, legal instruments and policy measures that directly or indirectly relate to the management of soil resources. The findings are taken forward to provide a rationale for the SPP, identify the key issues that it should address and propose options for enhancing the governance of soil protection.

Soil resources in Luxembourg

Soil is a living system that does vital work for life and the economy. It is an integral part of terrestrial ecosystems and supports a vast below ground biodiversity, as well as the plants and organisms that live above ground. Its fertility determines the ability of land to produce food, forest products and bioenergy crops. It regulates the water cycle, affecting available water resources and risks from flooding. It stores more than three times as much carbon as above ground vegetation and consequently changes in soil carbon stocks have profound implications for climate change and global warming. As well as supporting human access to food and water, soil is a platform for buildings and holds an archive of cultural artefacts and landscape history.

A variety of soil types exist in Luxembourg with distinct properties that make them optimal for supporting different land uses and services. The soils in the Oesling region are more uniform than those in the Gutland region, with the latter having an unusually rich variety of soil types. These different soils in combination with different land uses are more or less at risk of different forms of degradation.

Soil erosion may be caused by wind or water, but only the latter is a significant problem in Luxembourg. Soils with higher sand and silt contents on slopes are more likely to erode and this risk is increased when they are cultivated and left bare of vegetation. Exact information on soil erosion by water across all of Luxembourg is not available. However, areas of light soils (silty to sandy loam) in the south of the Gutland are anticipated to be most at risk of erosion with local estimations above 2 Mg/ha/yr, which is higher than accepted rates of soil formation.

Soil Organic Carbon (SOC) makes up about 58% of Soil Organic Matter (SOM) and is a key component of healthy soils – it provides an energy substrate for soil organisms and is a structural material in soil aggregates. Its level depends on the relative rates of organic matter additions from plant and other residues relative to releases of carbon dioxide (CO_2) from respiration, which balance is affected especially by clay content, wetness and land use. The distribution of SOC stocks in cropland in Luxembourg has been found to have a mean stock in the depth range 0-30 cm of 91 Mg C/ha for the Oesling region compared to about 70 Mg C/ha for the Gutland region. In permanent grassland, mean SOC stock in Oesling is about 90 versus 111 Mg/ha in Gutland. The overall stock estimate for forest soils was higher for Oesling than for Gutland, with mean values of around 132 Mg C/ha and 102 Mg C/ha respectively. A new study on SOC contents has been released in January 2021 by the Administration of Technical Agricultural Services of the Ministry of Agriculture. It shows that the main factors influencing the trajectory of SOC stocks over time are both land management practices (land uses and land management, including defined Good Agricultural Practices) and natural conditions (for example clay content and climate). This indicates that the evolution of SOC stocks is or will be partially sensitive to climate change.

Soil compaction is mainly caused by excessive surface loadings from machinery used in agriculture and forestry under unsuitably wet soil conditions. Surface compaction of soil is common and can be limited by appropriate soil management, but compaction of subsoil is less easily corrected. Soil compaction restricts root extension and the movement of air and water through soil and so its fertility. Soil compaction increases rates of surface water runoff, which increases risks from flooding and reduces groundwater recharge. While field observation of soil compaction is common, obtaining data on its extent across wider landscapes is problematic and such data are not available for Luxembourg, as for most countries.

Soil diffuse contamination is widespread as a result of different sources such as industrial and traffic emissions leading to atmospheric deposition, chemical applications and waste spreading to agricultural land. Site-specific (or local) pollution of land by industrial processes, historic waste disposal and accidental releases falls in the realm of a specific soil management based on risk to human health, water and ecosystems; this needs significance and liability rules as well as streamlined procedures that are to be defined in the future Soil Protection Act. Therefore, this specific aspect is not considered in this report. Diffuse soil contamination sometimes exceeds levels at which it presents an unacceptable risk to food production and may affect plant growth directly, but current understanding about how it may harm soil organisms and soil functionality is limited. Systematic data on the occurrence of diffuse soil pollution across Luxembourg is anticipated in the near future but is not yet in the public domain.

Soil acidification results from both natural and anthropic factors. In general, natural soil acidification does not cause environmental harm but it can decrease agronomic fertility. Where necessary, the acidity of agricultural soils is corrected by liming. Human-induced soil acidification arises mainly from emissions of SO_2 and NO_x followed by their deposition, but is also caused by the use of ammonium-containing fertilizers. Therefore soil acidification can be considered as a kind of diffuse soil contamination. Soils that have formed from alkaline parent are less sensitive to human-induced acidification than those formed from more acidic parent materials. For example soils in the Oesling region can have a higher acidity, especially under coniferous forests, leading potentially to heavy metal leaching and/or aluminium (Al) toxicity. Options for preventing environmental harm from locally excessive soil acidity are to replace coniferous with deciduous trees or spread lime (environmental liming).

Soil sealing is the permanent covering of land and soil with an impermeable artificial material often combined with the removal of the functional top-soil layers. It occurs within areas of existing and new ‘land take’, meaning land that has been taken into the built environment from agricultural, forest and semi-natural lands. Soil sealing destroys the ability of soil to deliver key services, particularly its support for food, forest and biofuel production, its ability to mitigate global and local climate and it prevents infiltration of water into soil increasing surface water runoff and risks of flooding and reducing groundwater recharge. The rate of land take by extension of the built environment and infrastructure in Luxembourg is high relative to other European countries. Currently, 4.24 % (equivalent to 110 km², reference year 2015) of the country’s land area is sealed with an annual increase of 0.56 % between 2006 and 2015. This corresponds to almost 100 football pitches per year.

The legal framework for soil protection

At the global level, the UN Sustainable Development Goals (SDGs) set a frame for sustainable development, including in relation to soil protection: three of the goals (SDG 2, 3 and especially 15) are relevant directly and four goals (SDG 6, 11, 13 and 14) are linked indirectly to land and soil management. SDGs 8 and 12 are also relevant indirectly to a lesser extent. Target 15.3 relates directly to soil protection. It aims to combat desertification, restore degraded land and soils, […] and to strive to achieve a land degradation-neutral world. Congruent with the SDGs, successful implementation of commitments made under the Paris Agreement is strongly dependent on managing soil resources, as these are by far the largest terrestrial stock of carbon. Sustainable land management has been highlighted by the recent IPCC Special Report on Climate Change and Land, as a key measure to reduce and reverse land degradation in support of several SDGs and with potential co-benefits for climate change adaptation and mitigation.

At the European level, soil is an increasing focus for new policy which aims to bring the protection of soil to the same level as that for air and water. This is being addressed directly by the development of a new soil strategy in a Communication from the EC in 2021, which will have objectives on limiting soil degradation to be achieved by actions covering: improved soil management practices, monitoring and knowledge within a context of increased community funding and congruence with global initiatives. Soil protection is embedded in recent overarching policy such as the Biodiversity Strategy 2030, the Farm to Fork Strategy, the Zero Pollution Action Plan and the revision to the Common Agricultural Policy (CAP). The latter is anticipated to introduce soil protection as a core activity and set mandatory standards for protecting SOC in peatlands and wetlands and for crop rotations to maintain SOC levels in croplands. These current developments build on past progress, notably that flowing from the EU Soil Strategy adopted in 2006 and some soil-related requirements within existing Directives, albeit these are often secondary to the main purpose of these Directives. One important specific soil protection requirement is in the Industrial Emissions Directive, which requires operators to demonstrate that no increment in soil contamination has occurred during licensed operations.

At the national level, the draft Soil Protection Act and the SPP aim to bring soil protection in Luxembourg up to the same level as that for air and water. In the meantime, there are existing policies, legal instruments and other measures that are protective of soil resources. The spatial planning system provides a framework for efficient land allocation to moderate land take, which also limits the soil sealing associated with land being taken into the built environment. The draft Forest Act protects forest soils from conversion to cropland or transfer into the built environment, which avoids soil sealing and reduces the risks of soil erosion and losses of SOC. Since 1999, the Act on classified installations is an important tool for identification and remediation of soil contamination related to industrial activities.

Developing a Holistic Soil Protection Approach

The rationale

The need for a holistic soil protection approach rests on soil's critical role in the national economy. Factor costs are affected by the capacity of soil to support a range of non-traded but important services as well as production of traded goods such as food and forest products. Therefore, soil degradation impacts on national economic performance. The argument for public policy intervention to protect soil is reinforced further by inequities in the distribution of costs and benefits arising from soil use. Soil is part of land and therefore subject to the laws and customs relating to land ownership. Good governance of soil requires that there is an appropriate balance between the rights to exploit and the duties to steward land as these affect soil management. Recent research has highlighted the relatively large externality costs of soil (likely exceeding 25 million euros per annum in Luxembourg) and that these fall disproportionally on the wider community rather than the direct user of soil resources, for example as an increased risk of flooding and higher carbon emissions to the atmosphere.

The rationale for a holistic soil protection approach as outlined above is fully consistent with that for global and European policy initiatives, with the latter setting future mandatory requirements for soil protection in relevant Directives and under the CAP.

Strategic objectives

The first strategic objective should be to protect soil resources from irreversible losses and damages. The main threat to this seems to be from soil sealing in the built environment and infrastructure, while soil erosion is important locally. While diffuse soil contamination has been widespread in the past, existing measures to limit new contamination suggest this a lower priority. Nonetheless there are emergent concerns about hitherto unrecognised pollutants such as Per- and polyfluoroalkyl substances (PFAS), micro-plastics and pharmaceutical drug residues.

The second strategic objective should be to protect soil resources from degradation even where this can be reversed, to avoid ongoing losses of services and future remedial costs. Here the main threat is loss of SOM and SOC, in particular on agricultural and forest land and through the expansion of sealed surfaces; this is of increasing importance because of the urgent need to reduce GHG emissions, as well as because levels of SOC need to be optimised to maintain soil health. Soil compaction seems to be a lesser threat but nevertheless requires attention.

A third strategic objective should be to develop infrastructure to support an efficient and effective targeting of soil protection. The main need is for data infrastructure, specifically a national spatial inventory of soil resources and a systematic soil monitoring system, building on and integrating these developments with existing data initiatives at European and national levels.

Approach

The approach should consolidate and enhance rather than duplicate existing actions. There are already strong controls on changes in rural land use from forestry to grassland and from grassland to cropland. Soil sealing is indirectly constrained by existing planning guidance that constrains land take by extension of the built environment – it would be more efficient to introduce specific measures relating to soil sealing to the existing planning guidance and regulations at municipal level than to introduce a new standalone measure.

Land management within cropland requires rigorous implementation of GAEC conditions under the CAP to address any continuing decline of SOM and soil erosion in agricultural land. This needs effective inspection as well as impartial guidance, innovation, advice and training.

Appropriate design of mutually supportive land and climate policies, institutions and governance systems at all scales can successfully contribute to land-related adaptation and mitigation. Effective governance for soil protection requires stakeholder motivation and capacities to be developed. Ideally, behaviours and motivation should be positively aligned with the aspirations of the Plan. This requires engagement with stakeholders, to increase their awareness and understanding and equip them with relevant knowledge and tools.

The knowledge and tools that are relevant to the SPP and indeed all aspects of its formulation and implementation should be developed collaboratively by the various public agencies with key roles include the Administration de l’Environnement (AEV), Administration des Services Techniques de l’Agriculture (ASTA), Service d’économie rurale (SER), Département de l’Aménagement du Territoire (DATer), Administration de la Nature et des Forêts (ANF) and the Administration de la Gestion de l’Eau (AGE).

1 INTRODUCTION

Degradation of soil and land are major global challenges and a World Soil Charter promoting sustainable soil management[1] has been adopted by the United Nations Food and Agriculture Organisation (FAO).

In May 2020, the European Commission (EC) adopted, as key elements of the European Green Deal[2], the new EU Biodiversity Strategy for 2030 to bring nature back into our lives[3] and the Farm-to-Fork Strategy for a fair, healthy and environmentally-friendly food system[4]. Both strategies aim to address land take and to preserve, protect and restore land and soil ecosystems. Those goals are reinforced in the European Union (EU) 8th Environmental Action Programme (EAP) as one of its thematic priority objectives, namely "protecting, preserving and restoring biodiversity and enhancing natural capital, notably air, water, soil, and forest, freshwater, wetland and marine ecosystems".[5]

In November 2020, the EC opened a consultation on a Roadmap towards drafting a new soil strategy that it anticipates publishing as a Communication in 2021[6]. The existing Soil Thematic Strategy was proposed by the EC in 2003[7] and adopted by the European Union in 2006, since when it has been the cornerstone of current and future EU soil policy. It aims at the protection of soil and its sustainable use, prevention of further soil degradation and restoration of degraded soils. It also proposed a Soil Framework Directive[8] but agreement on this was not reached by member states. Consequently, subsidiarity applies to many aspects of soil protection. The EC intends that the new soil strategy will consolidate, complement and steer action in the different policy areas that affect and depend on soil (such as pollution prevention, agriculture, research), guiding the implementation of sustainable soil and land management practices via horizontal measures.

In the European context and those of the United Nations (UN) Agenda 2030[9] and the National Plan for Sustainable Development in Luxembourg[10], the Government of the Grand Duchy of Luxembourg

---

[1] FAO, 2015. Revised World Soil Charter. 10 p
http://www.fao.org/documents/card/en/c/e60df30b-0269-4247-a15f-db564161fee0/
[2] European Commission, website visited in 2021. A European Green Deal
https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
[3] European Commission, website visited in 2021. Biodiversity strategy for 2030
https://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm
[4] European Commission, website visited in 2021. Farm to Fork strategy
https://ec.europa.eu/food/farm2fork_en
[5] European Commission, 2020. Proposal: General Union Environment Action Programme to 2030. 35 p
https://ec.europa.eu/environment/pdf/8EAP/2020/10/8EAP-draft.pdf
[6] European Commission, website visited in 2021. Healthy soils – new EU soil strategy
https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12634-New-EU-Soil-Strategy-healthy-soil-for-a-healthy-life
[7] European Commission, 2006. Communication: Towards a Thematic Strategy for Soil Protection. 35 p
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52002DC0179
[8] European Commission, 2002. Proposal: Directive establishing a framework for the protection of soil and amending Directive 2004/35/EC. 30 p (see p 14)
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52006PC0232&from=EN
[9] UN, website visited in 2021. Transforming our world: the 2030 Agenda for Sustainable Development
https://sdgs.un.org/2030agenda
[10] IMSLuxembourg, website visited in 2021. Presentation of National Plan for Sustainable Development
https://imslux.lu/eng/news/193_presentation-of-national-plan-for-sustainable-development

brought forward a bill on soil protection and the management of polluted sites. A Soil Protection Plan (SPP) is envisaged to assist its implementation. The overall aim[11] is to bring the protection of soil up to the same level as that for air and water and to maintain soil quality in the long term.

The draft Soil Protection Act designates the Ministère de l'Environnement, Climat et du Développement durable (MECDD) as the responsible ministry and identifies the Administration de l'Environnement (AEV) as the competent authority.

The aim of this report is to support the development of a rationale and key objectives for a holistic soil protection approach. It presents the important role of soil resources in sustainable development and the global, European and national framework for soil protection. It collates and assesses information about the current status of soils in Luxembourg and the existing legal framework for soil protection and provides a commentary on how soil policy measures might be developed to release economic benefits.

The first part of this report describes the soil system and the services and goods that it supports, followed by overview of the types of soil degradation and their occurrence in Luxembourg.

The second part reviews existing global, European and national policies, legal instruments and policy measures that directly or indirectly relate to the management of soil resources.

Finally, the third part summarises an economic rationale for a soil protection approach and some first key elements of a future soil protection plan. Finally, a commentary is presented on options for enhancing the governance of soil protection.

[11] Emwelt.lu, website visited in 2021. Projet de loi sur la protection des sols et la gestion des sites pollués https://environnement.public.lu/fr/natur/sol/projet-de-loi-sols.html

2 Soil resources in Luxembourg

2.1 The soil system and the services it supports

Soil is the Earth's living skin, overlying surface geology and making terrestrial life possible. The soil system is a biological engine in which a large and diverse community of microbes and higher life forms use plant-derived carbon as an energy source to do work that supports terrestrial life. The habitat for this community has a complex architecture of micro and macro pores constructed from mineral and organic phases. Sub-assemblies of organisms provide vital functions for the soil system, specifically: organic matter decomposition, nutrient recycling, maintenance of the soil physical structure and community regulation. Working together as a system, the soil community supports essential ecosystem services for the wider terrestrial environment. These services include provisioning and regulating ones on which human society depends. Therefore, soil is vital to a sustainable economy.

Six services of high importance to society that depend on soil have been identified in the *"Projet de loi sur la protection des sols et la gestion des sites pollués".*

These services are summarised below.

1. Supporting services for life and biodiversity (*"*vivier de la biodiversité*")*

The number of organisms in a handful of soil exceeds that of the entire human population. Soil is a habitat for a vast and diverse below-ground flora and fauna representing a quarter of terrestrial biodiversity; it includes microbes, protozoa, nematodes, arthropods and insects. Furthermore, soil provides a medium for plant growth and support for above-ground ecology and therefore it is a critical part of terrestrial life.

2. Provisioning services for food, fibre and bioenergy crops (*"production de biomasse"*)

Fertile soils are the foundation for human food production. Soil resources are finite and therefore their protection is essential to food security.

A continuing supply of forest products and services requires healthy soil resources, as does the production of bioenergy crops.

3. Regulating services for nutrient, water and carbon cycles *(« stockage, filtrage et transformation de substances, y compris d'éléments nutritifs, de polluants et d'eau » et « réservoir de carbone »)*

The soil system provides a vital nutrient regulating service by decomposing plant and animal residues and releasing nutrients for plant uptake, in particular nitrogen and phosphorus. Additionally, the soil microbial community captures atmospheric nitrogen, making it available to plants. Therefore, soil resources are vital for sustaining the supply of nutrients needed to maintain the productivity of land. Soil resources regulate water resources. Soil pore widths range in size from a few microns to centimetres; smaller pores are able to hold water by capillary action while larger pores modulate flow through the soil to groundwater. Surface infiltration followed by storage of water in soil pores and its later release moderates surface runoff in storm events and re-charges groundwater and aquifers. Therefore, soil resources play an important role in flood risk management and in maintaining water resources.

Soil resources also regulate water quality. Filtering and attenuation of nutrients and pollutants by soil helps to protect surface water and groundwater quality. Nutrients are held in the soil biota, on soil surfaces and in soil organic matter for later release to plant roots. Toxic substances are absorbed by soil. Therefore, the management of soil is essential to water quality management in river and groundwater catchments.

The soil system has a major role in regulating the global carbon cycle. The Earth's soils contain more than three times the amount of carbon in the atmosphere and four times the amount stored in all living plants and animals[12]. Soil organic matter (SOM) is the product of processing of plant and animal residues by the soil system. The level of soil organic carbon (SOC) in a soil reflects a balance between carbon additions from above ground plant, roots and animal residues relative to its respiration and release to the atmosphere by soil organisms. Most of the added carbon is quickly respired, but a proportion is converted to long-lived forms, including some that have half-lives of hundreds of years. In addition, there are mechanisms by which carbon is stored in long-lived mineral forms. Therefore, managing carbon stocks in soil is crucial for controlling atmospheric carbon levels and mitigating climate change.

