ETC/ULS Report | 02/2018

Land cover changes and soil functions

An approach for integrated accounting

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European Environment Agency
European Topic Centre on Urban, Land and Soil Systems

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Abbreviations

7th EAP	Seventh Environment Action Programme
Benelux	Belgium, the Netherlands and Luxembourg
CAP	Common agricultural policy
CICES	Common International Classification of Ecosystem Services
CLC	Corine Land Cover
EC	European Commission
EEA	European Environment Agency
EEA-39	39 member and cooperating countries of the EEA
EU	European Union
EU-28	28 Member States of the EU
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
Gt	Gigatonne
JRC	Joint Research Centre
LCF	Land cover flow
NUTS	Nomenclature des unités territoriales statistiques
OECD	Organisation for Economic Co-operation and Development
PO	Priority objective
SDG	Sustainable Development Goal
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

Glossary

Biomass production potential	The soil function biomass production indicates that soil is the basic condition to produce biomass (e.g. crops, grass, forest). The results presented in this study represent the potential of the soils to provide this soil function. Even though the actual land use (e.g. arable land) is different from a specific biomass production potential (e.g. forest), the soil theoretically still has the potential to produce this kind of biomass (e.g. in the case of land use changes) (based on Tóth et al., 2013).
Land accounting	A model to describe resource stocks and flows over time in a consistent and systematic way; the EEA Land and Ecosystem Accounting system is based on an accounting grid (adapted from EEA, 2006b).
Land cover	Corresponds to a (bio-)physical description of the Earth's surface. It is that which overlays or currently covers the ground. This description enables various biophysical categories to be distinguished, e.g. vegetation (trees, shrubs, herbaceous cover), bare soil, hard surfaces (rocks, buildings), mires, bogs and open water bodies (EEA, 2017).
Land cover flow	Overlaying different land cover layers for change detection allows for up to 1 892 possible combinations (44 CORINE land cover classes). To interpret this amount of information, land cover changes are classified according to major land use processes into land cover flows (EEA, 2006b).
Land processes	Major land cover change drivers resulting from the thematic grouping of land cover flows. The definition of the land processes can be found in Table 2.1.
Land take	This is the result of the expansion of residential areas, as well as industrial, commercial and other artificial surfaces: the area of land that is 'taken' by infrastructure itself and other facilities that necessarily go along with infrastructure, such as filling stations on roads and railway stations (EEA, 2017).
Land use	Corresponds with the socio-economic description (functional dimension) of areas: areas used for residential, industrial or commercial purposes, for farming or forestry, for recreational or conservation purposes, etc. Unlike land cover, land use is difficult to 'observe' from remote sensing only. Distinctions between land use and land cover, and their definition, have impacts on the development of classification systems, data collection and information systems in general (EEA, 2017).
Natural capital	Any stock of natural resources or environmental assets which provide a flow of useful goods and services, now and in the future (de Groot et al., 2002).
Soil	The top layer of the land surface of the Earth, i.e. a three-dimensional body performing a wide range of socio-economic and ecological functions. It is a complex medium composed of disintegrated rock particles, humus, water and air, formed by a porous matrix, in which air, water and biota occur together with the fluxes of substances and fluids between these elements. Alteration of soil processes leads to changes in the functioning of ecosystems, and many environmental problems that become

	apparent in other media actually originate within the soil (EEA, 2017).
Soil function	Soil functions are general or specific capabilities of soil to support various agricultural, environmental, landscape and urban applications. Specific soil functions are manifold and can be grouped as (1) biomass production, (2) storing, filtering, and transforming nutrients and water, (3) hosting the biodiversity pool, (4) acting as a platform for most human activities, (5) providing raw materials, (6) acting as a carbon pool, and (7) storing geological and archaeological heritage (adapted from Tóth et al., 2013).
Soil sealing	The loss of soil resources as a result of land being covered for housing, roads or other construction work (EEA, 2017).

Acknowledgements

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Internal and external reviewers
The material in this report has been presented and discussed at two Eionet (European Environmental Information Observation Network) thematic workshops. In addition, the report has also drawn on consultation with Eionet.

Executive Summary

Context and objectives

The current assessment represents the first attempt to assess land use efficiency at a European scale. Several new data sets relating specifically to soil functions, were published only recently, which made this assessment possible. A key aim of this work was to study land cover changes and their positive or negative impacts on soil functions, and to obtain a disaggregated hotspot analysis and an overall balance of those impacts on soil functions.

Land is the physical basis for most human activities, and its conditions are important drivers for management decisions and land use change, either directly or indirectly. It can be described in two spatial dimensions: horizontally, land use (management) and land cover (vegetation, buildings and infrastructure, surface waters), and vertically, soils. Soil is a finite, non-renewable resource because its regeneration takes more than a human's lifetime. It is a key component of the natural capital, and contributes to basic human needs by supporting, for example, food provision, clean water and clean air, and by acting as major store for organic carbon.

Ecosystems and landscapes provide multiple ecosystem services based on soil functions and are thus considered multi-dimensional and multi-functional. Understanding linkages and interactions between ecosystem services, and the causes and drivers for the improvement or decline of the environmental condition, is a key challenge for sustainable ecosystem and landscape management. Changes in land cover and land use threaten the capacity of soils to provide its ecosystem-related functions. These functions condition management options and ecosystem performance.

Land resource efficiency strives to maximise societal (socio-economic) and environmental benefits offered by land and its resources, while avoiding its degradation and loss. The need to protect land resources is stated in the EU's Seventh Environment Action Programme (7th EAP). The 7th EAP also recognises the importance of the proper knowledge base. This ETC/ULS report provides new insights to the effect of land cover change on soil functions in Europe.

Data used for the analysis

Harmonised and validated pan-European data about land cover change were combined with pan-European spatial data about soil functions. Land cover accounting helps to establish a more systematic overview of land cover and its change over time. Currently, published land accounts and its methods only consider land cover and land use at the land surface. This report aims to present an approach, which also considers the vertical dimension of land accounting: soils. Qualitative and quantitative information about soil functions were compiled and analysed in the context of land cover change.

Spatial data about **land cover change** were derived from the Corine programme (CLC, reference years 2000, 2006 and 2012). For evaluation and interpretation, different Corine change categories were summarised into land cover flows (LCFs). The assessment considers the following seven key land processes aggregated from LCFs and applying the definitions presented in Table 2.1:

- urban expansion;
- agricultural intensification;
- agricultural extensification;
- agricultural expansion;
- forest expansion;
- forest fellings; and
- water bodies expansion.