4. Provisioning services - soil as a platform for the built environment ("*environnement physique et culturel de l'homme et des activités humaines*")

Soil provides a foundation for artificial surfaces, buried infrastructure and buildings. The depth and mineral properties of different soils affect their performance of this platform service. Important factors are their ability to support static loads, their hydrological properties and the presence of expansive clay minerals. The latter cause shrinking and swelling that can damage foundations and buried infrastructure. Soil supports the grounding (earthing) of electrical networks and infrastructure and this is affected by soil properties. Therefore, the management of soil resources as a platform for the built environment is important.

5. Provisioning services - soil as a source of raw materials ("*source de matières premières*)"

Soil itself is used as an economic raw material, in addition to and separate from sand, gravel, clay and other parent materials that are extracted from beneath soil. Common uses of soil are for the construction of earth bunds and other landscape features and in horticulture as a component of growth media. Peat soils in Luxembourg are nearly inexistent, but peat-based growth media may be imported causing degradation of soil resources elsewhere.

6. Cultural services - soil as an archive of geological and human culture (« *conservation du patrimoine géologique et architectural* »)

Soil stores information about the natural and cultural history of landscapes. Different soils form depending on geological and climatic conditions over time and information about past environments can be inferred by studying soils. Soils can preserve archaeological artefacts depending on the soil

[12] Ontl and Schulte, 2012. Soil Carbon Storage. Nature Education Knowledge https://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790/

type and the artefact material and soil stratigraphy provides information about the history of human settlements and societies[13]. Therefore, soil protection is needed to conserve cultural heritage.

2.2 The soils of Luxembourg[14,15]

The predominant soils of the Oesling region can be classified as Cambic Umbrisols. They are relatively young slightly-acidic loamy and stony soils with a structural subsoil horizon and have formed on moderately weathered metamorphic rocks (schists, quartzite and shales) of the Ardennes plateau. In the Oesling region, there are some small local areas of soils with histic properties; these soils could be peaty soils (Histosols) as estimated by a European scale study (about 3.5 km^2)[16] but the national soil inventory provided by ASTA has not identified real Histosols yet (mapping is in progress with 76% of the national area covered in 2018)[15].

The soils of the Gutland region are much more varied than those of the Oesling and have an unusually rich variety of soil types. These include Arenosols, Podzols and Regosols (formed from sand and marl parent materials, especially in the Lias Cuesta landscape[17]), Calcaric Cambisols (loams with calcareous subsoil), Stagnic Luvisols (wetter soils with clay subsoil), Fluvisols (loams formed in alluvial material) and even Vertisols (heavy expansive clay).

Forest, grassland and arable land uses occur in both the Oesling and Gutland regions, with forest more dominant in the former and arable and grassland in the latter[18].

2.3 Soil degradation in Luxembourg

A 2015 review by the RECARE project on soil threats in Europe[19] provides a framework for identifying and assessing the types, extent and consequences of soil degradation in Luxembourg. Those that need to be considered are soil erosion by wind and water; decline in soil organic matter; soil compaction;

---

[13] Kibblewhite, Tóth, and Hermann, 2015. Predicting the preservation of cultural artefacts and buried materials in soil. Science of The Total Environment. 14 p
https://www.sciencedirect.com/science/article/pii/S0048969715004854

[14] JRC, website visited in 2021. Cartes des sols du Grand-Duché de Luxembourg au 1:100 000
https://esdac.jrc.ec.europa.eu/content/carte-des-sols-du-grand-duche-de-luxembourg-soil-map-great-duchy-luxembourg

[15] Marx and Flammang, 2018. La cartographie des sols au Grand-Duché de Luxembourg – Légende de la carte des sols détaillée à l'échelle 1:25 000. 39 p
https://agriculture.public.lu/de/publications/pflanzen-boden/boden1/legende-carte-sols-detaillee.html

[16] Tanneberger et al., 2017. The peatland map of Europe. Mires and Peat. 17 p
http://mires-and-peat.net/media/map19/map_19_22.pdf

[17] Cammeraat, Sevink, Hissler, Juilleret, Jansen, Kooijman, Pfister, and Verstraten, 2018. Soils oft he Luxembourg Lias Cuestas Landscape In: Kooijman, Cammeraat, and Seijmonsbergen, 2018. The Luxembourg Gutland Landscape. Springer. 276 p
https://doi.org/10.1007/978-3-319-65543-7_6

[18] sapce4environment, website visited in 2021. High-resolution land cover map 2018 for Luxembourg
http://space4environment.com/news/news-detail/news/high-resolution-land-cover-map-2018-for-luxembourg/?tx_news_pi1%5Bcontroller%5D=News&tx_news_pi1%5Baction%5D=detail&cHash=24591d2188979eb9ad7e260268349d4d

[19] JRC, 2016. Soil threats in Europe. JRC technical reports. 207 p
https://esdac.jrc.ec.europa.eu/public_path/shared_folder/doc_pub/EUR27607.pdf

decline in soil biodiversity; soil contamination and soil sealing. Desertification and soil salinization do not occur in Luxembourg because the necessary climatic conditions are absent. Further soil-related problems that are included as threats in the EU Soil Thematic Strategy adopted in 2006[20] are flooding and landslides; although an increased risk of these does arise because of soil degradation, they are not strictly soil degradation processes and are not considered as such in this report. Soil acidification is identified as a type of soil degradation in the 2012 Soil Thematic Strategy[21], although it was not included by the RECARE project or in the 2006 EU Soil Thematic Strategy. Nonetheless, it is considered a potential threat to the soils of Luxembourg and is likely to be included in future versions of the Soil Thematic Strategy[22].

[20] European Commission, 2006. Communication: Thematic Strategy for Soil Protection. 12 p http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52006DC0231&from=EN

[21] European Commission, 2012. Report: The implementation of the Soil Thematic Strategy and ongoing activities. 15 p https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52012DC0046

[22] Montanarella and Panagos, 2021. The relevance of sustainable soil management within the European Green Deal. Land Use Policy. 6 p https://www.sciencedirect.com/science/article/pii/S0264837720304257#bib0245

2.3.1 Soil erosion

Soil erosion and its effects on services from soil

Soil erosion occurs when kinetic energy in wind or flowing water is sufficient to break the forces that bind soil together and to mobilise soil particles. Downslope movement of soil caused by tillage and soil removal with harvested crops are also forms of soil erosion. Soil erosion also occurs during construction activities when bare ground erodes during storms.

Factors that influence the rates of soil erosion by water are rainfall volumes and intensities, soil texture (a fine sandy soil is more prone to erosion than a heavy clay soil), the organic matter content of soil, slope angle and length, vegetation density and land cover and land management.

Soil erosion represents a chronic and continuing loss of soil resources and of the services that it supports. The mean rate of soil formation in Europe[23] has been estimated to be about 1.4 Mg/ha/yr, which may be regarded as a tolerable rate of soil erosion. This rate is often exceeded in Europe by both modelled and observed rates of soil loss by erosion. A consequence of soil erosion by water is increased and excessive sediment loadings in surface waters, which damages river habitats and fisheries and can increase the costs of the ditch maintenance and river dredging required to reduce flood risk and to maintain navigations.

Soil erosion in Luxembourg

For Luxembourg as elsewhere, the spatial coverage of empirical data on actual soil erosion rates is patchy. Soil erosion by wind is not very significant in Luxembourg and has been estimated[24] at less than 0.25 Mg/ha/yr. The modelled estimates of soil erosion by water made in the Pesera project[25] for Luxembourg are generally less than 0.5 Mg/ha/yr, except for areas of higher risk close to the River Sûre and in some parts of the Gutland, where they may exceed 2 Mg/ha/yr. However, these are central estimates for relatively large areas and are likely to obscure locally higher rates of soil erosion. A spatial estimation of the percentage of precipitation draining in surface water runoff is presented in Figure 1, assuming a mean precipitation rate of 41.6 mm/h and a return period of 20 years. This provides a partial proxy for erosion rates because higher rates of runoff increase the risk of soil erosion. It indicates that there is less risk of soil erosion on the stony soils of the Oesling than on light textured soils in the south of the Gutland region.

The risk of soil erosion is reduced by vegetative cover and the extent of this reduction in Luxembourg has been estimated spatially, as presented in Figure 2. Those areas in the Gutland with light textured

[23] Verheijen, Jones, Rickson, and Smith, 2009. Tolerable versus actual soil erosion rates in Europe. Earth-Science Reviews. 15 p https://doi.org/10.1016/j.earscirev.2009.02.003

[24] Soil Loss European Map (Mg/ha/yr) https://esdac.jrc.ec.europa.eu/public_path/GIS-RWEQ.png

[25] Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1, 2003. https://esdac.jrc.ec.europa.eu/public_path/Pesera.pdf

soils (silty to sandy loam) and limited vegetative cover are expected to be where there is most risk of soil erosion

In summary, erosion is a cause of soil degradation in Luxembourg and is expected to significantly exceed rates of soil formation in certain localities.

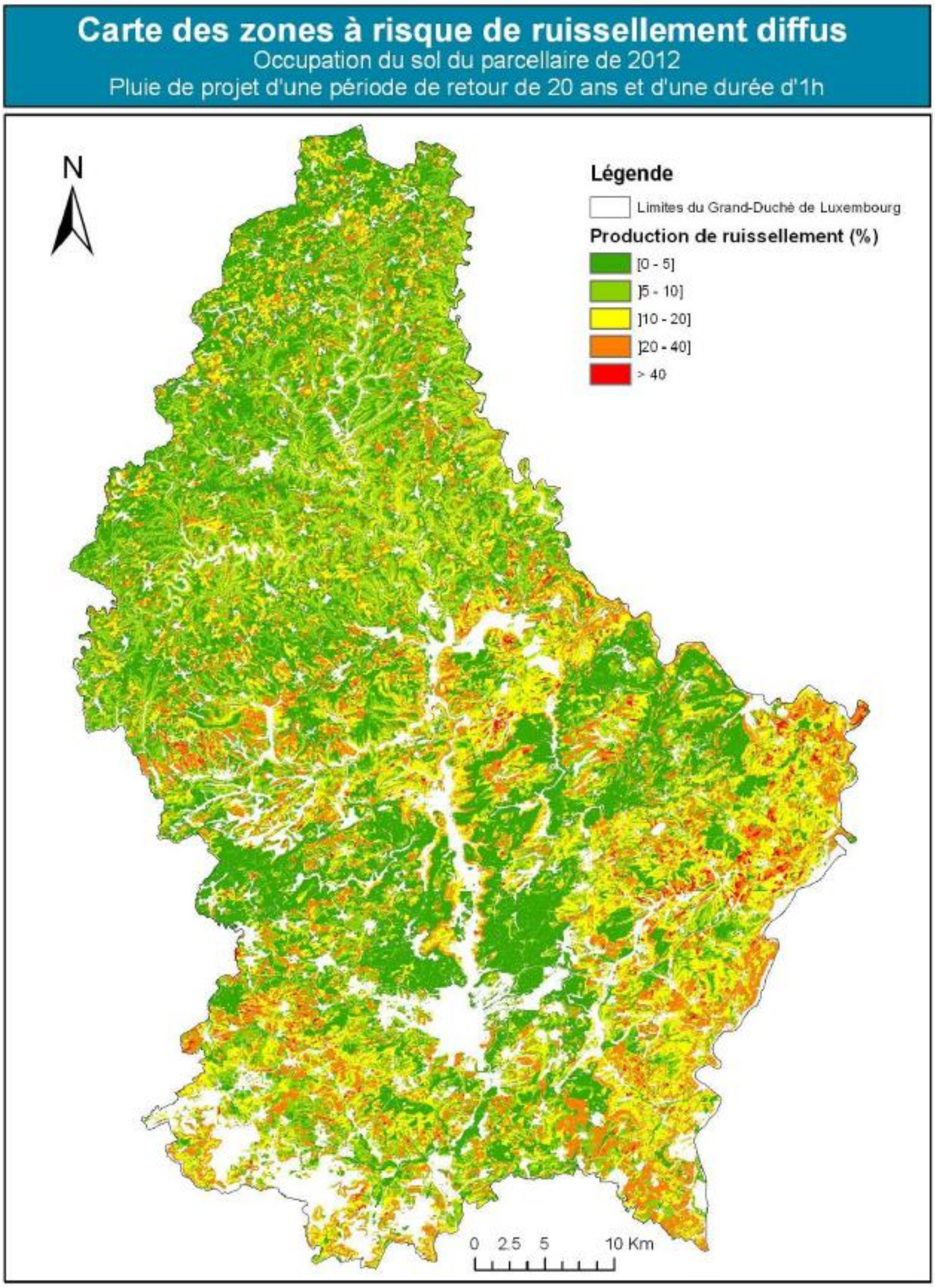

Figure 1: Map of the risk of diffuse surface water runoff (Rauw et al., 2013[26])

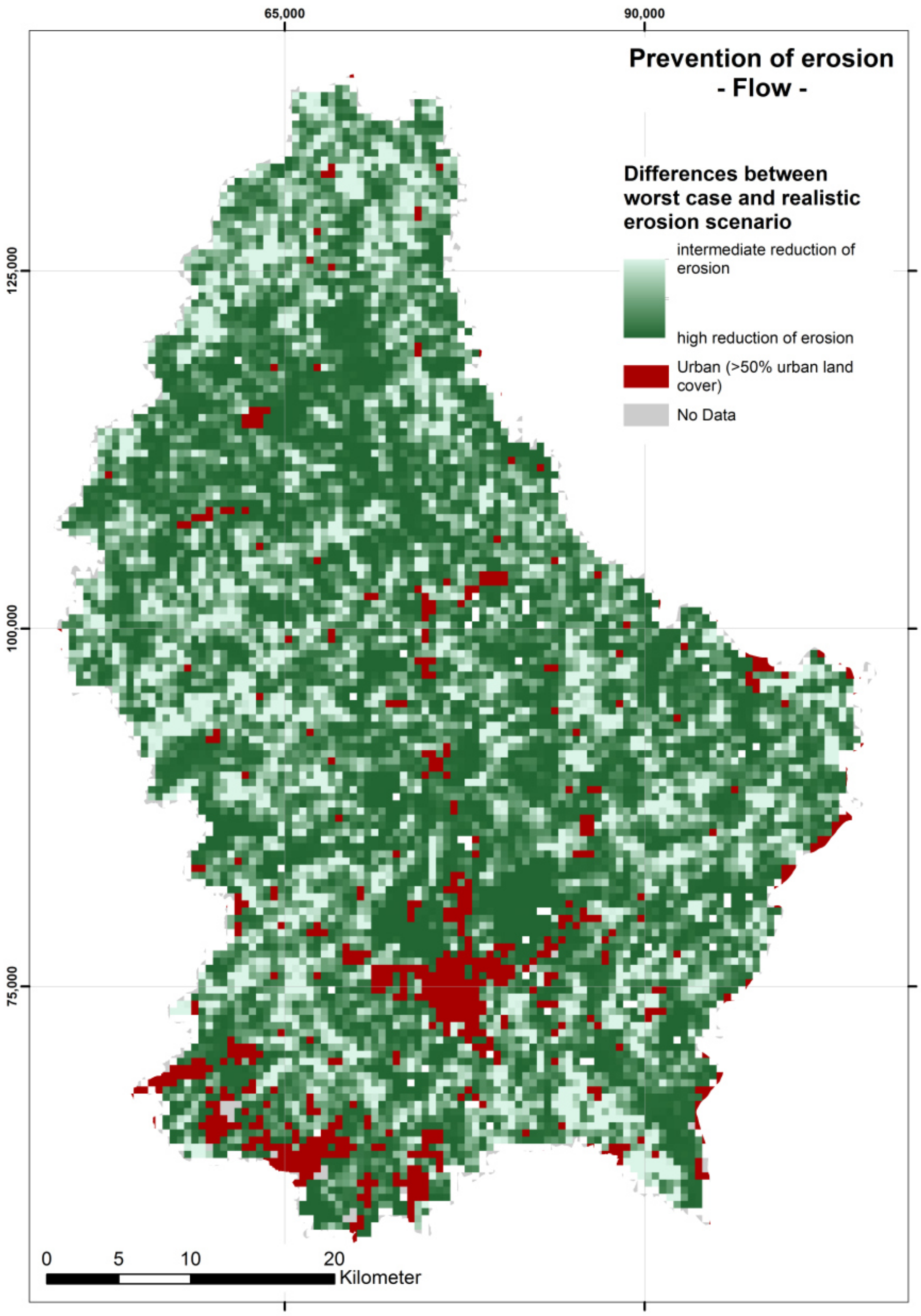

Figure 2: Spatial estimation of effect of vegetative cover on risk of soil erosion (Becerra-Jurado et al., 2015)[27]

[26] Rauw J., Marx S. & Degré A., 2013. Avenant à la convention de recherche relative à l'établissement d'une carte thématique sur les zones à risque d'érosion et de ruissellement au Grand-Duché de Luxembourg à partir de la carte des sols. Ministry of Agriculture. 93 p

[27] Becerra-Jurado, Philipsen, and Kleeschulte, 2015. Mapping and assessing ecosystems and their services in Luxembourg – Assessment results. Ministère du Développement durable et des Infrastructures. 75 p https://www.researchgate.net/publication/298394420_Mapping_and_Assessing_Ecosystems_and_their_Services_in_Luxembourg_-_Assessment_results

2.3.2 Decline in Soil Organic Matter

Soil Organic Matter and its role in services from soil

Soil organic matter (SOM) is a heterogeneous mixture of organic materials with varied molecular structures, a carbon content of about 58% and a ratio of carbon to nitrogen of about 10:1. It is produced by microbial decomposition of plant and animal residues. It can be divided into labile, slow turnover and stable fractions, each being progressively less accessible to microbes as an energy substrate. In most studies, Soil Organic Carbon (SOC) rather than SOM is measured with a factor of 1.72 applied to estimate SOM[28].

SOM provides a continuing supply of energy and nutrients for soil organisms. Plant growth is sustained by nutrients released from SOM. SOM has exchange sites that retain pollutants, protecting groundwater. SOM is a structural component of soil aggregates and helps to maintain soil pore structure and overall system architecture, which positively affects soil hydrology and plant root growth.

Decline in SOM reduces soil water retention, particularly in sandy soils, and adversely affects soil strength, which increases the risk of soil erosion and compaction.

The level of SOM in a soil depends on the balance of carbon inputs from plant and animal residues relative to the carbon released as carbon dioxide by respiring soil biota. The soil system is better able to maintain an optimal output of services if the level of SOC is adequate. Therefore, an indicator of a healthy soil is the level of SOC. A falling level of SOC indicates that the soil system is consuming carbon reserves faster than they are being replenished.

SOC stocks are a vital part of the global carbon cycle. Carbon released to the atmosphere when SOM declines contributes to Greenhouse Gas (GHG) emissions to the atmosphere and global warming. However, soil becomes a net sink for atmospheric carbon when SOM decline is reversed. Therefore, managing soil to avoid SOM decline and where possible to increase its level is an important action for mitigating climate change.

Soil organic matter in the soils of Luxembourg

The European Union's LUCAS survey[29] includes Luxembourg and has measured SOC in soil samples from its agricultural land while the Biosoil project has done the same for samples from forest land.