Soil functions data express the potential of a given soil to supply a specific function, independent of the current land cover or land use. This potential is modelled on soil-inherent information (such as texture or pH), climate information, topographic data and land cover information. Datasets are available from the JRC European Soil Data Centre as grid layers with a spatial resolution of 1 km². The assessment covers seven soil functions, four of which have further sub-functions:

- biomass production (sub-functions (i) arable crops, (ii) grass and (iii) forest);
- raw material provision (sub-functions (i) organic material and (ii) construction material);
- storing and filtering of water and nutrients/substances (sub-functions (i) substance storing, (ii) substance filtering and (iii) water storing);
- soil organic carbon pool (sequestration);
- soil biodiversity pool;
- platform for human activities;
- storing geological and archaeological heritage (sub-functions (i) bones/teeth, (ii) metals, (iii) organics and (iv) stratigraphic evidence).

Each land process can influence soil functions in a negative or a positive way. A dedicated evaluation matrix was developed to identify the predominantly positive or negative impacts of a given land process on the various soil functions. This matrix then supports the analysis of the balances.

Time scale: As most of the soil function data sets refer to the reference year 2000, the analysis looks at the impact of land cover changes for the period 2000-2012 compared with the soil function potentials for the reference year 2000.

Geographical scale: The assessment includes the pan-European scale (EEA-39 or EU-28, depending on the input data set), the country scale and the regional scale at NUTS 3 (Nomenclature des unités territoriales statistiques) level.

Selected findings

At a **pan-European scale**, forest expansion and fellings occur most often and have the highest shares in terms of affected land. Both land processes account for almost three quarters of all land cover changes between 2000 and 2012 in Europe (fellings with 39.6 %, and forest expansion with 32.8 %). However, the predominant land use, forestry, has not changed. Urban development accounted for 8.5 % of the area undergoing land cover change, whereas agricultural intensification was observed for 5.6 % of the area.

At the **country level**, land cover flows dominate as follows:

- Urban expansion dominates in the Netherlands, affecting 1.52 % of the country's area, followed by Cyprus with 1.49 % and Albania with 1.03 %.
- Agricultural extensification dominates in the Czech Republic, affecting 1.95 % of the country's area, whereas agricultural intensification is highest in Estonia with 0.82 %, Portugal with 0.74 % and Hungary with 0.63 %. Agricultural expansion is a minor process, Cyprus being most affected with 0.38 %.
- Forest expansion is highest in Sweden with 5.5 %, followed by Portugal with 2.9 %. Forest fellings dominates in Latvia and Portugal with 5.0 % and 4.9 %, respectively.

An analysis of **regional hotspots of impacts on soil functions** is presented in the report. In this context, a hotspot is defined as a NUTS 3 region in which land cover changes and positive or negative impacts on soil functions are outstanding compared with the total sample of NUTS 3 regions. This assessment was limited to the biomass production function, the biodiversity potential and the soil carbon potential. Urban expansion was identified as the most relevant land cover flow in the regional assessment, affecting 93% of European regions and exerting a negative effect on all soil functions. The assessment identified 69 hotspots with negative impacts on the biomass production function, with the largest cluster (21 regions) located in the Netherlands. All other hotspots are scattered across Europe and correspond to metropolitan areas. Despite the broad occurrence of urban expansion in Europe, and when effects on soil functions are considered, various countries do not have any hotspots, including the Scandinavian countries, the Baltic countries, Austria, France, Iceland, Slovakia, Switzerland, and the Balkan countries with the exception of Albania. The situation in the United Kingdom is quite remarkable, where many regions managed to limit their losses of agricultural land despite considerable population growth.

Comparing the “positive” (extensification) and the “negative” (intensification) land cover changes, regions with predominantly negative impacts prevail. A negative balance means that the region is at risk of experiencing a decrease in the capacity of its soils to provide one or more soil functions. Overall, it seems that agricultural uses such as the cultivation of grasslands and forests, in combination with urban expansion, are key threats to soils. Geographically, there is a corridor starting in the Netherlands and western Germany, extending south-west across France (mainly through coastal regions and the Rhône valley), and covering almost the entire Iberian Peninsula. In addition, the Baltic countries, parts of eastern and south-eastern Europe (Bulgaria, Greece, south-western Poland, Romania and Slovakia), Austria, western Finland, Italy, southern Sweden and parts of the United Kingdom also show these conditions.

Predominantly positive impacts can be seen in the Czech Republic, Ireland and most parts of Sweden. Other more isolated regions are located in France, Germany, southern Hungary and Spain.

Conclusions

The current assessment represents the first attempt to assess land cover changes and its effects on soil functions at European scale. The results of the study add value to the discussion about land use resource efficiency, by providing pan-European information on (1) the spatial analysis of land cover changes, (2) its importance and impact on the capacity of soils to properly function (hotspots), and (3) the total balance between “positive” and “negative” land cover change and soil multi-functionality. The study, therefore, contributes to filling a gap in the knowledge base following priority objective 5 of the 7th EAP, concerning the use and management of land and the protection of Europe`s soils and, hence, natural capital (priority objective 1). The analysis also supports bridging knowledge gaps in the context of the land degradation neutrality objective put forward after Rio+20 and in the Sustainable Development Goals (in particular target 15.3).

The European scale of the assessment does not allow for recommendations on local decision-making about soil and land conservation. More precise data and assessments are needed to overcome this limitation. For example, further comparisons with higher-resolution national or regional data could reveal how far the results of this pan-European assessment coincide, or where drivers or covariates are identified which could not be detected so far. The results presented here may serve as a starting point for improving input data, and for designing future studies, in support of the 7th EAP or follow-up processes and policy demands.

1 Introduction

This chapter will:

- investigate land and soil in the context of land resource efficiency;
- provide an overview of the most important European and global policies related to land degradation neutrality;
- introduce soil functions as an element of land and ecosystem assessments;
- introduce the concepts of land multi-dimensionality and multi-functionality and the role soils play therein; and
- formulate the objectives of the report and indicate the target audience.

1.1 Context

Land is the physical basis for most human activities, and land use changes are driven, directly and indirectly, by almost all economic activities. The medium 'land' comprises different spatial dimensions: land cover and land use (area coverage and vegetation growth, both horizontal), and a third, the vertical dimension of soil and the underlying geology (EEA, 2015). Land, and here specifically soil, is a finite resource. Since the regeneration of soil takes more than a human's lifetime (1-2 cm soil formation in 100 years), soil can be considered a non-renewable resource. Soil is one component of natural capital (de Groot et al., 2002) and contributes to basic human needs by supporting food provision, clean water and clean air, and it is a major carrier for soil biodiversity (Keesstra et al., 2016).

Land take, i.e. the land taken by urban and other artificial land development, includes soil sealing; this is soil covered with an impervious layer, which has been identified as one of the major threats to soils in the 2002 European Commission (EC) Communication 'Towards a Thematic Strategy on Soil Protection' (EC, 2002; see also EC, 2006, and EC, 2012). As soil is the point of contact between the pedosphere and the atmosphere, sealed soil decouples important processes inside and between the biosphere and the lithosphere, and in consequence disrupts potential services and functions of the soil (EEA, 2016a). This relates to water and nutrient cycling, but also to other vital soil-based services, such as biomass production, provision of raw materials and hosting of the biodiversity pool (see illustration of soil functions in Figure 1.1). In general terms, soil functions refer to soil-based ecosystem services and are, therefore, an important aspect of the soil system which contributes to the provision of goods and services (Schulte et al., 2014).