---

[28] Soilquality.org.au, website visited in 2021. Fact sheet: Total organic Carbon http://soilquality.org.au/factsheets/organic-carbon#:~:text=Organic%20matter%20(%25)%20%3D%20Total%20organic%20carbon%20(%25)%20x%201.72&text=However%20this%20can%20vary%20with,vary%20in%20size%20and%20decomposability.

[29] Orgiazzi, Ballabio, Panagos, Jones, and Fernàndez-Ugalde, 2018. LUCAS Soil, the largest expandable soil dataset for Europe: a review. European Journal of Soil Sciences. 13 p https://onlinelibrary.wiley.com/doi/full/10.1111/ejss.12499

These small data sets have been combined and geostatistical modelling used to estimate that the mean level of SOC in soil across Luxembourg is 3.0 % w/w[30].

The highest levels and stocks of SOC should be found in peaty soils but their area in Luxembourg is very small. For instance, only 4900 m^2 of peatland are recorded in the cadastre of open ecosystems (code 7140 – Tourbières de transition et tremblantes)[31]. The estimation of SOC stocks requires soil bulk density data as well as measurements of SOC contents. Higher levels of SOC are observed in surface topsoil and reducing levels with increasing depth, meaning that for stock estimation SOC data is required relating to soil depth as well as spatially. Therefore, the estimation of SOC stocks is not a trivial task. Topsoil SOC stocks to a depth of 30 cm have been successfully estimated and mapped for four land covers (cropland, permanent grassland, forest, vineyard) in Luxembourg[32,33]. The distribution of SOC stocks in cropland was found to have a median values of 91 Mg C/ha for the Oesling region compared to about 70 Mg C/ha (ranging from 50 to 89 Mg C/ha depending on soil types) for the Gutland region. In permanent grassland, median values go up from 90 Mg C/ha in the Oesling region to 110 Mg/ha in the Gutland region, ranging from 80 to 147 Mg C/ha depending on soil types. The overall stock estimate for forest soils was higher for Oesling than for Gutland, with central values of around 130 Mg C/ha and 99 Mg C/ha respectively. All over the country, median SOC stocks are about 78 Mg C/ha in arable land, 107 Mg C/ha in grassland and 108 Mg C/ha in forest.

These data are consistent with established trends for temperate soils. There is a lower limit to SOC levels that is controlled by the soil clay content and wetter soils generally have higher levels of SOM[34]. As a rule, the level of SOM follows the land use pattern: cropland < grassland < forest, reflecting a shift to a later ecological succession status as well as less soil disturbance by tillage.

The main factors influencing the trajectory of SOC stocks over time are land management practices and natural conditions[33]. For example, changing land use from grassland to cropland reduces the net flow of carbon to soil, shifting the trajectory of SOC levels and stocks downwards, which trend may continue for decades before a new lower equilibrium SOC level is reached. Some Good Agricultural Practices (GAP) may help to preserve or possibly even improve SOC stocks, where these increase the net flow of carbon to soil and are sustained over longer time periods. The impact of land take for

[30] JRC, website visited in 2021. Predicted distribution of SOC content in Europe in the context of the EU-funded SoilTrEC project https://esdac.jrc.ec.europa.eu/content/predicted-distribution-soc-content-europe-based-lucas-biosoil-and-czo-context-eu-funded-1

[31] Geoportail.lu, website visited in 2020 https://www.geoportail.lu/fr/

[32] Stevens, van Wesemael, Marx, and Leydet, 2014. Mapping topsoil organic carbon stocks in Grand-Duchy of Luxembourg. Ministry of Agriculture-ASTA and UCL. 16 p https://agriculture.public.lu/content/dam/agricult%09ure/publications/asta/boden/rapport-corg-stock-map-lu-stevens-2014-vfinale.pdf

[33] Chartin, van Wesemael, Marx, Steffen, and Leydet, 2020. Recent evolution of soil organic carbon in the Grand Duchy of Luxembourg. Ministry of Agriculture. 67 p https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiksezQt6TzAhVNhv0HHe5VBu8QFnoECAMQAQ&url=https%3A%2F%2Fagriculture.public.lu%2Fcontent%2Fdam%2Fagriculture%2Fpublications%2Fma%2Frecherche%26pei%2Fprojekte_boden_wasser_biodiversitaet%2Fc_organique%2FEtude-Evolution-SOC-LU-ASTA-UCL-2020-EN.pdf&usg=AOvVaw37KKfTcmZq4dL4M-qXEiyU

[34] Verheijen, Bellamy, Kibblewhite, and Gaunt, 2006. Organic carbon ranges in arable soils of England and Wales. Soil Use and Management. 8 p https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1475-2743.2005.tb00099.x

development and associated soil removal and sealing may also be important factors affecting SOC stocks in Luxembourg, but this has not been studied[33]. SOC dynamics are influenced by climate (especially its influence over soil wetness) which interacts with soil properties (for example clay content), and therefore climate change has an impact on SOC stocks in Luxembourg - which is currently of uncertain nature and scale.

Measuring changes in SOC levels is made difficult by the high spatial variability of both SOC levels and rates of change in SOC; changes above field scale cannot be reliably detected over time periods of less than 5 years and often longer[35]. However, the conservation of SOC stocks in Luxembourg clearly requires that land use change from forest to grassland or cropland, or of grassland to cropland is restricted, regardless of the problems of making reliable measurements of changes in SOC to confirm the benefits of such restrictions. Land use/land cover changes over time can be approximated by using the time series of national land use/land cover data available at very high resolution for Luxembourg (namely the maps on Occupation Biophysique du Sol/OBS from 1999 and 2007 as well as land use/land cover maps from 2015 and 2018, with newer data becoming available). Shorter term but often ephemeral increases in SOM at field scale can be achieved by modifying cultivation practices; for example, by introducing cover crops and / or temporary grassland to arable rotations.

[35] Saby et al., 2008. Will European soil-monitoring networks be able to detect changes in topsoil organic carbon content? Global Change Biology. 10 p
https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2486.2008.01658.x

2.3.3 Soil compaction

Soil compaction and its effect on services from soil

Soil compaction is “The densification and distortion of soil by which total and air-filled porosity are reduced, causing the deterioration or loss of one or more soil functions”[36] and occurs when soils are subjected to static or dynamic pressures that exceed their ability to resist structural deformation. The strength of soil reduces with increasing water content and therefore the risk of soil compaction is higher when soils are wet. Wheels, tracks, rollers or the passage of animals and humans can all cause soil compaction. Tillage and harvest operations when soils are too wet and the in-field use of road vehicles with high pressure tyres are particular hazards to agricultural soils. The recent increase in the size and weight of agricultural machinery has heightened the risk of soil compaction, although low pressure tyre systems help to offset this risk. Similarly, soil compaction is caused by the heavy machinery and transport used in forest operations and especially for logging.

Compaction at the soil surface reduces water infiltration, which accelerates surface water run-off and increases the risks of soil erosion and flooding. Subsoil compaction can reduce soil fertility by restricting root extension and the movement of gases and water.

Topsoil compaction in croplands is relatively easily corrected by ongoing cultivations. However, compaction of grassland soils and of subsoil requires specific and potentially costly remedial measures.

Soil compaction in Luxembourg

No systematic information on the extent of soil compaction in Luxembourg appears to be available. The main economic impact of soil compaction in Luxembourg is likely to arise from increased flood risk rather than a loss of soil fertility.

2.3.4 Decline in soil biodiversity

Soil biodiversity

Biodiversity is defined in the Convention on Biological Diversity[37] as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”. Decline in soil biodiversity is the reduction of the forms of life living in soils, both in terms of their abundance and diversity. Soil is living system and soil biodiversity decline threatens its functionality, resilience to challenges and capacity to support services. Therefore, soil

[36] JRC, 2008. Environmental assessment of soil for monitoring – Volume I: Indicators and criteria. JRC scientific and Technical reports. 358 p
https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/environmental-assessment-soil-monitoring-volume-i-indicators-criteria

[37] Convention on Biological Diversity, website visited in 2021. Convention text – Article 2: Use of Terms
https://www.cbd.int/convention/articles/?a=cbd-02

biodiversity is fundamentally important to soil health and the capacity of soils to support the terrestrial environment.

The soil biome is one part of the overall soil-plant-water-air system and is intimately connected to the above ground biota and therefore soil biodiversity is affected by land use and management. Key factors for conserving soil biodiversity are the supply of carbon as an energy substrate and maintenance of the soil pore structure, which forms the habitat for the soil biota. A continuing supply of carbon in plant litter and root residues is essential for the health of microbes and meso- and macrofauna. Higher trophic levels graze and predate those below them with microbes at the base. Moreover, microbes convert some fresh organic material to less tractable forms of SOM that provide longer-term energy reserves that contribute to resilience. Therefore, maintaining inputs to and levels of SOM is important to conserving soil biodiversity and these tend to decline where land is used for intensive arable production. In addition, tillage disrupts soil aggregates and the soil habitat, compromising its functionality. In summary, soil biodiversity underpins the natural functioning of soil and sustainable land use requires that land use and management provide favourable conditions for conserving it. Such conditions are best supported by land management that promotes higher and uninterrupted carbon inputs, such as grassland and arable cropping with crop rotations that include grass breaks and cover crops, and also by minimising tillage and pesticide uses.

Soil biodiversity in Luxembourg

Declining biodiversity is a serious problem across Europe. Numerous above ground and aquatic species have become less abundant or locally extinct. Contributing factors are a loss of structural diversity in the landscape, extension of the built environment, agricultural intensification and environmental pollution (for example chemical pollutants, noise, artificial light, spreading of exotic species). In Luxembourg, several projects have studied biological parameters in soils, such as earthworm populations[38], earthworms' impacts on hydrological processes[39] and indicators of microbial activity. However, sufficient data on changes in soil biodiversity in Luxembourg are not available to directly assess its current status and trajectory over time.

2.3.5 Soil contamination

Soil contamination and its effects on services from soil

A wide range of contaminants are found in soil due to historic and continuing human activities. These include contaminants that are hazardous to humans, animals, plants and to the soil system itself. Sometimes this contamination is confined to a local site (local soil contamination) and arises from previous or ongoing site-specific activities. This local soil contamination is a source of risk to connected environmental compartments such as water resources and to the future use of the site when the risk from the contamination to humans and other receptors is unacceptable (meaning that there is a significant possibility of significant harm). Another kind of soil contamination is present over large

[38] AEV, 2006. Bodenmonitoring Luxembourg : Sachstandsbericht nach Abschluss der ersten Beprobungskampagne. 287 p

[39] CAOS, website visited in 2021. Catchments As Organized Systems project https://www.caos-project.de/

areas (diffuse soil contamination) and arises when soil becomes a sink for contaminants in atmospheric deposition, polluted surface and ground waters and land spreading of wastes.

Local soil pollution is well documented and studied across the European Union. Contaminated or potentially contaminated sites in Luxembourg are identified in the Contaminated Sites and Suspected Areas Register (Cadastre des anciennes décharges et des sites contaminés, CASIPO). The register records sites where historical activities indicate the possible presence of land or groundwater contamination[40]. Identifying and managing land with local soil contamination is a major responsibility of regulators and landowners. However, essentially, it is a curative management of potentially or polluted sites and a management of polluted excavated soil (albeit historically deposited) rather than soil protection *per se*. Therefore, the focus of this commentary is on diffuse soil contamination.

Diffuse soil contamination that is toxic to the soil biota presents a direct risk to the functionality of the soil system and therefore to the services which it supports. Examples are certain metals and some insecticides and veterinary medicines. The level of contaminants influences the level of risk to the soil system. Generally, this impact is not observed easily unless levels are very high and the risk becomes acute, while chronic or more subtle effects on the soil system are more obscure. In addition, there is limited knowledge about the specific mechanisms by which contamination impacts soil functionality by compromising the soil biota. However, under the precautionary principle, it is essential to keep new contamination of the soil system to a minimum and where possible to prevent it altogether.

Diffuse soil contamination is a source for contamination of connected environmental compartments: it increases the risks of water pollution and transfer of toxic substances to agricultural produce and the human food chain and it can affect above ground biodiversity. Therefore, it is important to identify and manage existing diffuse soil contamination and, especially, to prevent further inputs of contaminants to soil.

Diffuse soil contamination in Luxembourg

There are many potential historic and current sources of diffuse soil pollution in Luxembourg. These include atmospheric deposition arising from long-range and local stationary and mobile sources; historic land spreading of industrial wastes (e.g. Thomas slag) and sewage sludge; deposition to soil of polluted suspended sediments during flood events and agricultural pesticide use. Consistent with observations in neighbouring countries with similar economic backgrounds, it is likely that levels are enhanced above natural background in some soils for cadmium, copper, lead and other metals, as well as pesticides and organic pollutants, for example polycyclic aromatic hydrocarbons (PAHs).

Between 2002 and 2006, a national systematic sampling of soils was done to collect information on the level of background pollutant concentrations (concentration de fond). Sixty sites were studied that were located within a 6 km square grid covering the whole country. For each site, three or four sub-sites were sampled to collect information on soils within local land-uses (grassland, arable land and forest, plus vineyard for some sites). A soil description was made for each site and samples were

[40] AEV, 2006. Das Altlasten und Verdachtsflächenkataster Luxemburg. 6 p
https://environnement.public.lu/fr/publications/dechets/altlastenkataster.html

analysed for heavy metals, PAHs, and Polychlorinated Biphenyls (PCBs). In 2007, an additional sampling campaign was made to collect more information on background concentrations in the more urbanized south-western area of the country. In total, more than 900 samples were analysed.

In 2006, the available data were analysed and the results published in a book: Bodenmonitoring[41]. Based on the 2006 data, it was found that certain geological layers and human activities have enhanced background levels of heavy metals, especially in the south of the country. However, this publication did not take into account the data collected in 2007. For this reason, a new data analysis has been undertaken in 2020.

2.3.6 Soil acidification

<u>Soil acidification and its effects on services from soil</u>

Soil acidification is a natural process that is promoted by acidic plant root exudates, by precipitation and consequent hydrolysis of minerals in soil parent material and by organic matter decomposition and its microbial transformation to acidic compounds. In temperate and wetter climates, soil weathering and leaching removes basic cations (Ca, Mg, K, Na) from the topsoil leading to its acidification. This process can be slowed or even offset by the buffering effect of alkaline parent materials rich in Ca or Mg carbonates. Thus under natural conditions, soil acidification occurs until an equilibrium is reached between inputs of acidity and its neutralisation.

Soil acidification can be enhanced by anthropogenic activities, such as the use of ammonium-containing fertilizers, oxidation of mining spoils and the deposition of acidic substances derived from airborne emissions of SO_2 and NO_x from fossil fuel combustion. Certain types of land use such as coniferous plantations can also enhance soil acidification.

The availability of most plant nutrients decreases below pH_{water} 5.5 and can cause micronutrient deficiencies in crops. Moreover, in highly acidic soils (pH_{water} < 5.0) the solubility of some elements including toxic metals and Al is increased. This can lead to the transfer of toxic metals in to the food chain and to contamination of aquifers used for water supplies, whilst dissolved Al is toxic to most of crops and limits agricultural productivity[42].

<u>Soil acidification in Luxembourg</u>

Three different soil types can be distinguished in Luxembourg formed from different parent materials: more alkaline soils develop on carbonate materials, neutral soils develop on less alkaline parent materials and acidic soils form on acidic parent materials.

In the Gutland region, the parent material generally contains carbonates, encouraging the formation of alkaline soils whose acidity is low due to the buffering action of carbonates (pH_{water} > 7); however,

---

[41] AEV, 2006. Bodenmonitoring Luxembourg : Sachstandsbericht nach Abschluss der ersten Beprobungskampagne. 287 p

[42] Pierzynski and Brajendra, 2017. Threats to soils: Global trends and perspectives. UN: convention to combat desertification. 28 p

natural weathering processes in these soils can still leach basic cations from surface to lower horizons causing acidification of topsoil horizons. This phenomena is particularly marked in soils developed on sandstones (Podzol). In the Oesling region, the soil forming parent material is generally less basic (for example schists, shales and quartzite) and the soils are more acidic.

While soil acidification occurs in agricultural soils, for example due to the use of ammonium-containing fertilizers, their acidity is regularly assessed and corrected by liming.

Luxembourg is in an industrial region of Europe which suffered from the effect of acid rain up to the 1990s, caused by SO_2 and NO_x atmospheric emissions from fossil fuel combustion. SO_2 emissions had been reduced drastically by the end of 1990s following regulation at global and European scales[43], but the consequences of past emissions for soil acidification may still be significant locally and can be accentuated under forest production. Another factor is that, after the 1940's, there was widespread planting of coniferous trees that grow fastest on shallow, sloping and north-facing soils; these trees may encourage soil acidification where soils are naturally already acidic, such as in the Oesling region, with consequent risks of Al toxicity and/or heavy metal leaching.

2.3.7 Soil sealing

Soil sealing and its effects on services from soil

Soil sealing ("*imperméabilisation des sols*") is the permanent covering of land and soil with an impermeable artificial material (for example asphalt or concrete). It is distinct from 'land take' ("*consommation d'espace*")[44] which is the land area taken into the built environment, especially through the construction of buildings and roads at the expense of stocks of agricultural, forest or other semi-natural land. The area of land take has both sealed and non-sealed soil surfaces and includes urban greenspaces in gardens, parks, road verges, sports and leisure facilities, etc. Sealed surfaces are found to varying degrees in all the built environment land cover categories including residential, commercial (offices, factories, etc.), infrastructure (roads, railways, parking areas, roundabouts, etc.) and industrial (construction sites, quarries, mines, landfills, etc.).

Soil sealing permanently degrades the functionality of the soil system by disconnecting it from above ground systems. Therefore, it limits the capacity of soil resources to support services. Additionally, construction normally removes topsoil and adds extraneous materials (bricks, debris from construction, etc.) to soil, causing further degradation.

Generally, human settlements have evolved where local food production has been favoured by access to fertile soils. Moreover, flatter land is optimal for the built environment and transport infrastructure, but it is also often more fertile. Consequently, land take and soil sealing caused by extension of existing settlements disproportionally affects more fertile agricultural soils.

[43] Grennfelt et al., 2019. Acid rain and air pollution: 50 years of progress in environmental science and policy. The royal Swedish academy of sciences. 16 p https://doi.org/10.1007/s13280-019-01244-4
[44] EEA, 2019. The European environment – state and outlook 2020: knowledge for transition to sustainable Europe (p 117) 499 p https://www.eea.europa.eu/publications/soer-2020

Soil sealing compromises above ground biodiversity through habitat loss and is often accompanied by changes in species diversity, including the introduction of exotic species alongside a loss of native species. It limits surface infiltration of water, limiting water regulation by soil, which increases the volume and intensity of surface water runoff and reduces groundwater recharge. SOC dynamics are altered by soil sealing because new organic matter addition from above ground vegetation is confined to inputs from roots that extend from non-sealed or partially sealed areas. Soil sealing also has a negative impact on the local climate; sealed surfaces absorb heat and increase surface and ambient air temperatures (the 'urban heat island effect'). Finally, the cultural service of soil is disrupted, because buried artefacts are damaged directly as a result of mechanical disturbance and indirectly by altered soil hydrology.

Soil sealing in Luxembourg

Luxembourg's population of 626,108 inhabitants (as of 31 December 2019)[45] is distributed very unevenly across the country. While around 60 % of the population live in the two cantons of Luxembourg and Esch-sur-Alzette, the three northernmost cantons of Clervaux, Wiltz and Vianden have only 7 % of all inhabitants while stretching over more than 25% of the country's territory (see the location of the cantons in Figure 3 below).[46] Continuing economic growth is driving population growth, which grew by around 44 % between 2000 and 2020, corresponding to an average of 2.2 % per annum, one of fastest rates in the European Union[47]. Therefore, it is not surprising that the rate of land take for the built environment and infrastructure is high. The European Environment Agency (EEA)[48] reports that the rate of land take in Luxembourg between 2000 and 2018 was the fourth highest out of 39 countries, at 313 m^2/km^2, with an even higher rate of 384 m^2/km^2 during the last 6 years. Ministry of space planning (Ministère de l'aménagment du territoire) points out that land take was on average 0.44 ha/d between 2007 and 2015, and it increased over the period 2015-2018 to reach an average of 0.53 ha/d[49].

On the other hand, land re-cultivation by the conversion of urban areas into semi-natural land, was also one of the highest in Europe with a yearly rate of 82 m^2/km^2 between 2000 and 2018 and this even exceeded 90 m^2/km^2 for the period 2012-2018. Currently, 4.24 % (equivalent to 110 km^2, reference year 2015) of the country's land area is sealed with an annual increase of 0.56 % between 2006 and 2015[50].

---

[45] Le portail des statistiques – Grand-Duché de Luxembourg, website visited in 2021. Territoire et environnement, Population et emploi, Etat de la population, population totale 1821-2020 https://statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12856&IF_Language=fra&MainTheme=2&FldrName=1

[46] Le portail des statistiques – Grand-Duché de Luxembourg, website visited in 2021. Territoire et environnement, Population et emploi, Etat de la population, population par canton et commune 1821-2021 https://statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12861&IF_Language=fra&MainTheme=2&FldrName=1

[47] Eurostat, website visited in 2021. Population and population change statistics https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_and_population_change_statistics

[48] EEA, website visited in 2021. Land take in Europe https://www.eea.europa.eu/data-and-maps/indicators/land-take-3/assessment

[49] Oral communication, ministry of space planning, 23.03.2021

[50] EEA, website visited in 2021. Imperviousness in Europe

A preference to live away from urban centres, rising prices in urban centres, demand for larger dwellings and rapid growth of the highway network all drive high rates of land take. However, over the last two decades, the area covered by artificial surfaces per capita in Luxembourg has decreased despite rapid population growth. While 620 m² per inhabitant were covered by artificial surfaces in 1999 (based on the national reference layer Occupation Biophysique du Sol, OBS), this number decreased to 536 m² per inhabitant in 2018 (derived from the most recent national Land Use 2018 data).[51]

https://www.eea.europa.eu/data-and-maps/dashboards/imperviousness-in-europe

[51] In 1999, artificial surfaces covered almost 273 km² of Luxembourg with a total population of 439539 inhabitants, whereas in 2018, 323 km² were artificial with a total population of 602005 inhabitants. Reference land use/land cover data can be accessed on the Luxemburgish Geoportail in the general catalog, theme “Land surface” (http://www.geoportail.lu).

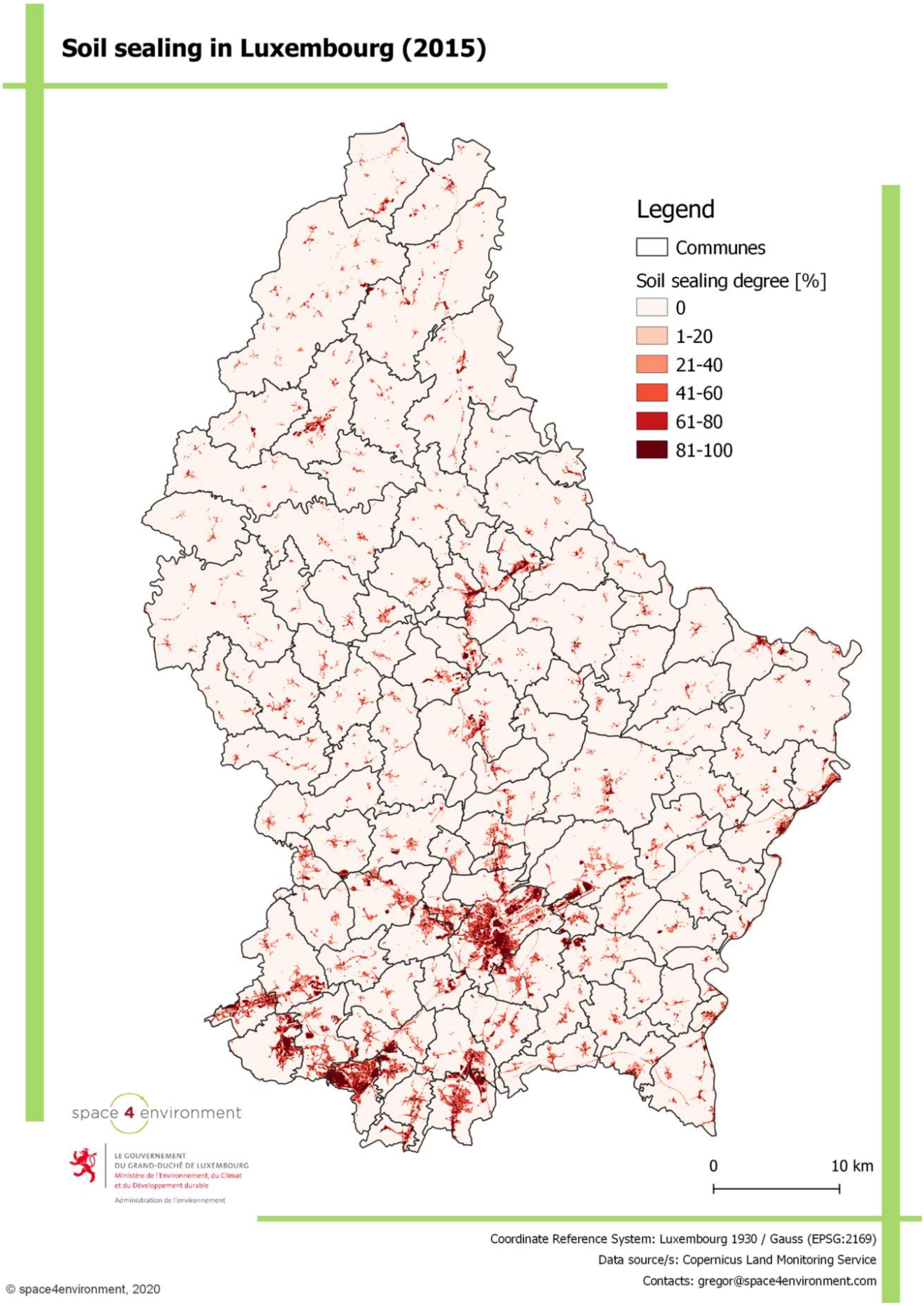

Figure 3: Map of sealed surfaces in 2015 (source: HRL Imperviousness[52])

[52] Copernicus, website visited in 2021. Imperviousness
https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness

3 THE LEGAL FRAMEWORK FOR SOIL PROTECTION

3.1 Global policies and actions

Agenda 2030 and the Sustainable Development Goals (SDGs)

A UN General Assembly was held in 2015 under the heading "Transforming our world: the 2030 Agenda for Sustainable Development". The member states agreed 17 goals for sustainable development[53], integrating an economic, social and ecological vision. These "Sustainable Development Goals" (SDGs) are a framework for developing and implementing specific measures and actions.

Figure 4: The Sustainable Development Goals

Each SDG is accompanied by specific objectives. Several SDGs are particularly relevant to soil and its protection: three of the goals (SDG 2, 3 and especially 15) are relevant directly and four goals (SDG 6, 11, 13 and 14) are linked indirectly to land and soil management (see Table 1). SDGs 8 and 12 are also relevant indirectly to a lesser extent.

[53] UN, website visited in 2021. Take action for the sustainable development goals https://www.un.org/sustainabledevelopment/sustainable-development-goals/

SDG	Main aim and sub-categories, complemented by relevant Eurostat SDG indicators (see footnote 61)
Goal 2	**End hunger, achieve food security and improved nutrition and promote sustainable agriculture** **2.3** – By 2030, double the agricultural productivity […] **2.4** – By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality. - Eurostat indicator sdg_02_40: Area under organic farming - Eurostat indicator sdg_02_51: Harmonized risk indicator for pesticides (HRI1), by groups of active substances (source: DG SANTE)
Goal 3	**Ensure healthy lives and promote well-being for all at all ages** **3.9** – By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
Goal 6	**Ensure availability and sustainable management of water and sanitation for all** **6.1** – By 2030, achieve universal and equitable access to safe and affordable drinking water for all **6.3** – By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and sustainability increasing recycling and safe reuse globally - Eurostat indicator sdg_06_40: Nitrate in groundwater (source: EEA) - Eurostat indicator sdg_06_50: Phosphate in rivers (source: EEA) **6.6** – By 2020, protect and restore water-related eco-systems, including mountains, forests, wetlands, rivers, aquifers and lakes - Eurostat indicator sdg_06_60: Water exploitation index, plus (WEI+) (source: EEA)
Goal 11	**Make cities and human settlements inclusive, safe, resilient and sustainable** **11.1** – By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums **11.3** – By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries - Eurostat indicator sdg_11_31: Settlement area per capita **11.7** – By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities
Goal 13	**Take urgent action to combat climate change and its impacts** **13.1** – Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries - Eurostat indicator sdg_13_10: Greenhouse gas emissions, including LULUCF (source: EEA)

Goal 14	**Conserve and sustainably use the oceans, seas and marine resources for sustainable development** **14.1** – By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution
Goal 15	**Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss** **15.1** – By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements - Eurostat indicator sdg_15_10: Share of forest area - Eurostat indicator sdg_15_20: Surface of terrestrial sites designated under Natura 2000 (source: DG ENV, EEA) **15.2** – By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally **15.3** – By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world - Eurostat indicator sdg_15_41: Soil sealing index (source: EEA) **15.5** – Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species - Eurostat indicator sdg_15_50: Estimated soil erosion by water - area affected by severe erosion rate (source: JRC)

Table 1: Soil-related SDGs

Target 15.3 is probably the target most directly related to soil protection. It aims to combat desertification, restore degraded land and soils, […] and to strive to achieve a land degradation-neutral world. The UN Rio+20 Summit outcome document 'The future we want'[54] highlighted soil degradation as part of land degradation and called for a land degradation-neutral world in the context of sustainable development. The EU also subscribes to this goal which is recognised in the EU's' Seventh Environment Action Programme to 2020 (7th EAP) priority objective 1 on protecting, conserving and enhancing the EU's natural capital[55]. As previously mentioned, the SDGs, which the EU strives to implement through relevant policies (see next paragraph), provide the most recent high-level policy

[54] UN, 2012. Resolution: The future we want. 53 p
http://sustainabledevelopment.un.org/futurewewant.html
[55] European Parliament, 2013. Decision 1386/2013: General Union Environment Action Programme to 2020 "Living well, within the limits of our planet". 30 p
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013D1386

targets supporting land-degradation neutrality, in particular SDG target 15.3[56]. Sustaining ecosystem services is central to the concept of land-degradation neutrality.[57]

International initiatives have been developed to help achieve the SDGs, including the Land Degradation Neutrality (LDN) fund[58]. This was launched in 2017 at the initiative of several public institutions, including the Government of Luxembourg, as well as private companies. The LND fund combines resources from the public, private and philanthropic sectors and is dedicated to financially supporting worldwide private projects on land rehabilitation and sustainable land management.

European Union soil policy supporting the SDGs

The EU is committed to implementing the 2030 Agenda for Sustainable Development and the SDGs, both within the member states and through development cooperation with partner countries. The Agenda reflects many of the EU's priorities for sustainable development[59] and is identified as an opportunity to anchor the EU’s strategic direction strongly in the global effort to build a sustainable future. The SDGs are already being pursued through many of the EU's policies and integrated in to all the EC's priorities.

A full overview of how European policies and actions contribute to the SDGs is presented in a Staff Working Document that was published in parallel to the Communication “Next steps for a sustainable European future”[60]. This summarises the most relevant actions adopted by the EU for each of the 17 SDGs. The European Statistical Office (Eurostat) has provided an overview of the selected indicators, their development over time and key findings related to the SDGs (see Table 1)[61].

The European Environment Agency (EEA)[62] has noted that “… many global policy frameworks, including the SDGs, 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

[56] UN, 2015. Resolution: Transforming our world – The 2030 agenda for sustainable development. 35 p http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E;

[57] ETC/ULS, 2019. Report: Integrated accounting of land cover changes and soil functions – an approach for integrated accounting. 112 p https://www.eionet.europa.eu/etcs/etc-uls/products/etc-uls-report-02-2018-integrated-accounting-of-land-cover-changes-and-soil-functions

[58] UN – Convention to combat desertification, website visited in 2021. The Land degradation neutrality fund. https://www.unccd.int/actions/impact-investment-fund-land-degradation-neutrality

[59] EC, website visited in 2021. EU holistic approach to sustainable development. https://ec.europa.eu/info/strategy/international-strategies/sustainable-development-goals/eu-holistic-approach-sustainable-development_en

[60] UC, 2016. Communication: Next steps for a sustainable European future. 19 p https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2016%3A739%3AFIN

[61] Eurostat, website visited in 2021. Sustainable development goals – Overview https://ec.europa.eu/eurostat/web/sdi/overview

[62] EEA, website visited in 2021. Soil and United Nation sustainable development goals. https://www.eea.europa.eu/signals/signals-2019-content-list/infographics/soil-and-united-nations-sustainable/view

particular, European and global policies fall short of setting targets and commitments — let alone binding ones”.

Paris Agreement

At the 21st Conference Of Parties (COP 21) of the United Nations Framework Convention on Climate Change (UNFCCC)[63] in December 2015, parties to the UNFCCC reached a landmark agreement to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future.[64] The Paris Agreement’s central aim is to strengthen the global response to the threat of climate change by keeping the global temperature rise this century to well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. Additionally, the agreement aims to increase the ability of countries to deal with the impacts of climate change, and to make the flows of finance between countries and in the global economy consistent with a low GHG emissions and climate-resilient pathway. Implementation of the Agreement is based on actions of the signatory countries and requires countries to identify “nationally determined contributions” (NDCs).

Important elements of the Paris Agreement are the conservation and enhancement of greenhouse gas sinks and reservoirs as well as averting, minimizing and addressing losses and damage linked to climate change. As soils are one of the most important sinks and reservoirs (see 2.1 above), their protection in Luxembourg via the planned national soil protection law and the associated soil protection plan can make an important contribution towards Luxembourg meeting its commitments under the Agreement[65]. A specific and important initiative developed under the Paris Agreement at the instigation of France is the 4 per 1000 international initiative[66]. By attempting to federate all voluntary stakeholders of the public and private sectors (national governments, local and regional governments, companies, trade organisations, NGOs, research facilities, etc.) under the framework of the Lima-Paris Action Plan (LPAP), the initiative aims to reach the main objective of the Paris Agreement. Itis based on the hypothesis that an annual growth rate of 0.4 % in the soil carbon stocks, or 4‰ per year, in the first 30-40 cm of soil, would significantly reduce the CO_2 concentration in the atmosphere related to human activities. To reach this goal a “4 per 1000” Initiative Strategic Plan 2.0 has been approved in 2020[67].

IPCC “Special Report on Climate Change and Land”

The Intergovernmental Panel on Climate Change (IPCC) is the UN body for assessing the science related to climate change, its implications and potential future risks, and for identifying adaptation

[63] UN – Climate change, website visited in 2021. Homepage https://unfccc.int/
[64] UN – Climate change, website visited in 2021. The Paris agreement https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement
[65] UN – Climate change, website visited in 2021. Luxembourg https://unfccc.int/node/61104
[66] 4per1000 initiative, website visited in 2021. What is the “4 per 1000” initiative? https://www.4p1000.org/
[67] 4per1000 initiative, 2020. Strategic Plan. 9 p https://www.4p1000.org/sites/default/files/francais/strategic_plan.pdf

and mitigation options to support policy- and decision-making. In its 2019 Special Report "Climate Change and Land, an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems" (hereafter abbreviated as SRCCL)[68], the IPCC took a comprehensive look at the whole land-climate system and the relation between human- and climate change-induced pressures on land.

The report highlights that, globally, the current geographic spread of the use of land, the large appropriation of several of the ecosystem services land provides and loss of biodiversity are unprecedented in human history. At the same time, the global mean temperature has increased (+0.87 °C) and this has had observable impacts on the land system. Warmer temperatures and changing precipitation patterns have altered the timing and length of growing seasons, causing regional crop yield reductions, reduced freshwater availability and putting biodiversity under more stress. In addition, there is strong evidence that climate change can aggravate land degradation processes, for instance by increasing the likelihood, intensity and duration of rainfall, which can lead to increased soil erosion. Moreover, land is both a source and a sink of carbon. Future net increases in carbon emissions from soils due to the changing climate are projected to be partially offset by increased sequestration due to organic fertilisation and longer growing seasons. The balance between these different processes is a key source of uncertainty for determining the future of the land carbon sink.

At the same time, projected increases in population and income, combined with changes in consumption patterns, result in an increased demand for food, feed, and water by 2050. These socio-economic changes, combined with land management practices, also have repercussions on land use change, food security, terrestrial GHG emissions, and carbon sequestration potential. Urban expansion will likely lead to the conversion of cropland causing losses in food production which may jeopardise parts of the food system.

In terms of adapting to and mitigating climate change, the SRCCL presents evidence that beneficial land-related response options and actions include, for instance, sustainable food production, soil organic carbon management, and ecosystem conservation and land restoration. While some response options show instantaneous effects (e.g. conservation of high-carbon ecosystems such as peatlands), others take decades to deliver measurable results (e.g. restoration of high-carbon ecosystems, and the reclamation of degraded soils). However, not all land-based options that are beneficial for carbon sequestration in soil or vegetation sequester carbon indefinitely, and accumulated carbon in vegetation and soils is at risk from future loss (or sink reversal) caused by disturbances such as flood, drought, fire, pest outbreaks, climate change or future poor management.

Several options for land management, for example to increase soil organic carbon content, do not require any land use change and do not create demand for more land conversion. Other response options, such as increased food productivity or dietary choices (e.g. by reducing meat consumption), can even reduce the demand for land conversion. Overall, response options that reduce the competition for land are possible and are applicable at different scales. Achieving land degradation neutrality depends on the integration of multiple responses across local, regional and national scales

[68] IPCC, website visited in 2021. Homepage https://www.ipcc.ch/srccl/

and across multiple sectors including agriculture, pasture, forest and water. Land degradation in agriculture systems can be addressed through sustainable land management, using options that reduce the vulnerability to soil erosion and nutrient loss, such as growing green manure crops and cover crops, crop residue retention, reduced/zero tillage, and maintenance of ground cover through improved grazing management.

Reducing and reversing land degradation, at all scales, can support several Sustainable Development Goals (SDGs) with several co-benefits for adaptation and mitigation. Appropriate design of mutually supportive land and climate policies, institutions and governance systems at all scales can contribute to land-related adaptation and mitigation, complemented by measures such as land use zoning, spatial planning, integrated landscape planning, regulations, incentives, and voluntary or persuasive instruments.