Land take is an ongoing process. In Europe, for the period 2006-2012, it consumed 1 065 km² annually at the level of the 39 member and cooperating countries of the European Environment Agency (EEA-39), based on Corine Land Cover (CLC) data. This corresponds to 6 390 km² in total (EEA, 2016b). Soil sealing, which has the most detrimental effects on the environment, increased by 1 454 km² annually between 2006 and 2009 (EEA-39, based on Copernicus high-resolution layer (HRL) imperviousness data), which corresponds to a total of 4 364 km² (EEA, 2016a).

Figure 1.1 Soil as an integrated element of land and ecosystems

Source: CircUse, 2013

In addition to the pressure caused by urbanisation (i.e. the demand for housing, commerce, industry and infrastructure), the demand for food, bioenergy and other crop- or wood-derived products is one of the major drivers for land degradation. This demand is provoked by ongoing population growth and the need to feed a growing number of people. Recent forecasts predict a global population of approximately 11 billion people by 2100, leading the United Nations (UN) Food and Agricultural Organization (FAO) to estimate that agricultural productivity needs to increase by 60 % before 2050 to provide sufficient food for the estimated global population (Schulte et al., 2015, 2014). However, the majority of the population growth will happen in the developing world, in Africa, large parts of Asia and Latin America. Europe, on the other hand, will experience a stagnation or even a decline in population, driven by socio-economic factors such as increasing life expectancy and decreasing fertility and birth rates (Bongaarts, 2009).

The generally increasing demand can only be met by expanding agricultural land or by increasing the productivity of the existing agricultural land. It has been observed that, globally, the area used for growing crops had increased by around 11 % between 1961 and 2007, with large regional differences (increases in, for example, Africa and Asia, but decreases in Europe and North America) (UNCCD, 2012; UNEP, 2014). While developing the so-called global planetary boundaries concept, to ensure a safe operating space for humanity, Rockström et al. (2009) postulate that "*no more than 15 % of the global ice-free land surface should be converted to cropland*", allocated to the most productive land.

However, agricultural expansion over non-agricultural land and agricultural intensification go along with greater management efforts such as increased nutrient inputs, higher degree of mechanisation and/or irrigation. This may lead to higher biomass production (higher crop yields, root biomass and plant residues), however, negative impacts can also be expected from unsustainable management practices, e.g. salinisation, compaction, erosion, and reduced soil biodiversity (Schulte et al., 2015).

Moreover, soil functions other than biomass production (crop- or wood-derived products) have attracted great attention over past years. The capacity to store carbon makes soil the largest carbon reservoir of the terrestrial carbon cycle (FAO, 2004a) and one of the most promising carbon sinks in times of global warming and increasing greenhouse gas emissions (FAO, 2001). However, recent studies have shown that there is great uncertainty about the duration of the effect (Smith, 2004), the short-term effect of the capacity of soil carbon sequestration (He et al., 2016) and the limited capacity of soils for carbon sequestration (Sommer and Bossio, 2014). The role of soils as a habitat for living organisms has emerged as a central research topic, which sees soil biodiversity as a key aspect to consider when discussing soil degradation (Orgiazzi et al., 2016). The way soil is used and the intensity of its use are essential for the performance of both regulating functions. Forest and grassland are considered the best land uses for providing these functions. Nevertheless, the level of management and the types of trees and grazing affect the capacity to deliver these functions.

From the above it emerges that ecosystems and landscapes are multi-dimensional and multi-functional, i.e. they simultaneously provide multiple ecosystem services and soil functions to various extents across various landscapes (Haygarth and Ritz, 2009; Raudsepp-Hearne et al., 2010). In this context, multi-functionality can be defined as 'the characteristics of ecosystems to simultaneously perform multiple functions that might be able to provide a particular ecosystem service bundle or bundles' (Berry et al., 2015, p. 1). Understanding the linkages and interactions between these ecosystem services (and soil functions are soil-based ecosystem services), as well as the causes and drivers of their respective improvement or decline, is one of the key challenges of ecosystem and landscape management (Raudsepp-Hearne et al., 2010).

In general, land multi-functionality is highly dependent on the way land is used and managed. Land resource efficiency aims at maximising societal (socio-economic) benefits, without degrading land resources. Currently, there is no common EU policy on soil protection, i.e. the EU legal framework fails to address all soil functions in a comprehensive way. Moreover, even if some soil functions are addressed in existing regulations and directives, these provisions mainly aim at preventing the reduction of isolated soil functions rather than improving them, and hence do not target soil multi-functionality (Glaesner et al., 2014). At the global level, the UN Rio+20 Summit (UNGA, 2012) outcome document 'The future we want' highlighted soil degradation as part of land degradation and called for a land degradation-neutral world in the context of sustainable development. This is also a goal to which the EU subscribed and which is reiterated 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 (EC, 2013). The UN Sustainable Development Goals (SDGs), which the EU strives to implement through relevant policies, provide the most recent high-level policy targets that support the concept of land-degradation neutrality, in particular SDG target 15.3 (UNGA, 2015; UNCCD, 2016, Decision 3/COP12, p. 8). Ecosystem functions and services are central to the concept of land-degradation neutrality.

The 7th EAP also puts forward an objective to define targets for sustainable land and soil use (EC, 2013). This, however, requires recognition of the importance of soils as an integrated part of land and ecosystems and, moreover, the availability of suitable, reliable and targeted information on soils and their potential to provide the goods and services required by society. Although efforts have increased in recent years to include ecosystem services and their protection in land management and biodiversity policies, there is still a lack of information on the availability of services and functions, their associations and interaction, and the impact of policies on their provision (Mouchet et al., 2014). Furthermore, soil and soil parameters are not yet included in any accounting approaches.

In this report, pan-European land-cover change data (Corine land-cover changes and derived land-cover flows — see also Section 2.1) were combined with pan-European soil function data that cover all EU countries. The latter were produced by the European Commission Joint Research Centre (JRC) and are available for all soil functions presented in Figure 1.1 (see also Section 2.2.2). The multi-functionality of soils and their capacity to provide various soil functions is largely determined by land use, so using land cover-derived data on the major land processes allows analysis of the threats posed by those processes to soils and their functions.

1.2 Aim and structure of this report

How soils are utilised and managed is basically determined by the functions it delivers and the societal and biological demands (Mouchet et al., 2014, p. 299). Data about soil functions were used here to represent soils' ecosystem services, while land cover change data reflect the effects of human interventions.

Land accounting pursues a systematic overview of the stocks of land cover and their changes over time. So far, the additional vertical dimension of soils has not yet been considered: quantitative and qualitative information about soil functions were used and compared with spatial land cover change data. The report does not claim to cover all elements of land resource efficiency, but intends to contribute to the understanding of land process and its effects on soils. To enable easier interpretation of the complex soil input data, reclassification of map legends was applied (from up to 10 classes in the original data, down to three classes for this report: 'poor', 'average' and 'good' provisioning of a certain soil function). If the potential for a specific soil function is poor, the assessment of the effects of land processes (i.e. the underlying drivers of land cover changes) on the potential becomes less relevant, so the analysis concentrated on good and average soils.

To enable comparison across Europe, harmonised and validated pan-European data sets were employed. Moreover, to get a stronger change signal the time window of the land cover change data is set at 12 years instead of the usual 6-year CLC cycle. Likewise, the land cover flows as proxy for the major land processes are grouped specifically for the purpose of this report. It is acknowledged that the grouping entails some generalisation of processes; however, this was considered acceptable for the pan-European scope of this report. The same reasoning holds true for the balances that describe the quality of the impact of the land processes on the soil functions per reference unit (EU, country or NUTS 3 (Nomenclature des unités territoriales statistiques) region). The findings cannot reflect details of specific European regions. Given the accumulation and propagation of errors related to the various harmonised data sources used in the analysis, more accurate results can probably be produced with data available at local level. However, what the findings can transmit is an overview (based on comparable information) of whether regional trends (as a consequence of land cover changes) regarding the potential of soils to provide one or more soil functions are predominantly positive or negative.

With that in mind, the report addresses policymaking agents and attempts to answer the following questions:

- What is the area share of each NUTS 3 region in Europe that is impacted by specific land processes?
- How are the good and average soils for providing certain soil functions distributed across Europe?
- What is the impact of land processes on the potential of soils to provide certain soil functions?
- Where are the regions in Europe that have the potential to provide more than one soil function located?
- Where are hotspot regions in Europe, i.e. regions in which the balance of predominantly positive and negative impacts is disadvantageous?

The report follows a logical flow, first presenting the input data, followed by the impact analysis of land cover changes on soil functions and the resulting balances (comparison between positive and negative impacts), before closing with an assessment of the implications on land resource efficiency.

Chapter 1 provides an introduction to the context of the study. It lays out a framework by giving information on the status of land and soil in the context of land resource efficiency, listing the most relevant current global and European policies, and introducing the concepts of soil function and land multi-functionality.

Chapter 2 provides details of the study's input data, and in particular the land cover flows that underlie the land processes and their distribution across Europe, as well as the pan-European soil function data and their respective spatial distribution. Finally, the concept of multi-functionality is further explained and the impact evaluation matrix is presented, serving as the basis for the impact analysis and the balance calculations.

The combined presentation of land processes and soil functions is the major topic in Chapter 3, whereas Chapter 4 then focuses on the impacts of a number of selected, sector-related land processes on several of the soil functions. The latter also identifies a number of hotspot regions at the NUTS 3 level in which the potential of soils to provide certain functions might be substantially affected.

At the end of the report, Chapter 5 provides information on the balance of impacts, by looking at the predominantly positive and predominantly negative impacts to assess the overall situation in Europe, but also at national and regional level. Finally, Chapter 6 identifies the implications of the analysis for land governance and attempts to shed light on the status of land resource efficiency in Europe.

2 Land cover changes and soil functions

This chapter will:

- explain the meaning of land cover flows (LCF) and how they represent major land cover change processes;
- present the land cover change data for Europe during 2000-2012, i.e. their distribution across Europe and their proportions;
- describe soil functions, based on available Europe-wide data sets;
- provide more details on the multi-functionality of soils; and
- present an evaluation matrix to assess the impact of land processes on soil functions.

2.1 Land cover changes

2.1.1 Grouping of land cover flows into main "land processes"

Land accounting consists of an area-based inventory of land cover changes (usually derived from CLC), here derived from land cover flows (LCFs) (EEA, 2006b). These LCFs are based on land cover change categories, assuming underlying processes and drivers such as urban residential development, the development of economic sites and infrastructure, agricultural conversion, or forest management. The LCFs were further grouped for this report: this has required expert knowledge about land use (change) processes which condition agricultural intensification or extensification. This grouping was also supported by comparisons between LCF layers and pan-European high nature value (HNV) farmland data ([1]), as well as land use maps by the VOLANTE project ([2]). While HNV farmland provides information about the naturalness of agricultural areas, the VOLANTE data consider transition processes and their impacts.

By default, LCFs are produced for the regular CLC change periods, i.e. 1990-2000, 2000-2006 and 2006-2012. To achieve a stronger change signal for the assessment in this report, LCFs have been specifically produced for this study that will cover the period 2000-2012 (methodology described in Annex 1). The year 2000 was selected as the reference year, since most of the soil function data sets refer to the reference year 2000. Thus, the analysis investigates the impact of land cover changes for the period 2000-2012 on soil function potential for the reference year 2000.

The LCFs were thematically (and spatially) combined into seven land cover change drivers or 'land processes', described in more detail in Table 2.1. It needs to be kept in mind that Corine itself is a hybrid product, i.e. while primarily providing land cover mapping, it also includes notions of functional land use. In consequence, 'land use' and 'land cover' are combined in this report.

Table 2.1 Description of the major land processes

Land process	**Description**
Urban expansion	This process consists of residential, industrial, commercial and infrastructure development. It often leads to land take and the (mostly) irreversible sealing of soil (see Section 1.1). 'Land take' is also known as 'urbanisation' or 'increase of artificial surfaces', and represents an increase of settlement areas (or artificial surfaces) over time, usually at the expense of rural areas (Prokop et al., 2011). When such urban development is dispersed, it is also referred to as urban sprawl (EEA, 2016c).