The Global Soil Partnership

The Food and Agriculture Organisation of the United Nations (FAO) initiated activities in 2009 to establish a Global Soil Partnership (GSP)[69]. Subsequently, the GSP was formalised with a secretariat and an International Inter-governmental Technical Panel. The GSP is a voluntary initiative and does not create any legally binding rights or obligations between or among its members. Nonetheless, it provides a framework for promoting and supporting soil protection at global, regional and national levels. The GSP has developed a set of "Voluntary Guidelines for Sustainable Soil Management" aimed at informing strategy and decision-making. The Guidelines set out objectives and key actions to minimize soil erosion; enhance soil organic matter content; foster soil nutrient balance and cycles; prevent and minimize soil contamination; prevent and minimize soil acidification; preserve and enhance soil biodiversity; minimize soil sealing; prevent and mitigate soil compaction; improve soil water management. A summary of the core actions identified in the Guidelines is as follows.

- Addressing soil protection within strengthened agricultural and environmental policies, to realise multiple benefits
- Encouraging investment in soil protection by providing positive incentives
- Ensuring that rights and duties of landowners and tenants encourage soil protection
- Ensuring an effective evidence base for decision-making, via research
- Restoring / rehabilitating soil resources alongside soil protection
- Developing capacities for soil protection by education and professional development
- Providing advice and training to land users on soil management
- Developing and maintaining data and information on soil resources by establishing and strengthening national soil monitoring and information systems.

[69] FAO, website visited in 2021. Global soil partnership http://www.fao.org/global-soil-partnership/en/

3.2 European policies and actions

European Green Deal

At the end of 2019, the newly appointed EC under President Ursula von der Leyen presented the European Green Deal (EGD) as its plan to make the EU's economy sustainable and enable the EU to become climate neutral in 2050 (see also the introduction of this report)[70]. This proposal is underpinned by a vision for a greener Europe: "Climate change, biodiversity, food security, deforestation and land degradation go together. We need to change the way we produce, consume and trade. Preserving and restoring our ecosystem needs to guide all of our work"[71][72].

The EGD comes with an action plan to boost the efficient use of resources by moving to a clean, circular economy and to restore biodiversity and cut pollution. The first cornerstones for the implementation of the EGD are the proposal for an EU Climate Law in March 2020, the adoption and publication of the EU Biodiversity Strategy 2030[73] and the Farm to Fork Strategy[74] in May 2020:

- The EU Climate Law focuses on maintaining and increasing natural greenhouse gas sinks of forest, soil, agricultural land and wetlands so that those greenhouse gases which cannot be avoided at source can be removed from the atmosphere.[75]
- The Biodiversity Strategy 2030 focuses on protection ("improving and widening our network of protected areas") and restoration ("developing an ambitious EU Nature Restoration Plan"); protection of primary and old-growth forests and other carbon-rich ecosystems, such as peatlands, grasslands or wetlands; addressing land take and restoring soil ecosystems including by revising updating the Soil Thematic Strategy in 2021, implementing the Zero Pollution Action Plan for Air, Water and Soil (also to be adopted in 2021) and focussing on soil sealing and the rehabilitation of contaminated brownfields with the upcoming Strategy for a Sustainable Built Environment.
- The Farm to Fork Strategy focuses on integrated pest management, integrated nutrient management action planning, "ensuring that the food chain, covering food production, transport, distribution, marketing and consumption, has a neutral or positive environmental impact, preserving and restoring the land, freshwater and sea-based resources on which the food system depends; helping to mitigate climate change and adapting to its impacts;

[70] EC, website visited in 2021. A European Green Deal – striving to be the first climate-neutral continent https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
[71] Von der Leyen, 2019. Political guidelines for the next European commission 2019-2024. 24 p https://ec.europa.eu/commission/sites/beta-political/files/political-guidelines-next-commission_en.pdf
[72] Montanarella and Panagos, 2021. The relevance of sustainable soil management within the European Green Deal. Land Use Policy. 6 p https://www.sciencedirect.com/science/article/pii/S0264837720304257#bib0245
[73] EC, website visited in 2021. Biodiversity strategy for 2030 https://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm
[74] EC, website visited in 2021. Farm to fork strategy https://ec.europa.eu/food/farm2fork_en
[75] EC, 2020. Regulation: The framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law). 46 p https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020PC0080&from=EN

protecting land, soil, water, air, plant and animal health and welfare; and reversing the loss of biodiversity".

More strategies, regulations and directives are anticipated in the near future including a Forest Strategy and an updated Common Agricultural Policy (CAP) to make agriculture more sustainable ("Greening the CAP").[76]

The need for protection and restoration are reinforced further in the EU's proposal for the 8th Environmental Action Programme (EAP) which has as a thematic priority objective of "protecting, preserving and restoring biodiversity and enhancing natural capital, notably air, water, soil, and forest, freshwater, wetland and marine ecosystems".[77]

The Thematic Strategy for Soil Protection of the European Union

The Communication from the EC proposing the Thematic Strategy for Soil Protection which was adopted in 2006[78] included a proposal for a Framework Directive (a European law) with an accompanying Impact Assessment. The Communication explained why further action was needed to ensure a high level of soil protection, set overall objectives and outlined the kinds of measures required. However, only the overall goal and objectives were adopted by the Council of Ministers. Moreover, the EU strategy is not binding on member states, who are free to only introduce those national soil protection measures that they think are appropriate to their territories.

The overall objective of the 2006 Strategy is protection and sustainable use of soil, based on the following guiding principles:

- Preventing further soil degradation and preserving its functions:
    - When soil is used and its functions are exploited, action has to be taken on soil use and management patterns, and
    - When soil acts as a sink/receptor of the effects of human activities or environmental phenomena, action has to be taken at source.
- Restoring degraded soils to a level of functionality consistent at least with current and intended use, thus also considering the cost implications of the restoration of soil.

The Commission published a policy report in 2012 on its progress with implementing the 2006 Strategy and ongoing activities[79]. This report provides an overview of the actions undertaken by the Commission to implement the four pillars of the Strategy, namely awareness raising, research,

[76] EC, 2019. Communication: Annex of the European Green Deal https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1596443911913&uri=CELEX:52019DC0640#document2
[77] EC, 2020. Decision: General Union Environment Action Programme to 2030. 35 p https://ec.europa.eu/environment/pdf/8EAP/2020/10/8EAP-draft.pdf
[78] EC, 2002. Communication: Towards a thematic strategy for soil protection. 35 p https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52002DC0179
[79] EC, 2012. Report: The implementation of the soil thematic strategy and ongoing activities. 15 p https://ec.europa.eu/environment/soil/three_en.htm

integration, and legislation. It presents soil degradation trends in Europe and globally, as well as future challenges to ensure soil protection.

Most recently in November 2020, the EC opened a consultation on a Roadmap towards drafting a new soil strategy that it anticipates publishing as a Communication in 2021[80] as was announced in the Biodiversity Strategy 2030. The EC intends that the new soil strategy will consolidate, complement and steer action in the different policy areas that affect and depend on soil (such as pollution prevention, agriculture, research), guiding the implementation of sustainable soil and land management practices via horizontal measures. This is one element of a response to the special report of the European Court of Auditors (ECA) on "Combatting desertification in the EU" which concludes that "while desertification and land degradation are current and growing threats in the EU, the Commission does not have a clear picture of these challenges, and the steps taken to combat desertification lack coherence."[81] The report recommends to the European Commission to "better understanding land degradation and desertification in the EU; assessing the need to enhance the EU legal framework for soil; and stepping up efforts towards delivering the commitment made by the EU and the Member States to achieve land degradation neutrality in the EU by 2030".

The consultation background for the EC's Roadmap - "New Soil Strategy – healthy soil for a healthy life" - sets out a rationale for a new strategy based on the current policy context and adverse trends in the degradation of soil resources. It proposes that the new strategy should provide an overarching framework and pathways for achieving the following objectives:

- Step up efforts to protect soil fertility and reduce soil erosion
- Increase soil organic matter and restore carbon-rich ecosystems
- Protect and enhance soil biodiversity
- Reduce the rate of land take, urban sprawl and sealing to achieve no net land take by 2050
- Progress in identifying and remediating contaminated sites and address diffuse contamination
- Address the growing threat of desertification Achieve land degradation neutrality by 2030

It outlines strategic actions to achieve these objectives as follows:

- Promoting the adoption of sustainable soil management practices
- Setting out actions to restore degraded soils and secure sufficient EU funding to this end
- Improving the monitoring of soil quality
- Adapting and improving the relevant EU policy framework in line with the European Green Deal objectives on climate neutrality, zero pollution, sustainable food systems and resilient ecosystems
- Developing knowledge and research
- Accelerating the transition towards sustainable soil management and the necessary behavioural change

---

[80] EC, website visited in 2021. Healthy soils – new EU soil strategy. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12634-New-EU-Soil-Strategy-healthy-soil-for-a-healthy-life

[81] European court of auditors, 2018. Special report: Combatting desertification in the EU – a growing threat in need of more action. 65 p
https://www.eca.europa.eu/Lists/ECADocuments/SR18_33/SR_DESERTIFICATION_EN.pdf

- Steering EU global action on soil under the Rio Conventions, EU external action and development cooperation.

The Common Agricultural Policy (CAP)

The first pillar of the current CAP includes requirements for good agricultural and environmental conditions (GAECs) linked to direct income support to owners and managers of agricultural land. The GAECs in the current CAP are designed to protect natural resources[82], including soil by

- preventing soil erosion by defining minimum soil cover and minimum land management practices (GAECs 4 and 5)
- maintaining soil organic matter and soil structure (GAEC 6).

Soil conservation may also be included in the current Rural Development Plans of member states under the second pillar that specifies and implements national agri-environment schemes.

The Commission has proposed nine objectives for the updated post-2020 CAP[83]. The most relevant to soil protection is an intention to adopt a "Higher ambition on environmental and climate action". Mandatory requirements under this objective are intended for:

- Preserving carbon-rich soils through protection of wetlands and peatlands
- Obligatory nutrient management tool to improve water quality, reduce ammonia and nitrous oxide levels
- Crop rotation instead of crop diversification.

Efficient soil management and protection are seen as a core activity to achieve this and other objectives of the new CAP.[84,85,86]

Under pillar one, the intended soil specific GAECs include protection of peatlands and wetlands, crop rotation (replacing crop diversification), minimum land management under tillage to reduce soil degradation, and soil cover. In addition, a compulsory GAEC requirement for all farmers would be use of the Farm Sustainability Tool (FaST) to develop nutrient management plans. This tool collates information such as satellite data, soil sampling and land parcel information to help farmers make informed and targeted decisions on nutrient requirements.

Under the second pillar, farmers can contribute further to environmental outcomes and be rewarded for going beyond mandatory requirements. Voluntary national eco-schemes will be developed to support and incentivise farmers to observe agricultural practices which are beneficial to the climate and the environment; these are likely to include practices targeted at soil protection. Examples of

---

[82] EC, website visited in 2021. Cross-compliance – linking income support to respect for European Union rules. https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/income-support/cross-compliance_en#gaec

[83] EC, website visited in 2021. The new common agricultural policy: 2023-27 https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/future-cap_en

[84] EC, website visited in 2021. Soil matters for our future. https://ec.europa.eu/info/news/soil-matters-our-future-2019-dec-05_en

[85] EC, 2018. CAP specific objectives – brief no 5 – efficient soil management. 16 p https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/cap-specific-objectives-brief-5-soil_en.pdf

[86] Montanarella and Panagos, 2021. The relevance of sustainable soil management within the European Green Deal. Land Use Policy. 6 p https://www.sciencedirect.com/science/article/pii/S0264837720304257#bib0245

beneficial soil farming practices that member states could include in their eco-schemes are enhanced management of permanent pastures, organic farming, afforestation and the creation of woodlands, agroecology and agroforestry and adoption of precision farming.

The Common Agricultural Policy (CAP) is a key instrument for achieving soil protection to contribute to the SDGs. The CAP has broad relevance to the SDGs but especially to SDG 2 (Zero Hunger) and SDG 15 (Life on Land).

Zero Pollution Action Plan

Pollution of air, water and soil is one of the five main drivers of biodiversity loss and is contributing significantly to the current species extinction. It comes at a high price for society and ecosystems, including as health-related costs (healthcare, lost workdays, lost productivity), reduced yields (in agriculture, fisheries and tourism), remediation costs (e.g. water treatment, soil decontamination, marine depollution) and loss of ecosystem services (e.g. pollination). To secure clean air, water and soil, healthy ecosystems and a healthy living environment for people, the EU needs to enhance measures to prevent, remedy, monitor and report on pollution. This means mainstreaming a zero pollution ambition into all policy developments and further decoupling economic growth from increased pollution. This requires the inter-linkages between environmental protection, sustainable development and people's well-being to be strengthened in line with UN efforts. The roadmap for the action plan has been published in October 2020, while adoption of the action plan is foreseen in the second quarter of 2021.

The Industrial Emissions Directive

The Industrial Emissions Directive (IED) (Directive 2010/75/EU [87]) is based on a Commission proposal recasting 7 previously existing directives (including in particular the Integrated Pollution Prevention Control Directive) following an extensive review of the policy[88]. The IED aims to achieve a high level of protection of human health and the environment taken as a whole by reducing harmful industrial emissions across the EU.

Permits can only be issued if certain environmental conditions are met with operators bearing full responsibility for preventing and remediating any pollution. Permitting ensures that the most appropriate pollution-prevention measures are used, and that waste is recycled or disposed of in the least polluting way possible. Prevention and control of soil pollution are included under the Directive. Baseline surveys of soil pollution are required prior to permits being issued and re-surveys and remediation of any additional pollution must be completed before permit holders are released from their obligations. This directive's first aim is to prevent local soil pollution from industrial activities, but it also helps to prevent diffuse pollution, including airborne emissions at production facilities.

[87] EC, 2010. Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control). 103 p https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32010L0075

[88] EC, website visited in 2021. The IPPC Directive – Revision of the IPPC Directive https://ec.europa.eu/environment/archives/air/stationary/ippc/ippc_revision.htm

The Environmental Liability Directive

The Environmental Liability Directive[89] sets up a framework based on the "polluter pays" principle to prevent and remedy environmental damage. Operators carrying out dangerous activities listed in Annex III of the Directive, including iron and steel production, fall under "strict liability", with no requirement to prove fault to establish liability provided a causal link between the activity and the damage is established. Soil is not specifically included in the relevant definitions but damage to soil is implicitly covered by land damage (defined as land contamination that harms human health) and water damage (this is defined as being adverse effects to water bodies within the scope of the Water Framework Directive, one cause of which is where polluted soil is the source of harm).

Extractive Industry Waste Directive

Under this Directive, specific guidance[90] is given on best available technology for the prevention or minimisation of soil pollution and for its remediation. However, the scope of this guidance does not cover unpolluted soils, meaning that for example it excludes guidance on the excavation, storage and re-instatement of unpolluted topsoil.

National Emission Ceilings Directive

The National Emission Ceilings Directive[91] (NECD) mainly aims to reduce emissions of certain atmospheric pollutants (SO_2, NO_x, non-methane VOC, NH_3 and fine particulate matter ($PM_{2,5}$)) from various sectors. It has to take into account local emission sources but also diffuses sources, some of which are directly linked to soil management. In order to assess the effectiveness of the national emission reduction commitments, Member States must ensure the monitoring of negative impacts of air pollution upon ecosystems, including natural and semi-natural habitats and forest ecosystems, based on a network of monitoring sites.

Land Use, Land Use Change and Forestry Regulation

This regulation[92] sets out the commitments of Member States for the Land Use, Land Use Change and Forestry (LULUCF) sector that contribute to meeting the greenhouse gas emission reduction target of

[89] Lawrence, 2006. Environmental liability directive – a short overview. 6 p https://ec.europa.eu/environment/legal/liability/pdf/Summary%20ELD.pdf

[90] EC, website visited in 2021. Directive 2006/21/EC: management of waste from extractive industries and amending Directive 2004/35/EC. 29 p https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02006L0021-20090807

[91] EC, 2016. Directive 2016/2284: the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC. 31 p https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.344.01.0001.01.ENG

[92] EC, 2018. Regulation 2018/841: the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation 525/2013 and Decision 529/2013/EU. 25 p https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.156.01.0001.01.ENG

the EU. This regulation enables to account the balance between emissions and removals of three gases (CO_2, CH_4 and N_2O) for each land uses of the sector and for six different C pools, including soil organic carbon. Through this regulation, the stakes related to soils are first to be able to maintain existing soil organic carbon stocks but also to enhance them wherever it is possible over time.

Directives that indirectly address soil protection

Many Directives indirectly affect soil protection by aiming to reduce pollution that can be addressed at least partly by improved soil management. Among these Directives are those concerned with Strategic Environmental Assessment, Environmental Impact Assessment, Landfill, Waste, Water and Groundwater, Priority Substances, Nitrates, Sewage Sludge, Floods, Dangerous Substances, Ambient Air Quality and Habitats. The wide scope and importance of these Directives emphasises the strategic importance of soil protection.

3.3 National policies and actions

To recap briefly, this report aims to support the development of a rationale and key objectives for and to assist the implementation of a national Soil Protection Plan, as envisaged by the draft Soil Protection Act that was recommended in the National Plan for Sustainable Development (PNDD). The following sub-sections outline the existing national policies and actions that paved the way for the Act and that have direct relevance to soil protection.

Implementation of the Agenda 2030 in and by Luxembourg

In 2017, the Government Council of Luxembourg adopted a report on the implementation of Agenda 2030 within and by Luxembourg ("Rapport de mise en œuvre de l'agenda 2030 au/par le Luxembourg")[93]. The report summarises Agenda 2030 and the international and national development of policies on sustainability, before evaluating how Agenda 2030 and its SDGs should be implemented in Luxembourg. Focussing here on the most relevant SDG (SDG15), the report lists national strategies, laws and regulations that are already or should be contributing to the SDG15 targets. The most important of these is the National Nature Protection Plan ("Plan National concernant la Protection de la Nature", PNPN) falling under the Nature Protection Law (as revised in 2004) and including the national biodiversity strategy; the National Plan for Sustainable Development (PNDD), the National Plan for Climate Protection, various Plan Sectoriels on for example transport and landscape, the Programme for Rural Development (PDR) and the National Forest Programme (PFN).

National Plan for Sustainable Development

Luxembourg's most recent National Plan for Sustainable Development (PNDD) was adopted in December 2019[94] and is a national response to the 2030 Agenda of the United Nations that addresses many issues identified in the Government report on the implementation of the Agenda 2030.

Sustainable development in Luxembourg is based on five basic principles, of which the most relevant in the context of soil protection are respecting the ecological limits (planetary boundaries) and the regenerative capacity of nature, when using natural resources. The SDGs and their 169 targets are generally built upon 5 main pillars, the so-called "5 P", namely Population, Planet, Prosperity, Peace and Partnership, and represent an integrated and inseparable set of actions.