([1]) https://www.eea.europa.eu/data-and-maps/data/high-nature-value-farmland
([2]) http://www.volante-project.eu/

Agricultural intensification	Agricultural intensification consists of conversion from arable land to any type of irrigated land, as well as conversion from permanent crops, orchards, vineyards and olive groves to irrigated and non-irrigated arable land. In addition, change from pasture to arable land and permanent crops is also included. Agricultural intensification is characterised by higher inputs of capital and/or labour to raise the productivity or yield (output) of a fixed land area (FAO, 2004b). In practice, this is accomplished through the use of high yielding crop varieties, mineral fertilisers, pesticides, irrigation, and mechanisation (Matson et al., 1997; Hazell and Wood, 2008).
Agricultural extensification ([a])	Agricultural extensification includes conversion from arable land to pasture, orchards and vineyards, as well the extension of set-aside fallow land, the extension of agro-forestry systems and the abandonment of farmland towards (semi-)natural land (e.g. Hatna and Bakker, 2011). Agricultural extensification can be described as the decreasing use of capital and input, e.g. reduced use of mechanised ploughing, reduced irrigation of a defined land area, or reduced use of fertilisers and pesticides compared with earlier practices (Eurostat, 2014).
Agricultural expansion	Agricultural expansion comprises all conversion from non-agricultural land into agricultural land, i.e. from forest and semi-natural land, wetland, or developed land into agricultural land, as well as from agriculture-nature mosaics into continuous agriculture. Like agricultural intensification, land conversion, i.e. the expansion of agricultural land, also changes the biotic interactions and patterns of resource availability in ecosystems, and can have serious local, regional and global environmental consequences (Matson et al., 1997; Hatna and Bakker, 2011).
Forest expansion	Forest expansion has two components: the afforestation of previously unforested land (including farming withdrawal with subsequent forest creation), and the reforestation of transitional woodlands, also including previously felled land (IPCC, 2000; Chazdon et al., 2016; FAO, 2016).
Forest fellings	The definition of forest fellings refers in this study to areas where existing forest has been removed either as part of forest management (e.g. clear-cut areas), with subsequent reforestation, or as deforestation, i.e. the conversion of forested land into non-forested land. In Europe, both forest-related processes (forest fellings and forest expansion/afforestation) are characteristics of regular forest management including growing/cutting/planting. They often occur over large areas and thus represent large numbers of hectares in the study data (IPCC, 2000; Chazdon et al., 2016; FAO, 2016). The two processes have been treated separately here, however, as they have been evaluated as having different effects on soil function potential for some functions. Neither process leads to a change in the overall land use, which is forestry. This assessment, which covers 12 years, has thus focused on transitionary effects, which may subside after 20 to 30 years of the new forest cycle. The cycle is commonly 70-100 years (see further discussion on forest management systems in Duncker et al., 2012).

Water body expansion	The area of water bodies increases mostly through the construction of new dams and reservoirs (e.g. drinking water, fire extinction ponds): construction either increases the size of an existing water body, or it creates a new one. It does not include temporarily flooded land, nor conversions of parts of a river to a standing water bodies.

([a]) In several international studies (e.g. Tachibana et al., 2001; Nkamleu, 2011), agricultural extensification corresponds to the extension of agricultural surfaces, i.e. to what this report describes as agricultural expansion, and not to the 'de-intensification' of agriculture (i.e. the reduction of input of all kinds). However, this report follows the definition given in the Eurostat Glossary (Eurostat, 2014).

Table A1.1 to Table A1.6 in Annex 1 provide details of the second- and third-level LCFs that make up the groups.

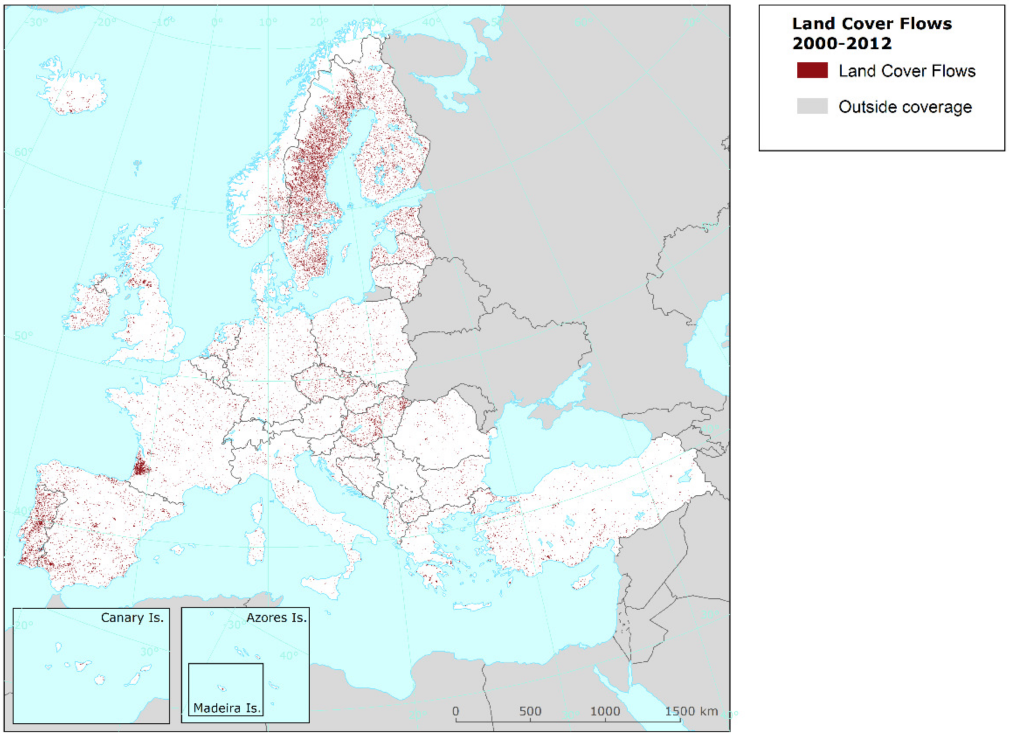
2.1.2 Land processes in the period 2000-2012

Before entering into more detailed analysis, this subsection presents an overview of the pan-European land-cover changes that occurred between 2000 and 2012, as well as the distribution and shares of the land processes across Europe.

Map 2.1 shows the location and distribution of all relevant CLC changes for the period 2000-2012. The map indicates that the highest shares of land processes (all LCFs combined) exist in Scandinavia (mainly Sweden), the Baltic countries (mainly Estonia and Latvia), Portugal, and the south-western part of France (in particular the area south of the Girondes estuary). Most of those LCFs are related to changes in forest land cover. On a national level (NUTS 0), this distribution reflects that Sweden (11.4 %), Portugal (10.5 %), Latvia (6.2 %) and Estonia (6.1 %) have the highest proportion of LCFs (see Map 2.2). In Sweden, the changes are almost exclusively related to forest activities (expansion and fellings), whereas the other three countries also show some agricultural and urban change processes.

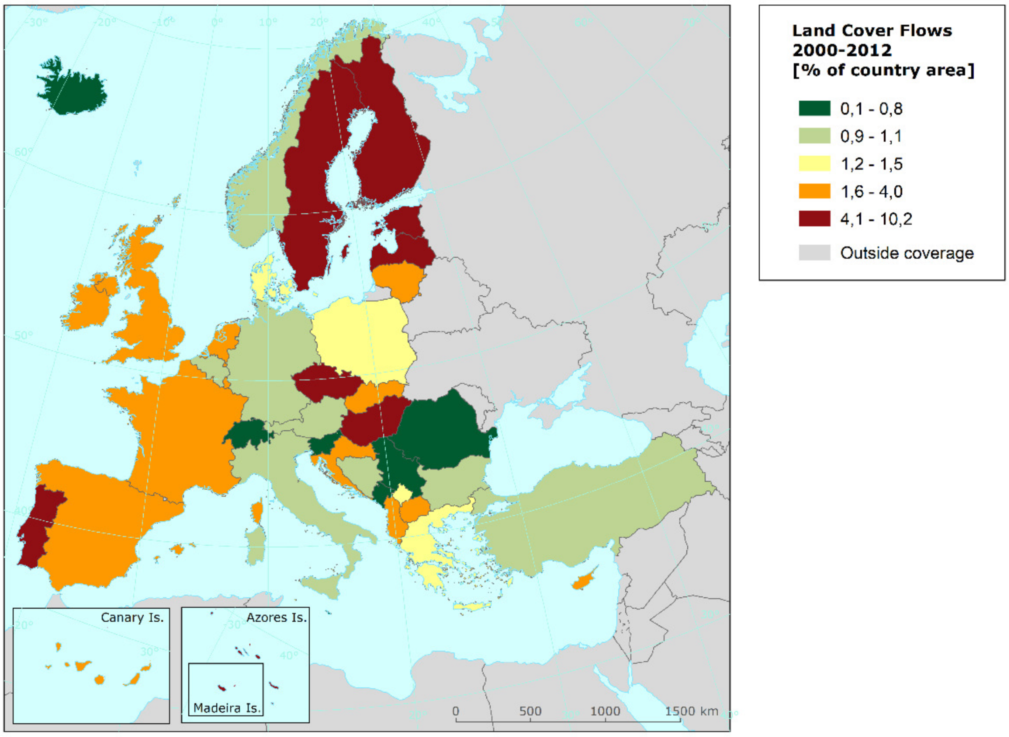
At the European level, forest expansion and fellings are the land processes that occur most often, and therefore possess the highest area proportions (see Figure 2.1; percentage values in the pie chart are rounded). Together these two land processes account for almost three quarters of all changes in Europe between 2000 and 2012 (fellings with 39.6 % and expansion with 32.8 %). While forest expansion and management are the major drivers of changes at the European level, the majority of those changes are forest-internal (EEA, 2013). Urban development activities account for 8.5 %, while agricultural intensification is responsible for 5.6 % of all changes in the period 2000-2012. Urban expansion is a major LCF across Europe, with concentrations around metropolitan areas as well as regions with high infrastructure development mainly located in France, Ireland, Italy, Portugal and Spain.

Map 2.1 Distribution of land cover flows in Europe



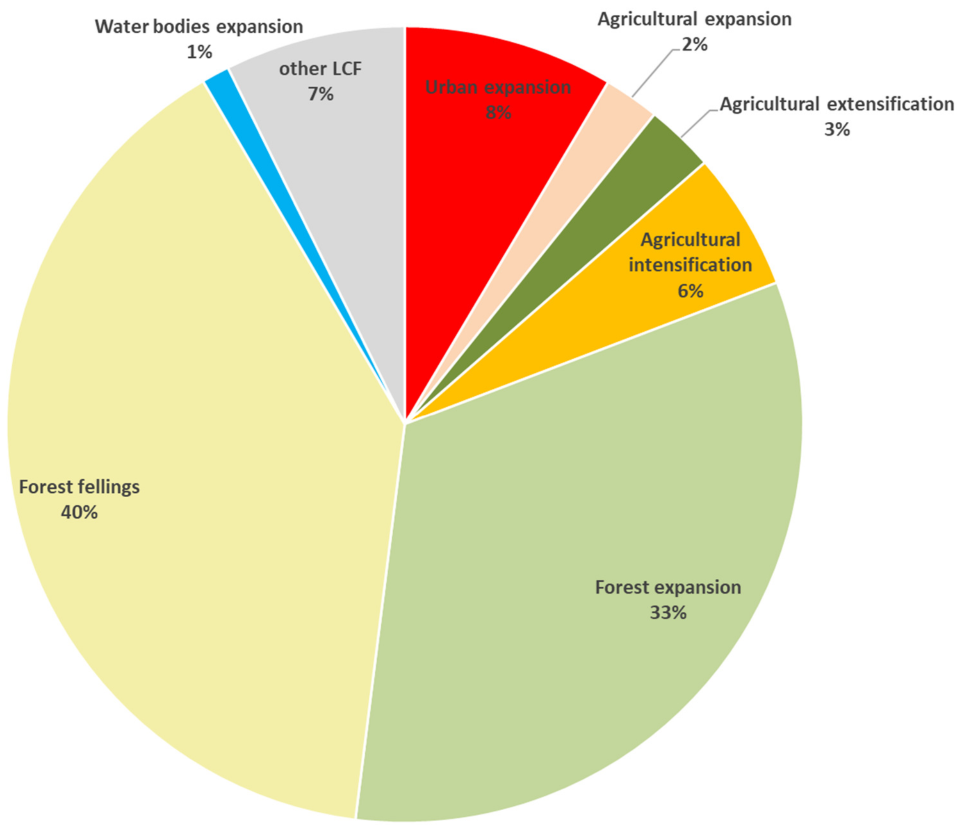
Note: The map shows the spatial distribution of all CLC changes for the period 2000-2012.

Map 2.2 Share of land cover flows per country



Note: The map shows the proportion of all CLC changes for the period 2000-2012 as a percentage of country area.

Figure 2.1 Proportion of the main land processes as a percentage of all land cover flows