During the presentation of the project for the update of the PNDD in 2018[95], a strategy for change with the following priority areas for action was proposed:

---

[93] Gouvernement en Conseil, 2018. Mise en œuvre de l'agenda 2030 au et par le Luxembourg – Transformer les vies tout en préservant la planète. 173 p https://environnement.public.lu/content/dam/environnement/documents/developpement-durable/rapport-meo-agenda2030.pdf

[94] Le Gouvernement du Grand-Duché de Luxembourg, 2018. Luxembourg 2030: 3ème Plan National pour un Développement Durable. 107 p https://environnement.public.lu/dam-assets/documents/developpement-durable/PNDD.pdf

[95] Le Gouvernement du Grand-Duché de Luxembourg, 2018. Luxembourg 2030: 3ème Plan National pour un Développement Durable. Présentation 15 p

- Ensure social inclusion and education for all
- Ensure conditions for a healthy population
- Promote sustainable consumption and production
- Diversify and ensure an inclusive and future-oriented economy
- Plan and coordinate land use
- Ensure sustainable mobility
- Stop degradation of our environment and respect the capacities of natural resources
- Protect the climate, adapt to climate change and ensure sustainable energy
- Contribute, globally, to the eradication of poverty and policy coherence for sustainable development
- Guarantee sustainable finances.

Of those ten priority areas the following two have most relevance to SDG15 and soil protection:

- Action 5 - Plan and coordinate land use ("Planifier et coordonner l'utilisation du territoire"), including the rational use of land and soil (include "la nouvelle loi du 17 avril 2018 sur l'aménagement du territoire"[96] and PDAT[97])
- Action 7 - Halt the degradation of our environment and respect the capacities of natural resources ("Arrêter la dégradation de notre environnement et respecter les capacités des ressources naturelles"), including the forthcoming Soil Protection and Management of Polluted Sites Act, but neglecting the most important target for soil protection SDG15.3 "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world".

The PNDD begins by reviewing the unsustainable trends and objectives previously identified in 2010 and links them to the SDGs, for example overuse of the natural resources and soils (see Figure 5), before providing details for each of the SDGs. A working group on targets has been set up and has identified 124 out of 169 targets that should be retained because of their relevance for Luxembourg. In addition, a National Monitoring Framework was developed by an expert group which proposed a set of 118 indicators for the 124 retained targets. The National Plan provides an initial evaluation of the status of those indicators developed and implemented in 2017/2018.

The previous 2010 PNDD set a target to limit future land take to 1 hectare per day until 2020, supported by a recommendation to introduce a tax on land sealing, enhance spatial planning measures and pass a specific law on soil protection. A report from 2015 on the implementation of the

---

https://environnement.public.lu/content/dam/environnement/documents/developpement-durable/presentation-projet-PNDD-20180927.pdf

[96] JO, 2018. Loi du 17 avril 2018 concernant l'aménagement du territoire. 17 p http://data.legilux.public.lu/file/eli-etat-leg-loi-2018-04-17-a271-jo-fr-pdf.pdf

[97] Portail de l'aménagement du territoire, website visited in 2021. Programme Directeur d'Aménagement du Territoire : PDAT ? https://amenagement-territoire.public.lu/fr/strategies-territoriales/NotreFuturTerritoire/LePDAT.html#:~:text=Le%20PDAT%2C%20ou%20encore%20Programme,de%20d%C3%A9velopper%20le%20territoire%20national.

PNDD concluded that neither the target of limiting land take to 1 hectare per day nor the land sealing tax had been implemented successfully.[98] However, recent calculations based on the time series of national land use data (OBS99, OBS07, LU15, LU18) indicated that the daily land take in Luxembourg between 1999 and 2018 was around 0.5 hectares.[99] This means that this target that was formulated in 2010 was in fact reached already before and remained stable over time up to the present.

Tendances non durables – **PNDD 2010**	Objectifs de qualité – **PNDD 2010**	Objectifs de développement durable – **Agenda 2030**
1. Surutilisation des ressources naturelles, perte de la biodiversité suite à une production et consommation non-durables	1. Protection de la biodiversité, conservation et exploitation durable des ressources naturelles 2. Consommation et production durables	ODD 2. Faim « Zéro » ODD 6. Eau propre et assainissement ODD 12. Consommation et de production responsables ODD 15. Vie terrestre
2. Consommation foncière trop importante, surutilisation des sols et fragmentation des paysages avec des effets négatifs sur le paysage et la récréation, la nappe phréatique et la biodiversité	3. Développement durable de l'organisation spatiale; construction, logement et travail durables	ODD 6. Eau propre et assainissement ODD 11. Villes et communautés durables ODD 15. Vie terrestre

Figure 5: Review of identified unsustainable trends in 2010 with the Agenda 2030 SDGs

<u>The draft Soil Protection and Management of Polluted Sites Act</u>

A key action in the PNDD is the establishment of an Act on soil protection and the management of polluted sites. In early 2018, a draft act on soil protection and the management of polluted sites was filed to the parliament “Chambre des Députés”[100]. The main intended purpose of the Act is to ensure the protection of soil and the maintenance and restoration of soil-related services. The final text of the bill contains two main sections: (i) a preventive section focusing on soil protection in the strict

[98] Ministère du Développement durable et des Infrastructures, 2010. Ein nachhaltiges Luxemburg für mehr Lebensqualität. 203 p https://environnement.public.lu/content/dam/environnement/documents/developpement-durable/rndd-version-finale-avec-annexes.pdf

[99] Personal communication, Ministère de l'Énergie et de l'Aménagement du territoire, November 2020; also communicated in the context of an EEA questionnaire addressing geospatial and/or statistical data regarding land take and land consumption that was sent out to all National Reference Centres Land Use and Spatial Planning Members in February 2020.

[100] Chambre des députés du Grand-Duché de Luxembourg, website visited in 2021. Projet de loi n° 7237 sur la protection des sols et la gestion des sites pollués. https://www.chd.lu/wps/portal/public/Accueil/TravailALaChambre/Recherche/RoleDesAffaires?action=doDocpaDetails&id=7237

sense and (ii) a curative section describing principles for managing potentially polluted or polluted sites.

"Soil protection" is defined as the prevention, mitigation and redress of threats and damages of soil quality. Next to the regular monitoring and surveillance of soil quality, promoting the maintenance of long-term soil quality and considering soil as non-renewable natural resource in decision-making, the bill foresees the establishment of a national soil protection plan. Its purpose is twofold: (i) to combat soil degradation processes and restore degraded soil quality and (ii) to control possible risks linked to background concentrations of pollutants in the soil. Finally, in the future soil should be protected in the same way as water and air.

This report is intended to be a supporting foundation when preparing the national soil protection plan.

Planning and coordinating land use: reducing land take and soil sealing

The National Spatial Planning Programme (NSPP) prescribes planning principles. The most recent revision was published in 2003[101] ; a key objective is to constrain extension of urban areas ("Définir une politique d'urbanisation prioritairement orientée vers la densification et le renouvellement urbain à l'intérieur des villes et villages existants et non sur une consommation supplémentaire d'espaces encore vierges" and "Réduire à l'indispensable l'utilisation d'espace non encore bâti à des fins de construction en périphérie"). The NSPP is administered at both national and local levels. National Government has the primary role in regulating economic development, rural planning, major public works, infrastructure projects and environmental protection. The role of the municipalities is in local development, town planning and urban regeneration.

The spatial planning system in Luxembourg is based on the following core components. The Act on Spatial Planning (1999)[102] introduces the concept of sustainable development as the overarching goal for spatial planning and it seeks to improve horizontal coordination at the national level and vertical coordination between the Government and the municipalities. The law emphasizes efficient use of soil, landscape protection and an appropriate balance between urban and rural development (Art 1.2 (a) and (d)).

The Act on the Development of Cities and other significant agglomerations (1937)[103] was replaced by the Act on the Planning of Communes and Urban Development (2004)[104], which regulates spatial planning at the municipality level and defines where this needs approval at the national level.

[101] Portail de l'aménagement du territoire, website visited in 2021. Programme directeur https://amenagement-territoire.public.lu/fr/strategies-territoriales/programme-directeur.html
[102] JO, 1999. Loi du 21 mai 1999 concernant l'aménagement du territoire, abrogée par la loi modifiée du 17 avril 2018 concernant l'aménagement du territoire http://legilux.public.lu/eli/etat/leg/loi/1999/05/21/n1/jo
[103] JO, 1937. Loi du 12 juin 1937 concernant l'aménagement des villes et autres agglomérations importantes http://legilux.public.lu/eli/etat/leg/loi/1937/06/12/n1/jo
[104] JO, 2004. Loi du 19 juillet 2004 concernant l'aménagement communal et le développement urbain http://legilux.public.lu/eli/etat/leg/loi/2004/07/19/n1/jo

In order to make the principles of the National Spatial Planning Programme operational an Integrated Transport and Spatial Development Concept for Luxembourg (IVL)[105] was elaborated with stakeholder consultation. A key objective of the IVL is to replace 25 % of private transport by public transport by 2020. A supporting strategy is to facilitate provision of affordable public transport by achieving the higher urban population density needed to allow affordable public transport.

The overall effect of current spatial planning policies is to reduce new land take and associated soil sealing, but currently it may increase soil sealing in the existing built environment by encouraging densification of existing urban areas to avoid further encroachment on to greenfield land. The slight increase of land take rate observed over the last six years suggests that even if the current spatial planning policies is efficient, they cannot totally avoid new land take which is driven by increased economic activities and population growth.

Conservation of Natural Resources

The Act on the Protection of the Environment and the Natural Resources (2018[106], replacing the 2004 Act[107]) presents seven main objectives all of which have a direct link to soil and soil protection. Its aim is to ensure that development is more sustainable by providing mechanisms for offsetting the loss of natural resources during construction projects. These include a scheme for developers to purchase points that fund public tree planting to replace trees that are lost through development. The Act also states that compensation measurements for biodiversity should not take place on highly productive agricultural soils. Additionally, the Act harmonizes decision criteria on green space development across all municipalities.

The 2018 draft Forest Act[108] consolidates numerous regulations and affirms requirements for sustainable forest management. One of the Act's main objectives is to maintain and protect forest health so that it can contribute better to sequestering carbon and protecting water and soil. Importantly, several soil-damaging actions in forests (for example removing the organic surface layer of soils) are only allowed in exceptional cases and require authorisation from the relevant administration. The Act also includes measures to reduce soil compaction by vehicles and traction during harvesting and other operations, by incentivising the use of horses and cables in place of heavy machines.

[105] Portail de l'aménagement du territoire, website visited in 2021. IVL: ein Integratives Verkehrs- und Landesentwicklungskonzept für Luxemburg
https://amenagement-territoire.public.lu/fr/strategies-territoriales/ivl.html

[106] JO, 2018. Loi du 18 juillet 2018 concernant la protection de la nature et des ressources naturelles
http://legilux.public.lu/eli/etat/leg/loi/2018/07/18/a771/jo

[107] JO, 2004. Loi du 19 janvier 2004 concernant la protection de la nature et des ressources naturelles, abrogée par la loi modifiée du 18 juillet 2018 concernant la protection de la nature et des ressources naturelles
http://legilux.public.lu/eli/etat/leg/loi/2004/01/19/n1/jo

[108] Chambre des députés du Grand-Duché de Luxembourg, website visited in 2021. Projet de loi n°7255 sur les forêts
https://www.chd.lu/wps/portal/public/Accueil/TravailALaChambre/Recherche/RoleDesAffaires?action=doDocpaDetails&id=7255

The National Forest Programme (Programme Forestier National, PFN, 2004)[109] prescribes the sustainable management of public forest land with key principles, with the following relating directly to soil protection:

- Maintaining health and vitality of forest ecosystems, including forest soil;
- Maintaining and appropriately improving protective functions in forest management (especially soil and water).

The National Forestry Accounting Plan (NFAP)[110], established in the context of the EU Regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry (LULUCF) in the 2030 climate and energy framework[111], reinforces sustainable forest management practices including keeping soil resources in an optimal state for conservation and production. Specific controls have been implemented to fully conserve forest lands and high-value habitats, including moors and peatlands.

Operating permits for classified installations (commodo)

To protect human health and limit environmental damage, such as soil pollution, from industrial activities, several laws have been successively enacted: in 1979 – the Act on hazardous, insalubrious and incommodious installations[112]; in 1990 – the Act on hazardous, insalubrious and incommodious installations[113]; in 1994 – the Act on the prevention and the management of wastes[114]; in 1999 – the Act on classified installations[115]. Since 1999, installations which are classified as presenting a risk of harm to human health and/or the natural environment require an operating permit. The permit authorisation process checks, among other things, that effective preventive measures to avoid soil pollution are implemented. These measures include air emission pollutant thresholds to restrain diffuse soil pollution. The 1999 Act also introduced a requirement to survey soil pollution after operations cease and before permit obligations are rescinded. If soil pollution arising from the

[109] Le gouvernement du Grand-Duché de Luxembourg, 2004. Programme forestier national. 76 p https://environnement.public.lu/dam-assets/documents/for%C3%AAt/pfntxtfin.pdf

[110] AEV, 2018. National forestry accounting plan Luxembourg. 35 p https://environnement.public.lu/dam-assets/documents/for%C3%AAt/nfap/NFAP-2018.pdf

[111] EC, 2018. Regulation 2018/842: Binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation 525/2013. 17 p https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R0842&from=EN#:~:text=Regulation%20(EU)%202018%2F841,be%20covered%20by%20this%20Regulation

[112] JO, 1979. Loi du 16 avril 1979 relative aux établissements dangereux, insalubres ou incommodes, abrogée par la loi modifiée du 10 juin 1999 relative aux établissements classés http://legilux.public.lu/eli/etat/leg/loi/1979/04/16/n6/jo

[113] JO, 1990. Loi du 9 mai 1990 relative aux établissements dangereux, insalubres ou incommodes, abrogée par la loi modifiée du 10 juin 1999 relative aux établissements classés http://legilux.public.lu/eli/etat/leg/loi/1990/05/09/n1/jo

[114] JO, 1994. Loi du 17 juin 1994 relative à la prévention et à la gestion des déchets, abrogée par la loi modifiée du 21 mars 2012 relative à la gestion des déchets http://legilux.public.lu/eli/etat/leg/loi/1994/06/17/n4/jo

[115] JO, 1999. Loi modifiée du 10 juin 1999 relative aux établissements classés http://legilux.public.lu/eli/etat/leg/loi/1999/06/10/n5/jo

permitted operations is found, the polluter pays' principle is applied, requiring the operator to remediate this soil pollution.

4 DEVELOPING A HOLISTIC SOIL PROTECTION APPROACH

4.1 The economic rationale for public policy intervention

Soil plays a critical role in the national economy. Table 2 identifies the services provided by soil and approaches to valuing their economic contributions. Soil resources support many valuable services and goods, some of which are traded, for example agricultural and forest products, but many important ones are not part of market transactions, for example the natural regulation by soil of water resources and of carbon emissions to the atmosphere. The extent to which soil resources support these traded and non-traded services affects factor costs in the national economy and ultimately its international competitiveness. They do this directly by affecting the costs of food, fibre and other production, and less directly by for example affecting the costs of water treatment and supply and the risk of flood damage and related insurance costs. Therefore, an effective legal framework is required to conserve soil stocks and their condition to support a sustainable economy.

Soil resources are a part of land resources to which are attached rights and duties linked to property ownership. Consequently, their effective protection depends on an appropriate balance between rights of usage and duties of stewardship. A problem arises because most of the costs of soil degradation occur offsite as externalities from reduced support for non-traded services. Therefore, the costs of inadequate soil protection are borne much more by wider society than by the landowners and users who benefit directly from soil use. Planning and building controls ensure that at least some of these external costs are returned to urban soil users, for example by requiring the construction of facilities to regulate the increased storm water flow caused by soil sealing. Nonetheless the external costs of urban soil use are not mitigated fully, for example those arising from soil erosion or carbon stock losses during construction. Mitigation measures to reduce the external costs arising from soil degradation by agriculture are also incomplete - these costs have not been quantified for Luxembourg but have been shown to be substantial elsewhere and in England and Wales, where there are similar levels of soil protection controls to those in Luxembourg, the costs of soil erosion, decline in SOM and soil compaction are estimated to be between 1.0 and 1.5 billion Euros per annum, with 80 % of these costs being external to land users[116]. The equivalent pro rata external cost of agricultural soil degradation on an area basis for Luxembourg would be about 25 million Euros per annum. Therefore, considering both urban and agricultural soils, there is a strong case for policy intervention to protect soil resources in the public interests of the wider economy[117].

[116] Graves et al., 2015. The total costs of soil degradation in England and Wales. Ecological Economics. 14 p https://www.sciencedirect.com/science/article/abs/pii/S0921800915003171

[117] EEA, 2016. Report 7/2016: Soil resource efficiency in urbanized areas – analytical framework and implications for governance. 94 p https://www.eea.europa.eu/publications#c7=en&c11=5&c14=&c12=&b_start=0&c13=soil%20resource%20efficiency

Table 2: Generic classification and valuation of ecosystem services with particular reference to soils (from 'Soil resource efficiency in urbanised areas -Analytical framework and implications for governance, EEA report No 7/2016)

Ecosystem service	Examples of services	Contribution of the soil resource, whereby a change in soil condition affects services and benefits	Approaches to monetary valuation of soil-related services, usually as a subset of the valuation of final goods and services
Supporting other processes and services	Soil formation Nutrient cycling Water and gas cycling Habitats/refuge Biodiversity	Context and facilitator of natural processes, including support to (above- and below-ground) biodiversity (habitats, species, genes)	Not directly valued
Provisioning of material goods and services	Biomass production (food, feed, fibre, fuel) Mineral and organic material extraction Genetic resources Water supplies Platform/carrier (a)	Effect on land use suitability/ capability/productivity in agriculture and forestry Water-holding capacity Water quality Provision of usable space for development: with load-bearing capability, stability, resilience	Yields effects valued at market prices of agricultural and forestry commodities Soil quality effects on farmland values Cost of substitution of soil contribution to production, water supply, carrying capacity Costs of avoiding losses/risks associated with loss of soil services (e.g. insurance, additional engineering costs)
Regulating natural/ ecosystem processes	Air quality Flood/drought control Erosion control Carbon storage Water purification Temperature regulation Waste assimilation Pollution attenuation Pest/disease control	Control of run-off, drainage, erosion, diffuse pollution and sedimentation Drought management Carbon sequestration Water filtration, storage and nutrient recycling Temperature management Waste assimilation (sewage sludge/composts)	Avoided urban flood damage/ flood defence costs Economic value of carbon storage Savings in water supply regulation and treatment costs Alternative waste disposal or treatment costs Avoidance of erosion, pollution, sediment transport and deposition costs Property prices and asset values
Cultural, provision of non-material services and goods	Heritage Landscape Amenity Recreation Social relations Interaction with nature	Preservation of archaeological artefacts Supporting landscapes, habitats and biodiversity (e.g. grasslands, peatlands) Supporting recreation, countryside access	Cost of substituting or maintaining soil services that underpin provision of cultural services Proportion of willingness to pay that is attributable to maintenance/protection of soil quality (e.g. in habitat creation, heritage preservation, green space, countryside recreation)

4.2 Priorities and opportunities for soil protection measures

4.2.1 Quantify and locate soil degradation

Throughout Luxembourg, the six types of soil degradation identified (see 2.3) can occur with varying intensity depending on soil characteristics, land-use, landscape features or local climate. To develop and then carry out an effective soil protection strategy, these degradations must first be quantified, located and prioritized. Using the results of this work, an effective and efficient soil protection strategy can be elaborated that prioritizes actions towards the most serious threats in terms of ecosystem services lost, cost of management, loss in quality of soil and / or irrecoverable losses of soil stocks.