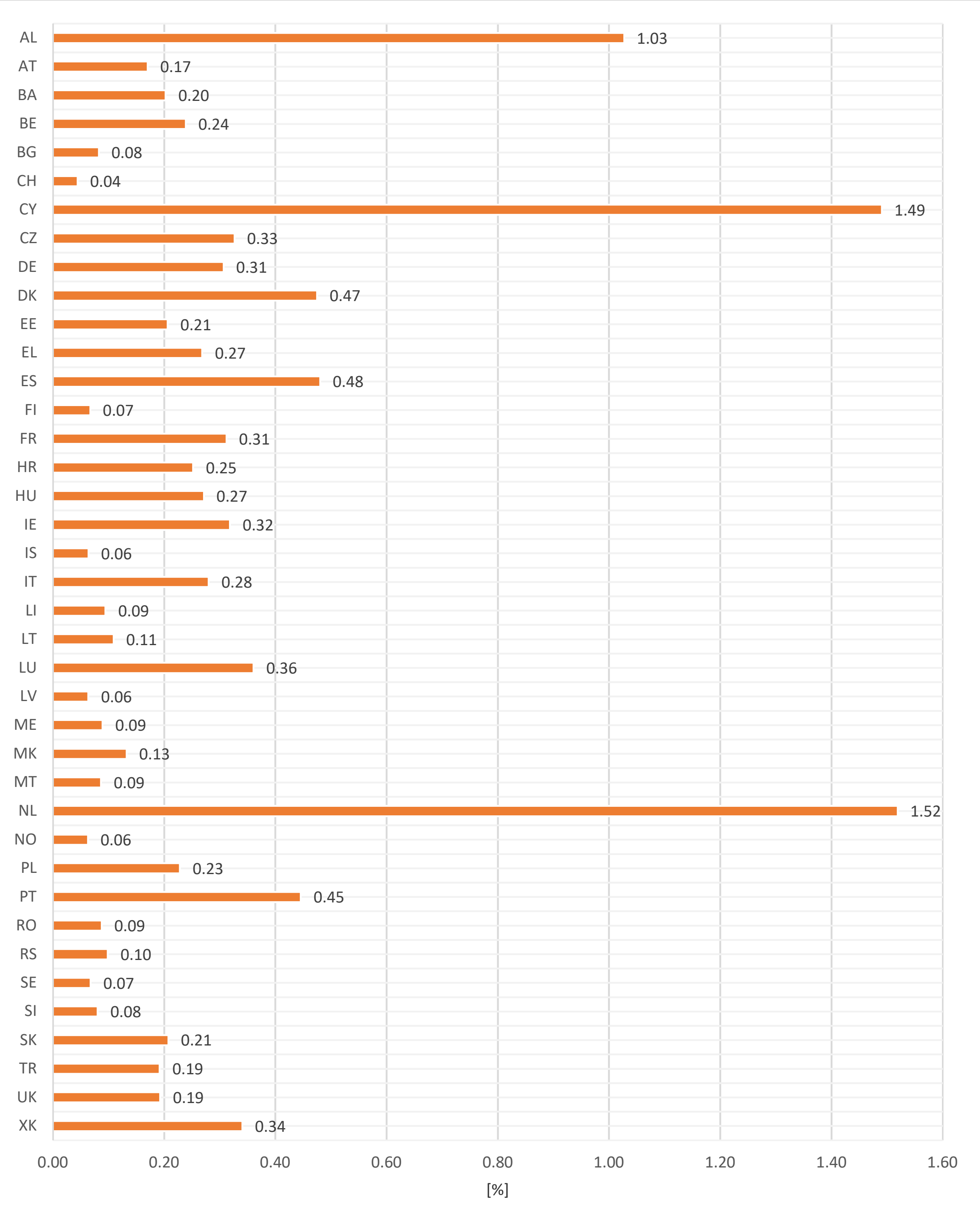
Analysing the three main land processes grouped per driver (urban expansion, agriculture and forest) at country level reveals interesting patterns (see Figure 2.2 to Figure 2.4). The highest values for urban expansion activities can be found in the Netherlands (1.5 % — i.e. 1.5 % of the country's land area experienced urban expansion activities), Cyprus (1.5 %) and Albania (1.0 %). In this case, the highest values are recorded for smaller countries with relatively high population densities. When compared with other countries, the absolute values as well as the urbanised areas per capita do not stand out as much as the proportions relative to country area do.

The highest values for agricultural intensification can be found in Estonia (0.82 %), Portugal (0.74 %) and Hungary (0.63 %), while agricultural extensification is most widespread by far in the Czech Republic (1.95 %), where it accounts for more than three times the area changed by the second largest change value. The absolute values for agricultural intensification are largest by far in Spain, followed by Germany and Turkey. But due to the size of these countries, their relative values are smaller than those mentioned previously. Agricultural expansion is almost non-existent in Europe; only Cyprus (0.38 %), Portugal (0.32 %) and Spain (0.24 %) show some occurrence ([3]).

In terms of the forest management regime, the highest shares of forest expansion can be reported for Sweden (5.5 %), Portugal (3.0 %) and Hungary (2.1 %). The total afforested or reforested area in Sweden is almost five times as high as that of the next country in the list, Finland. Forest fellings is most prominent in Latvia (5 %), Portugal (4.9 %) and Sweden (4.6 %); again, the highest total area can be found in Sweden, while Latvia has only the fifth highest value. Interestingly, while in Latvia and Portugal forest fellings clearly dominates over forest expansion, the situation is exactly the opposite in Sweden.

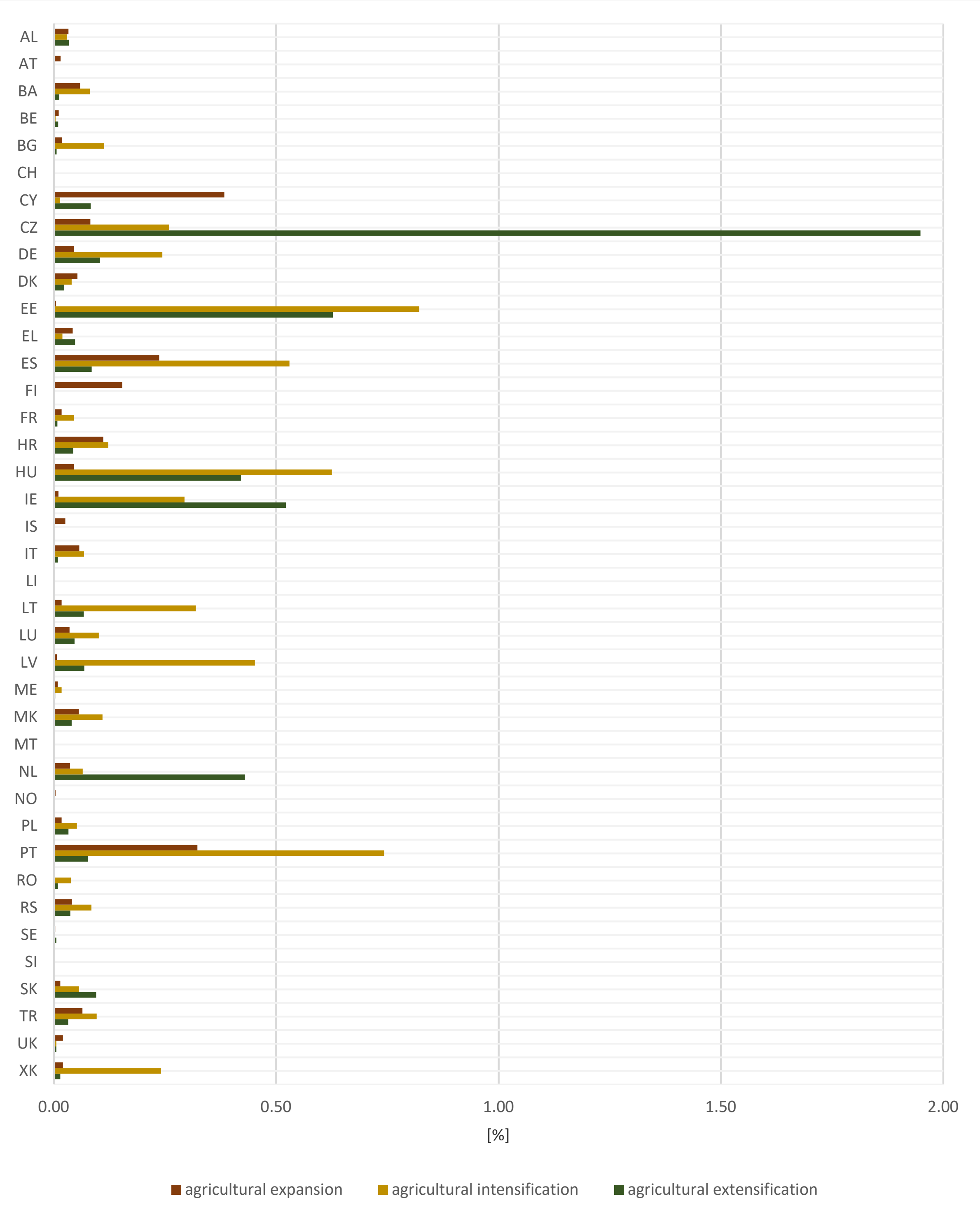
([3]) NB: despite the low occurrence of agricultural expansion, this process is nevertheless analysed later in the report in conjunction with agricultural intensification, as both processes have a predominantly negative impact on most soil functions.