An accurate quantification and location of soil degradation is essential to identify where it is most significant. This initial study can also provide a baseline against which the results of future surveys can be compared to identify temporal trends in soil degradation.

Although the soils of Luxembourg have been studied for decades, more data are needed to be able to quantify and locate the greatest extent and impacts of soil degradation.

- Existing data on soil sealing in Luxembourg indicates that this is an important cause of loss of soil stocks (see 2.3.6). However, monitoring of soil sealing during new land take and within the existing built environment is needed to quantify this problem properly. An important justification for measures to restrict soil sealing is to retain the contribution soil makes to mitigating flood risk by moderating run-off volumes and intensities. Non-sealed soil can also help to mitigate the local effects of climate change by combating the heat island effect in urbanized areas.
- Soil erosion on agricultural land is locally significant in Luxembourg and its risk is enhanced where potentially harmful agricultural land use and management practices are followed on particular soil types and landforms that are vulnerable to erosion (see 2.3.1). Spatially explicit modelling of the risk of soil erosion is a mature process and can be used to confirm which areas are of higher risk and where preventative measures should be targeted.
- Data on the changes in stocks of SOC in Luxembourg are not sufficient to reliably assess current trends. However, there is sufficient data to confirm the stocks are large and to demonstrate that their conservation is critical to managing national GHG emissions inventories[118], as well as for maintaining the condition of soil resources to support a range of services.
- The actual extent of soil compaction in Luxembourg is not known and would be difficult to measure reliably because of its variable occurrence across the wider landscape and the fact that topsoil compaction is ephemeral. Nonetheless it is observable and has economic consequences for producers and by increasing the volume and intensity of surface water run-off and related flood risk.
- Only limited information exists at present on the trajectory of soil biodiversity generally and information for Luxembourg is scarce. However, a decline of soil biodiversity is anticipated as a result of other types of soil degradation that reduce the availability of carbon as an energy substrate and damage the physical and chemical habitat for soil biota.

[118] See the most recent National Inventory Report of Luxembourg, accessible at: https://unfccc.int/documents/228020

- Historical emissions of contaminants have left a legacy of diffuse soil contamination that cannot be remediated easily and that has reduced the quality of soil stocks across Europe and the World. Emissions from transport, construction and agriculture, as well as small-scale industrial and domestic activities that fall below regulatory thresholds, contribute to continuing diffuse contamination of soils, although the overall inputs are much reduced compared to historic levels. Few data are available to quantify and assess the trends of this ongoing diffuse contamination. Moreover, natural background concentrations of some heavy metals in soils can be elevated where soil has formed on a particular geology; spatial data on heavy metal concentrations in soil is needed to assess the relative contributions to higher levels from diffuse soil pollution and geological anomalies, as well as to support assessments of any risk these present to the environment and/or human health.
- Agricultural soil acidity is corrected routinely by liming to maintain soil fertility. However, forest soil acidity is less regularly and systematically studied and so it is not yet fully possible to assess soil acidity and its evolution in forested soils. A better knowledge of the state of forest soil acidity would help to identify areas where soil acidification may exist or develop and where there is a risk of potential environmental issues due to heavy metal leaching or Al toxicity.

A systematic survey will allow a proper assessment of the extent of soil degradation across Luxembourg and identify where this is greatest and has the most serious societal impacts. This prioritization can then be used to optimally allocate limited human, time and financial resources to deal with the soil degradation that is of most concern. In this way, an efficient soil protection strategy can be elaborated and implemented. A critical point is that this prioritization and the subsequent development of a soil protection strategy need to be completed without delay to release early economic and other benefits. While temporal trends in soil degradation can only be reliably estimated over many years, this should not mean that corrective actions are postponed. Indeed, taking in to account the precautionary principle, action does not need to wait for perfect data and information. The soil protection strategy and implementation actions can and should be adapted periodically over time to take account of new data and knowledge about soils and their degradation.

4.2.2 Prioritization of soil degradations

4.2.2.1 Irrecoverable/recoverable degradations

The long time period compared to human lifetimes over which soil slowly forms means that it should be regarded as a non-renewable natural resource. In this context, it is useful to recognize two types of soil degradation: the first causes an irrecoverable loss of the volume of soil stocks as a resource for sustainable development; the second causes a loss in the quality of soil stocks, but one which may be recoverable although often only over a long time. Thus, dealing with irrecoverable degradation can be considered a priority over recoverable degradation.

Soil sealing and soil erosion are especially problematic types of soil degradation because they lead to a loss of the volume of soils stocks that can only be recovered with costly inputs and then not with soil in a natural state. Relevant technology includes soil improvement or soil construction using materials such as soil excavated during construction or dredged sediments. However, this technology is expensive and not fully developed and not practicable except for smaller areas.

Decline in soil organic carbon and soil compaction both degrade soil quality rather than the volume of soil stocks. As such and at least in principle, they are forms of degradation that are recoverable using the natural processes of the soil system itself, although this may take several years to show significant results.

Diffuse soil contamination does not cause a loss of soil stock volumes but a loss in soil quality. However, this contamination is not removed by natural soil processes and it cannot be remediated easily using artificial methods, due to a lack of sufficiently efficient decontamination processes and the very high cost of applying them to larger areas. In this context, diffuse (as distinct from local) soil contamination is effectively irrecoverable.

Human-induced soil acidification can be considered as a recoverable diffuse soil contamination. The main sources of this contamination are the deposition of acidic substances derived from airborne emissions of SO_2 and NO_x, and the use of ammonium-containing fertilizers.

Finally, it is realistic to consider loss of soil biodiversity as irrecoverable - at least in the medium term and given uncertainty about both the likely endpoints of any recovery and the trajectories that might be followed. There is no certainty that a degraded soil ecosystem will return to a similar state (i.e. ecosystem structures and functions) to its former state or that previously supported functions will be fully recovered. However, following a loss of soil biodiversity and over longer periods, a functional soil ecosystem can be recovered with suitable inputs and management, even if this is not identical to the original one and while recognizing that particular species may have been lost permanently.

4.2.2.2 Technical, economic and temporal aspects

A possible step when prioritizing future actions for soil protection and remediation is to identify those types of soil degradation that present the most problems in terms of technical feasibility, costs and time requirements. The rationale for this prioritization is based on soil degradation being considered less serious - if it can be remediated efficiently by existing proven processes, at a reasonable cost and within a period appropriate to the human time scale. From this point of view, for instance, soil sealing seems to be more problematic than a decline of SOC content, because the technical processes to rebuild a functional soil after it has been seriously degraded by sealing are not fully developed and are very expensive to apply, while technical processes to enrich soil in organic carbon are much better known and less costly.

4.2.2.3 Societal impacts

Another possible way to prioritize future actions for soil protection and remediation is to rank types of soil degradation according to their impacts on Luxembourg communities, in terms of the costs of remediation relative to the value of lost benefits from soil-supported ecosystem services. The starting point for such an analysis is data about the quantification, location and valuation of the services supplied by soils. Then estimates are required of the rates of soil degradation and accompanying loss of services. This analysis is not straightforward, because of the multifunctional nature of soil, the inter-relatedness of different types of degradation and the interconnectedness of soil to other parts of the overall ecosystem, which makes identifying the unique contribution of soil difficult. Moreover, the valuation of benefits interacts with the varying preferences of different societal groups, e.g. towards better protection of soil biodiversity by applying extensive agricultural management or intensifying agricultural production to guarantee food self-sufficiency; or, towards prioritization of development according to national or municipal priorities. Nonetheless, such cost-benefit analysis offers an objective approach to ranking policy priorities, even if methodological difficulties mean the analysis is complicated.

4.2.3 Some proposals to improve soil protection measures:

To prevent soil losses and soil sealing in the built environment:

Soil sealing is one consequence of land take into the built environment. It is driven by strong economic and demographic factors and it is hard or probably impossible to completely avoid new soil sealing at the national scale. However, it is possible to reduce soil sealing to a minimum by taking account of this aspect in construction projects' conception and design. Projects should consider the potential harm to and opportunities for enhancement of ecosystem services supported by soils.

Urban planners could better protect some soil ecosystem services (including surface water infiltration capability and agricultural production) by directing projects in the context of soil properties - the "best" soils could be conserved while some "less good" soils could be prioritized for developments and inevitable sealing. This approach would also facilitate a system of environmental compensation for lost soil ecosystem services, as urban planners would have an idea of the quality and the quantity of the soil ecosystem services lost for a given project. To make this approach possible, decision-support tools providing information on soil ecosystem services to urban planners are required. A valuable set of tools could be high resolution suitability maps indicating areas of "good" and "less good" soils, as assessed by considering, for example, the management of rainfall events, agricultural production, biodiversity protection, SOC storage, and levels of contamination. In parallel, actions should be encouraged to "de-seal" soils wherever this is feasible. Therefore a priority is to provide urban planners and stakeholders with data and supporting tools to inform where "de-sealing" is possible, and at what cost and which benefits.

Within both the existing built environment and its future development, there are opportunities to minimize the extent of soil sealing and its impacts through appropriate design. Hard surfaces, such as car parks and pedestrian paths, can be constructed with permeable materials. Urban gardens and amenity areas can be designed to optimize the functionality of residual urban soil resources.

To prevent serious soil erosion:

Due to the projected increasing likelihood of extreme precipitation events due to climate change, it can be expected that soil erosion will also become more prevalent in certain localities of Luxembourg (see chapter 2.3.1 and footnote 68). Specific local measures can be applied by land managers, ideally supported by advisory services, to conserve soil generally and in particular its fertility. The priority is to restrict locally inappropriate agricultural land use, such as tillage of erodible soils on slopes (see recommendation in the SRCCL, footnote 68). Properly applied, the existing Code of Good Agricultural Practices (COGAP) requirements for managing soil erosion, and others that may become mandatory in the next CAP, should assist. The national Administration of Technical Agricultural Services (ASTA: Administration des Services Techniques de l'Agriculture), which has already been working for several years on this topic, is the reference center for the elaboration of soil erosion data and maps and should be consulted with respect to the most up-to-date and relevant national information.

To maintain SOC stocks or even improve them where possible:

The priority is to prevent changes in land use which reduce inputs of carbon to soil from plant residues and / or increase rates of SOC loss, for example by additional tillage. The highest priority is to conserve stocks of SOC in soils with high SOM. For example, the upland peaty soils on higher ground in the Oesling region may not be extensive but could nonetheless valuable stocks of carbon as peatlands can sequester carbon for a very long time (see footnote 68). Other wetter and relatively undisturbed soils with organic surface soil horizons need similar protection, as do wetland soils generally. As the wetter and true wetland soils are generally under permanent grassland, they are mostly already protected against agricultural land use change to cropland, but should be better protected from urban land take. Overall, forest lands have higher SOC levels than those in agriculture and should be kept in forestry. The National Forestry Accounting Plan (NFAP) is specifically targeted at optimising the stocks of carbon in forest areas.

A decline of SOM can be theoretically arrested and in the long run reversed by altered land management practices within a given land use, but the feasibility of this is somewhat uncertain in the context of climate change and increasing average temperatures and lengthening and more frequent droughts, which may limit or even cancel out the effects of adapted land management.

Options to arrest declining SOM include increasing the sustainable input of organic matter by increasing the frequency of grass leys in rotations and using cover crops to minimize periods of bare ground, by spreading of organic materials and by reducing tillage, where these actions are relevant and have not yet been applied (see footnote 68). The direct benefits to agricultural enterprises of actively managing SOM have been estimated to be in the range 34 to 73 Euros per hectare[119] after a few years. Communicating this advantage to land managers provides a positive incentive, although not a very strong one as the financial incentive is limited. The technical difficulties and costs of making reliable shorter-term measurement of changes in SOC at field scales creates barriers to linking payments to carbon sequestration in soil. However, there is an option to promote activity-based practices that have demonstrable effectiveness for increasing SOC. Properly applied, the existing COGAP requirements for managing SOM, and others that may become mandatory in the next CAP, should assist.

To avoid soil compaction:

[119] DEFRA, 2004. To develop a robust indicator of soil organic matter status. 17 p http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=10433

Reducing the risk of soil compaction requires altered land management practices, specifically avoiding trafficking on soil or cultivating it when it is too wet and with high ground pressure machinery. Soil texture and topographic position affect the number of days when soil can be trafficked without causing soil compaction and could be used to identify soils at higher risk. A problem is that increasingly high-powered agricultural machinery easily provides the additional tractive effort to overcome wet soil conditions. It is also relatively easy to remove topsoil compaction before crop establishment. The most effective protective actions are likely to be training and advisory services. Properly applied, the existing COGAP requirements for avoiding structural damage to soil, and others that may become mandatory in the next CAP, should assist.

To prevent new diffuse soil contamination:

The future priority is to ensure that any additions to past contamination are minimized. There are already existing measures to prevent new soil contamination. The Waste Directive restricts waste recycling to land and makes it conditional on it causing no unacceptable harm. The Industrial Emissions Directive requires controls on airborne emissions (that may subsequently be deposited on soil) and action to limit the risks of accidental soil contamination. Moreover, within Luxembourg, there is a national platform on Disaster Risk Reduction (DRR), which is supported by the Ministère de l'Énergie et de l'Aménagement du Territoire (MEA) in cooperation with the Ministère de l'Intérieur (MI). This platform collects various data sets on natural and technological disasters that might occur in Luxembourg, including industrial accidents, Seveso sites, but also mass movements and soil erosion.

Apart from national efforts, internationally there needs to be a strict and extensive environmental vetting procedure for chemical substances during their authorization. A process has been developed by the European Chemical Agency (ECHA) and via the implementation of the "Registration, Evaluation, Authorisation and Restriction of Chemicals" regulation (REACH) as well as the regulation of "Persistent Organic Pollutants" (POP). An effective prevention of diffuse soil contamination is only possible via strict regulation and control of possible contaminants and their emission to the environment, including soil.

To prevent human-induced soil acidification:

Global and European air pollution regulations have very substantially but not completely reduced the emissions of substances responsible for soil acidification (SO_2, and NO_x), but emissions from mobile sources including road vehicles remain significant. It is important to assess the consequences of past and still continuing airborne emissions for soil acidification, especially in relation to naturally acidic and non-limed soils, for example the forest soils of the Oesling region. Forest managers should avoid planting new conifers on naturally acidic soils where there is a risk of additional acidification and actions to limit soil acidification (replacing conifers by deciduous trees and liming) need to be considered. Overall, more information is needed to properly assess the risks of soil acidification and identify appropriate responses.

To contain decline in soil biodiversity:

Only limited information exists at present on the trajectory of soil biodiversity generally and information for Luxembourg is scarce. However, a decline of soil biodiversity is anticipated as a result of other types of soil degradation that reduce the availability of carbon as an energy substrate and damage the physical and chemical habitat for soil biota. Therefore, addressing soil degradation generally is the primary means for avoiding a decline in soil biodiversity. This needs to be supported by ensuring that indicators of soil biodiversity are included in national soil monitoring.

4.2.4 Inter-organization cooperation

A sound cooperation between all organizations involved in soil management / use is vital to gather and collate all the necessary data, information and knowledge on soils, their services and their degradation and to prioritize actions to deal with soil degradation in Luxembourg according the national context: soil characteristics; land-uses; environmental, economic and political strategies; impacts on society; human, financial and technical resources; technical possibilities, existing and new legislation related to soil. An inter-organization working group dedicated to these topics and tasks should be created. Such a working group could take a lead in coordinating proposals for and the subsequent implementation of measures to protect the soils of Luxembourg.

4.3 Data infrastructure

Soil spatial inventory development

A wide variety of soil types occur in Luxembourg and within each type there are variations that affect their unique capacity to deliver different services. Therefore, a comprehensive spatial inventory of national soil resources is essential to inform priorities for soil protection and support the design of appropriate soil protection measures.

The soils of Luxembourg have been mapped at a scale of 1: 100,000 and at finer scales for most of the country. However, traditional soil maps need expert interpretation to support decision-making. Future decision-making can be met more effectively using recent advances in digital technology that allow the development of fine scale spatial inventories of soil types and their properties (i.e. digital soil mapping). Existing spatial data, including existing soil maps and historic soil profile data but also a range of other geographic information, can be used to train algorithms that predict soil properties within areas as small as 100 m^2. This is now a mature technology that is fully operational and already applied in some countries, including Ireland[120]. Over the past few years, the soil team of ASTA has been developed and used geostatistical models to elaborate national maps of agricultural and/or forest soil properties, such as SOC stocks, risk of soil erosion or hydrodynamic properties. This modelling should be extended to make spatial estimates of the capacity of soil to support particular

[120] DATA.GOV.IE, website visited in 2021. Irish soil information system national soils map https://data.gov.ie/dataset/irish-soil-information-system-national-soils-map

services and goods and to provide data on soil properties for environmental modelling for each soil type, including SUITMAs (soils of urban, industrial, traffic, military and mining areas).

Soil monitoring

Soil monitoring identifies and quantifies temporal trends in soil condition and its degradation. It provides essential data to target protective measures and to assess their effectiveness.

The first step is to agree a set of indicators of soil conditions. There are existing sets of indicators[121] that could be adapted to meet the needs of Luxembourg and recommendations on establishing a sampling scheme that allows meaningful data to be collected[122]. This has been done already by some members of the European Union, in particular France[123]. Such a systematic approach ensures access to complete and robust information about the current status of soil resources and trends in their condition. Unfortunately, rates of change in soil properties combine with uncertainties in sampling and testing to mean that meaningful data on changes in soil condition often cannot be observed over periods of less than several years. This means that the return on investment in a soil monitoring scheme is slow and generally longer than the policy making cycle, which presents a challenge when public investment is being prioritised towards shorter term needs. However, without this investment and the data it provides it is probable that some soil degradation will go unnoticed, concern to protect soil will not be at the same level as for air and water, and the benefits of soil protection will not be demonstrable. Moreover, in many domains (e.g. spatial planning, water protection, air quality and emissions, agriculture, forestry, public health…) soil data are of interest and often enough rough estimates need to be used as detailed data are lacking.

Experience across Europe indicates that getting agreement on a soil monitoring scheme is likely to be complicated because any feasible indicator set will not fully meet all stakeholders' ideal requirements. A good starting point is the outputs from European projects such as ENVASSO[124]. Likewise, the European component of the World Atlas of Desertification (WAD)[125], that also monitors soil degradation, could be used as an inspiration. It should also be kept in mind that the EC is currently elaborating a soil degradation monitoring concept as a response to the European Court of Auditor's special report on desertification and soil degradation in the EU (see chapter 3.2). A particular challenge is how to build on existing but disparate national monitoring exercises. Therefore, a national working group should be set up in which different stakeholders with differing information needs can contribute and that is able to critique the strengths and weaknesses of monitoring options and recommend an optimal scheme and how it can be implemented most efficiently.

[121] JRC, 2008. Environmental assessment of soil for monitoring – Volume I: Indicators and criteria. JRC scientific and Technical reports. 358 p
https://esdac.jrc.ec.europa.eu/projects/Envasso/documents/ENV_Vol-I_Final2_web.pdf
[122] Arrouays et al., 2012. Generic Issues on board-scale soil monitoring schemes: a review. Pedosphere. 13 p
https://www.sciencedirect.com/science/article/abs/pii/S1002016012600319
[123] GISSOL, website visited in 2021. Groupement d'Intérêt Scientifique SOL https://www.gissol.fr/
[124] JRC, website visited in 2021. ENVASSO: ENVironment ASsement of Soil for mOnitoring
https://esdac.jrc.ec.europa.eu/projects/envasso
[125] JRC, website visited in 2021. Convergence of global change issues – Europe Nuts
https://wad.jrc.ec.europa.eu/europe

Data availability

The following tables give a first overview of data sets that are available at a global, European (see Table 3) and national (see Table 4) scale for use in the context of soil protection. Even though global and European data sets might possess a resolution that is normally too coarse for national use, in particular for a small country as Luxembourg, they might still be an option where national data do not exist for a certain topic. The table is structured according to soil service and soil threat/soil degradation data.

Table 3: European and global data sets

Data set	Data provider	Web link and comments
Soil services data		
Supporting services for life and biodiversity ("Support de vie"): - Global Soil Biodiversity Atlas	Joint Research Centre (JRC)	https://esdac.jrc.ec.europa.eu/content/global-soil-biodiversity-maps-0
Provisioning serviced for food, fibre and bioenergy crops ("Production de denrées alimentaires et produits destines á d'autres finalités"): - Soil Biomass Productivity maps of grasslands and pasture, of croplands and of forest areas in the European Union (EU27)	Joint Research Centre (JRC)	https://esdac.jrc.ec.europa.eu/content/soil-biomass-productivity-maps-grasslands-and-pasture-coplands-and-forest-areas-european
Regulating services for nutrient, water and carbon cycles ("Régulation: les sols contribuent aux cycles de nutriments, de l'eau et du carbone"): 1. Maps of the Storing and Filtering Capacity of Soils in Europe 2. Maps of indicators of soil hydraulic properties for Europe 3. Soil Organic Carbon - Saturation Capacity in Europe	Joint Research Centre (JRC)	1. https://esdac.jrc.ec.europa.eu/content/maps-storing-and-filtering-capacity-soils-europe 2. https://esdac.jrc.ec.europa.eu/content/maps-indicators-soil-hydraulic-properties-europe 3. https://esdac.jrc.ec.europa.eu/content/soil-organic-carbon-saturation-capacity
Provisioning services – soil as platform for the built environment ("Support de civilization: les constituent la base pour le développement des activités humaines et de l'environnement bâti"):	Joint Research Centre (JRC)	https://esdac.jrc.ec.europa.eu/content/european-map-soil-suitability-provide-platform-most-human-activities-eu28

- European map of soil suitability to provide a platform for most human activities (EU28)		
Provisioning services: soil as a source of raw materials (“Matières premières: les sols nous fournissent directement ou indirectement la plupart de nos matières premières (par example sable et minerais)”): - Maps indicating the availability of Raw Material from soils in the European Union.	Joint Research Centre (JRC)	https://esdac.jrc.ec.europa.eu/content/map-indicating-availability-raw-material-soils-european-union-organic-soil-material-b-soil
Cultural services: soil as an archive of geological and human culture (“Les sols gardent la mémoire de l’évolution de la terre et l’humanité”): - Maps of preservation capacity of cultural artefacts and buried materials in soils in the EU	Joint Research Centre (JRC)	https://esdac.jrc.ec.europa.eu/content/maps-related-predicting-preservation-cultural-artefacts-and-buried-materials-soils-eu-0
Soil degradation processes/soil threats		
Soil erosion by wind and water: 1. Global soil erosion 2. Global rainfall erosivity 3. Soil erosion by water (RUSLE2015) 4. Soil erosion in forestland in Europe (using RUSLE2015) 5. Soil erosion by wind 6. Rainfall Erosivity in the EU and Switzerland (R-factor)	Joint Research Centre (JRC)	1. https://esdac.jrc.ec.europa.eu/content/global-soil-erosion 2. https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity 3. https://esdac.jrc.ec.europa.eu/content/soil-erosion-water-rusle2015 4. https://esdac.jrc.ec.europa.eu/content/soil-erosion-forestland-europe-using-rusle2015 5. https://esdac.jrc.ec.europa.eu/content/Soil_erosion_by_wind 6. https://esdac.jrc.ec.europa.eu/content/rainfall-erosivity-european-union-and-switzerland

7. Soil Erodibility (K- Factor) High Resolution dataset for Europe 8. Net erosion and sediment transport using WaTEM/SEDEM (for EU) 9. Global phosphorus losses due to soil erosion 10. Global soil erosion by water in 2070 11. Soil loss due to crop harvesting in the European Union		7. https://esdac.jrc.ec.europa.eu/content/soil-erodibility-k-factor-high-resolution-dataset-europe 8. https://esdac.jrc.ec.europa.eu/content/estimate-net-erosion-and-sediment-transport-using-watemsedem-european-union 9. https://esdac.jrc.ec.europa.eu/content/global-phosphorus-losses-due-soil-erosion 10. https://esdac.jrc.ec.europa.eu/content/global-soil-erosion-water-2070 11. https://esdac.jrc.ec.europa.eu/content/soil-loss-due-crop-harvesting-european-union
Decline in Soil Organic Matter (SOM): 1. Topsoil Soil Organic Carbon (LUCAS) for EU25 2. Carbon budget in the EU agricultural soils 3. Soil Organic Matter (SOM) fractions for 186 LUCAS 2009 soil samples (grassland, forest) 4. Pan-European SOC stock of agricultural soils 5. Global Soil Organic Carbon Estimates 6. OCTOP: Topsoil Organic Carbon Content for Europe 7. Soil Organic Matter	Joint Research Centre (JRC), European Environment Agency (EEA, 7.)	1. https://esdac.jrc.ec.europa.eu/content/topsoil-soil-organic-carbon-lucas-eu25 2. https://esdac.jrc.ec.europa.eu/content/carbon-budget-eu-agricultural-soils 3. https://esdac.jrc.ec.europa.eu/content/soil-organic-matter-som-fractions 4. https://esdac.jrc.ec.europa.eu/content/pan-european-soc-stock-agricultural-soils 5. https://esdac.jrc.ec.europa.eu/content/global-soil-organic-carbon-estimates 6. https://esdac.jrc.ec.europa.eu/content/octop-topsoil-organic-carbon-content-europe 7. https://www.eea.europa.eu/data-and-maps/indicators/soil-organic-carbon-1/assessment
Soil compaction - Natural susceptibility to soil compaction in Europe	Joint Research Centre (JRC)	https://esdac.jrc.ec.europa.eu/content/natural-susceptibility-soil-compaction-europe

Decline in soil biodiversity 1. Potential threats to soil biodiversity in Europe 2. Global Soil Biodiversity Atlas Maps 3. Biodiversity factor in soil erosion	Joint Research Centre (JRC)	https://esdac.jrc.ec.europa.eu/content/potential-threats-soil-biodiversity-europe https://esdac.jrc.ec.europa.eu/content/global-soil-biodiversity-maps-0 https://esdac.jrc.ec.europa.eu/content/biodiversity-factor-soil-erosion
Soil contamination - Progress in management of contaminated sites (LSI 003)	European Environment Agency (EEA)	https://www.eea.europa.eu/data-and-maps/indicators/progress-in-management-of-contaminated-sites-3/assessment
Soil sealing and land take - Imperviousness and imperviousness change in Europe (LSI 002, indicator, map data and dashboard) - Land Take (CSI 014, LSI 001, indicator, base data Corine Land Cover, dashboard)	European Environment Agency (EEA)	https://www.eea.europa.eu/data-and-maps/indicators/imperviousness-change-2/assessment https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness https://www.eea.europa.eu/data-and-maps/dashboards/imperviousness-in-europe https://www.eea.europa.eu/data-and-maps/indicators/land-take-3/assessment https://land.copernicus.eu/pan-european/corine-land-cover https://www.eea.europa.eu/data-and-maps/dashboards/land-take-statistics

Table 4: National data sets

Data set	Data provider	Web link and comments
Base data		
Land use/land cover data - Occupation Biophysique du Sol (OBS) 1989, 1999, 2007 - Land Information System Luxembourg (LIS-L) 2015 - Land _Use/Land Cover 2018	Ministère de l'Environnement, du Climat et du Développement durable & Ministère de l'Énergie et de l'Aménagement du territoire	https://geocatalogue.geoportail.lu/geonetwork/srv/fre/catalog.search#/metadata/b4836d86-2803-4dcf-a991-7e78ab9c41b6 https://data.public.lu/fr/datasets/obs-2007-landcover-2007/ https://geocatalogue.geoportail.lu/geonetwork/srv/fre/catalog.search#/metadata/bd672300-0851-4901-82c4-6099aff1fcf7 https://data.public.lu/fr/datasets/landcover-landuse-2015-1/ https://geocatalogue.geoportail.lu/geonetwork/srv/fre/catalog.search#/metadata/7012fa2f-5f37-4aa3-a929-d8c0cdedf408 https://geocatalogue.geoportail.lu/geonetwork/srv/fre/catalog.search#/metadata/5260f241-4bb8-467f-9eff-3782438c928e https://data.public.lu/en/datasets/inspire-annex-iii-theme-land-use-land-use-2018/#
Topographic database (base de données topo-cartographique, 2015)	Administration du cadastre et de la topographie (ACT)	https://data.public.lu/fr/datasets/bd-l-tc-2015/
Land use planning and sectorial master plans - Plan d'occupation du sol - Plan d'aménagement partiel - Plan d'aménagement global	Ministère de l'Énergie et de l'Aménagement du territoire	https://data.public.lu/fr/datasets/plan-doccupation-du-sol-plan-damenagement-partiel-plan-damenagement-global/ https://amenagement-territoire.public.lu/fr/plans-caractere-reglementaire/pos.html

- Projet de plan directeur sectoriel « Zones d'activités économiques » - PSZAE - Projet de plan directeur sectoriel « Logement » - PSL - Projet de plan directeur sectoriel « Transports » - PST - Projet de plan directeur sectoriel « Paysages » - PSP		https://data.public.lu/fr/datasets/projet-de-plan-directeur-sectoriel-zones-dactivites-economiques-pszae/ https://data.public.lu/fr/datasets/projet-de-plan-directeur-sectoriel-logement-psl/ https://data.public.lu/fr/datasets/projet-de-plan-directeur-sectoriel-transports-pst/ https://data.public.lu/fr/datasets/projet-de-plan-directeur-sectoriel-paysages-psp/
Agricultural parcel data (FLIK)	Administration des services techniques de l'agriculture (ASTA)	https://data.public.lu/fr/datasets/referentiel-des-parcelles-agricoles-flik/
Water quality data - Point measurements of groundwater nitrate concentration - Point measurements of surface nitrate concentration - Physico-Chemical status of flowing waterbodies - Ecological status of flowing water - Hydromorphological status of flowing water - Chemical status of flowing water (2008 105 EG ubiquitous substances) - Chemical status of flowing water (EU Directive 2013/39)	Administration de la Gestion de l'Eau	Data available on request

Soil degradation processes/soil threats		
Soil erosion Data on mass movements/landslides from the Service de Géologie of the Administration des Ponts et Chaussées	Administration des services techniques de l'agriculture (ASTA)	Data existing from Projet ERRUISSOL-LU: carte du risque d'érosion hydrique et de ruissellement; not publicly available (also here: http://www.partenariatsyr.lu/fr/files/praesentationen-wwt2019-starkregen.pdf Potential to use European data from JRC on soil erosion by water (https://esdac.jrc.ec.europa.eu/content/soil-erosion-water-rusle2015) - feedback from LIST (Christophe Hissler) not favourable, data too coarse
Soil Organic Matter/Carbon Map of the SOM/SOC content distribution in Luxembourg Map of SOM/SOC stocks distribution in Luxembourg Map of soil associations (1/100 000) Soil Map (1/25.000)	Administration des services techniques de l'agriculture (ASTA)	https://data.public.lu/fr/datasets/carte-de-la-distribution-des-stocks-de-carbone-organique-dans-les-sols/ (data set, based on developments as described in the following publication: https://agriculture.public.lu/dam-assets/publications/asta/boden1/rapport-corg-content-map-lu-stevens-2014-vfinale.pdf) https://agriculture.public.lu/dam-assets/publications/asta/boden1/rapport-corg-stock-map-lu-stevens-2014-vfinale.pdf)https://data.public.lu/fr/datasets/carte-des-associations-de-sols/ https://map.geoportail.lu
Soil compaction		No national data available
Decline in soil biodiversity		No national data available
Soil contamination Seveso sites register		Bodenmonitoring Luxembourg: Sachstandsbericht nach Abschluss der ersten Beprobungskampagne, 2006. Administration de l'Environnement, Divisions des Déchets. Imprimerie Centrale S.A., Luxembourg https://seveso.public.lu/fr.html

Layer of suspected potentially polluting activities (CASIPO)		https://map.geoportail.lu/theme/main?lang=en&version=3&zoom=10&X=668518&Y=6395005&layers=798&opacities=1&bgLayer=basemap_2015_global&crosshair=false&rotation=0 https://geocatalogue.geoportail.lu/geonetwork/srv/fre/catalog.search#/metadata/974688ed-130e-4704-ba2c-72154ed0cecb
Soil sealing		No national data available
Soil acidity	Administration des services techniques de l'agriculture (ASTA)	https://data.public.lu/fr/dataset/carte-du-statut-acido-basique-dans-les-sols-agricoles
	Soil protection measures	
Soil protection by protecting nature and biodiversity and, thus, restricting conversions with negative effects: Natura 2000 sites Protected zones of national interest Biotope cadastre of open landscapes		https://data.public.lu/fr/datasets/natura-2000-zac-special-areas-of-conservation-habitats-directive/ https://catalog.inspire.geoportail.lu/geonetwork/srv/eng/catalog.search#/metadata/227ba25a-a36a-42bd-bfba-67c01d2ec016 https://data.public.lu/fr/datasets/zones-protegees-dinteret-national-declarees/ https://data.public.lu/fr/datasets/inspire-annex-i-theme-protected-sites-biotope-cadastre-of-the-open-landscapes/

5 CONCLUDING DISCUSSION - RECOMMENDATION FOR NEXT STEPS

Soil resources are an integral component of land for which there is a long-established legal system conferring entitlements to use rights, but also defining stewardship duties. Ultimately, effective soil protection depends on ensuring that there is a correct balance between these rights and duties as they affect soil. A successful Soil Protection Plan will underpin this balance, adding economic value to society by reducing damage costs and conserving resources to underpin future development. It will also avoid regulatory duplication and unnecessary transaction costs.

Soil protection is already an integral part of many existing legislation and regulation and a future Soil Protection Plan should reinforce what has already been achieved and seek synergistic gains. At the same time, gaps in soil protection need to be closed by additional regulation, strategic plans or voluntary actions, particularly where these gaps present economic harm and lead to irrecoverable damages and constrain achievement of the SDGs. The appropriate approach is recommended by the GSP, which is to address "soil protection within strengthened agricultural and environmental policies, to realise multiple benefits", supported by evidence from the IPCC SRCCL recommending to design "mutually supportive land and climate policies, institutions and governance systems at all scales". This approach can be combined with positive incentives to encourage investment in soil protection and adoption of best practice.

The fact that soil protection is fundamental to sustainable development is fully recognised at the European level; there is increasing emphasis on the management of soil resources being integral to member states' contributions to European goals and to meeting their legal obligations. Efforts to define a Directive dedicated to soil protection were abandoned due to disputes over the subsidiarity principle. This emphasises the need for national regulation. There is no EU Directive focused specifically on soil protection and none is anticipated in the medium term. However, the new EU Biodiversity Strategy for 2030 announces an update of the EU Soil Thematic Strategy in 2021 and the EC has started a consultation process on its development. Moreover, there are direct requirements for soil protection and halting soil degradation, respectively, in other Directives and initiatives (F2F, IED, Waste…) and the full implementation of others requires effective soil management (especially Water). These requirements have already been transformed into national legislation with implementing regulations. Additionally, the current CAP requires protective soil management as a condition for Single Farm Payments and more stringent conditions are anticipated in the next CAP. The Plan should highlight all these existing EU requirements and seek to increase the effectiveness and efficiency of their delivery.

Luxembourg has a strong regulatory system controlling rural land use change. This appears to be sufficient to protect soil in forest and semi-natural areas. There is strict conservation control to prevent losses of forest land and other high value natural features. However, a side effect is that the pressure due to land-use change is concentrated on agricultural soils. The Plan should build on the existing controls to ensure that soil protection actions are appropriately prioritised, covered sufficiently in the relevant regulations and implemented effectively. In line with the general situation in Europe, quite strong controls on land use / management change within agriculture are accessible under the second pillar of CAP. Preventing conversion of permanent grassland to cropland is one of its priorities. The implementation of the next CAP in Luxembourg will have to maintain a high level of protection of permanent grasslands and support the establishment of new permanent grassland wherever this is appropriate. Land management within cropland requires rigorous and effective implementation of GAEC conditions under the CAP to maintain and increase SOM stocks, and prevent and decrease soil erosion in agricultural land. This needs effective inspection as well as science-based guidance, innovation, advice and training.

The EU treaties leave spatial planning and development control to national competence, although requirements for impact assessments are covered by Directives. Spatial planning and construction regulations are a critical national responsibility in regard to soil protection (see chapter 3.3). They should ensure land take and soil sealing are kept to a minimum consistent with sustainable development. The existing planning regime appears sophisticated, mature and progressive. However, it does not adequately address soil sealing in permitted development or the conservation of soil resources during construction, both of which are necessary.

Effective governance for soil protection requires stakeholder motivation and capacities to be developed. Ideally, behaviours and motivation should be positively aligned with the aspirations of the Plan. This requires engagement with stakeholders, to increase their awareness and understanding and equip them with relevant knowledge and tools. The range of stakeholders that should be targeted include politicians, public officials, private companies including farmers, landowners and managers as well as individual citizens.

Figure 6 provides an indicative map of stakeholder interests in and influence on the sustainable management of soils resources[126]. Different emphases on different aspects of soil protection are needed to optimise communication to the various stakeholders. In addition, it is essential to have an accessible evidence base for decision-making, to develop capacities by education and professional development and to provide advice and training to those who directly manage or set policy for soil use and management.

To propose a consistent and achievable strategy in the future Soil Protection Plan, all the public actors in charge of topics directly or indirectly related to soil (AEV, ASTA, SER, ANF, AGE, DATer…) should work together. A full cooperation between these actors will enable them to share experiences, data and working methodologies to take into account all specific concerns and objectives of each stakeholder (agriculture, land use planning, biodiversity, risk for health and ecosystems, water management, waste management…).

[126] EEA, 2016. Report 7/2016: Soil resource efficiency in urbanized areas – analytical framework and implications for governance. 94 p
https://www.eea.europa.eu/publications#c7=en&c11=5&c14=&c12=&b_start=0&c13=soil%20resource%20efficiency

Figure 6: An indicative map of stakeholder interests and influence in the sustainable management of soil resources (from 'Soil resource efficiency in urbanised areas -Analytical framework and implications for governance, EEA report No 7/2016)