Figure 2.2 Percentage of the land process 'urban expansion' per country, 2000-2012



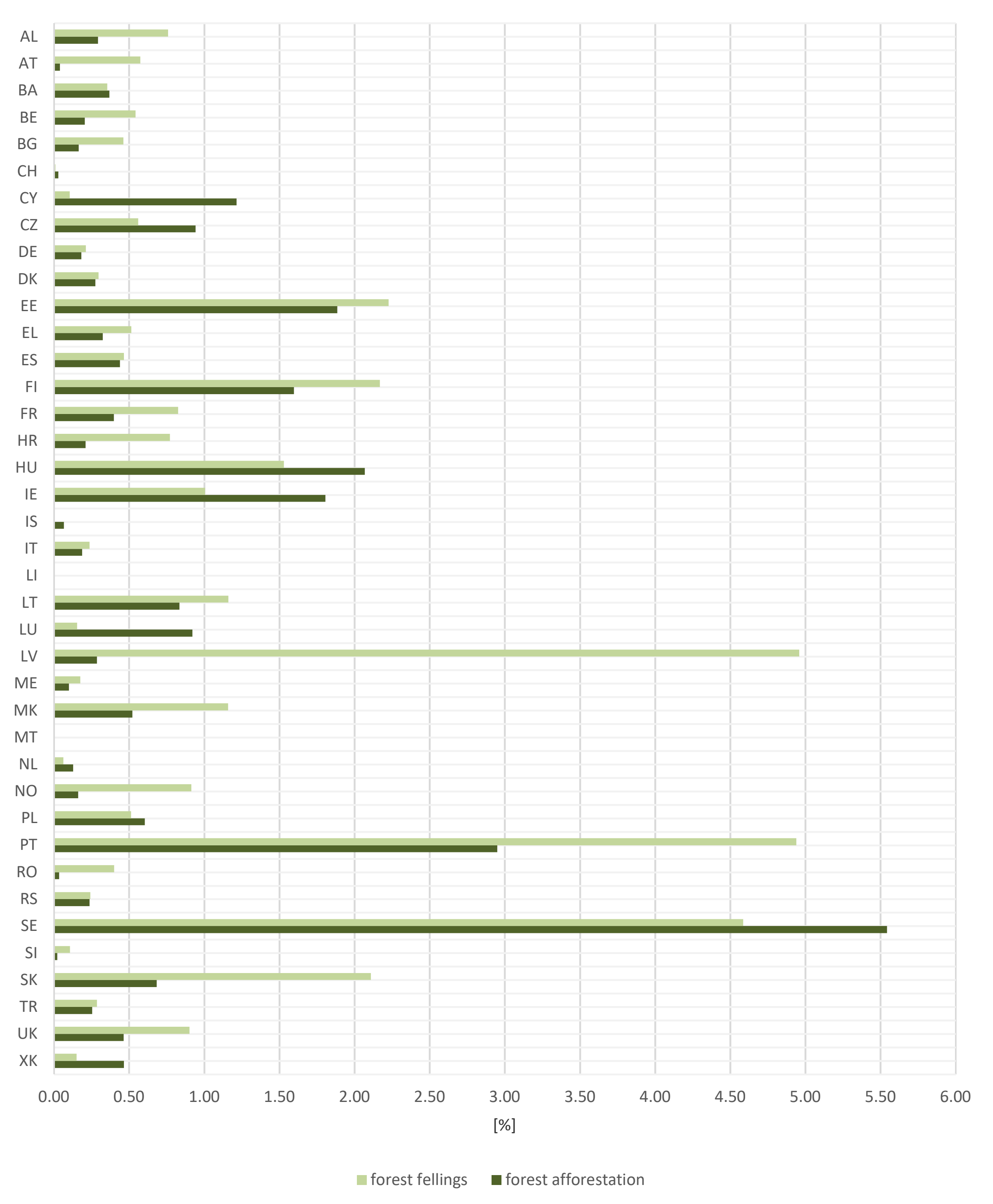
Source: CLC changes between 2000 and 2012, grouped into urban expansion flows (see Table A1.1 in Annex 1) and computed relative to country area.

Figure 2.3 Percentage of the land processes 'agricultural intensification', 'agricultural extensification' and 'agricultural expansion' per country, changes 2000-2012, sorted alphabetically



Source: CLC changes between 2000 and 2012, grouped into the three agriculture-related flows (see Table A1.2 to Table A1.4) and computed relative to country area.

Figure 2.4 Percentage of the land processes 'forest expansion' and 'forest fellings' per country, 2000-2012, sorted alphabetically



Source: CLC changes between 2000 and 2012, grouped into the two forest-related flows (see Table A1.5 and Table A1.6) and computed relative to the country area.

2.2 Soil functions and multi-functionality of soils

This study adds a dimension to the existing land accounts (EEA, 2006b) by including the functions that soils deliver and that are essential for humans and ecosystems (see Section 1.1 for the framework of soil functions). Before providing more details about the soil function data used, the crucial role of soil functions as a basic feature for ecosystem service delivery is presented.

2.2.1 Soil functions as a basis for ecosystem service delivery

Soil functions are general or specific capabilities of soil to support various agricultural, environmental, landscape and urban applications (Tóth et al., 2013). They are based on a combination of one or several soil properties and interactions of them and are influenced by land use and management as well as by climatic conditions and related water availability. They are crucial in the context of ecosystem assessment and mapping at European scale (Maes et al., 2012), since they support the delivery of many ecosystem services. They can be understood as soil-based ecosystem services, taking into account the definition of ecosystem services as the 'beneficial flows arising from natural capital stocks and fulfilling human need' (Dominati et al., 2010, p. 1859).

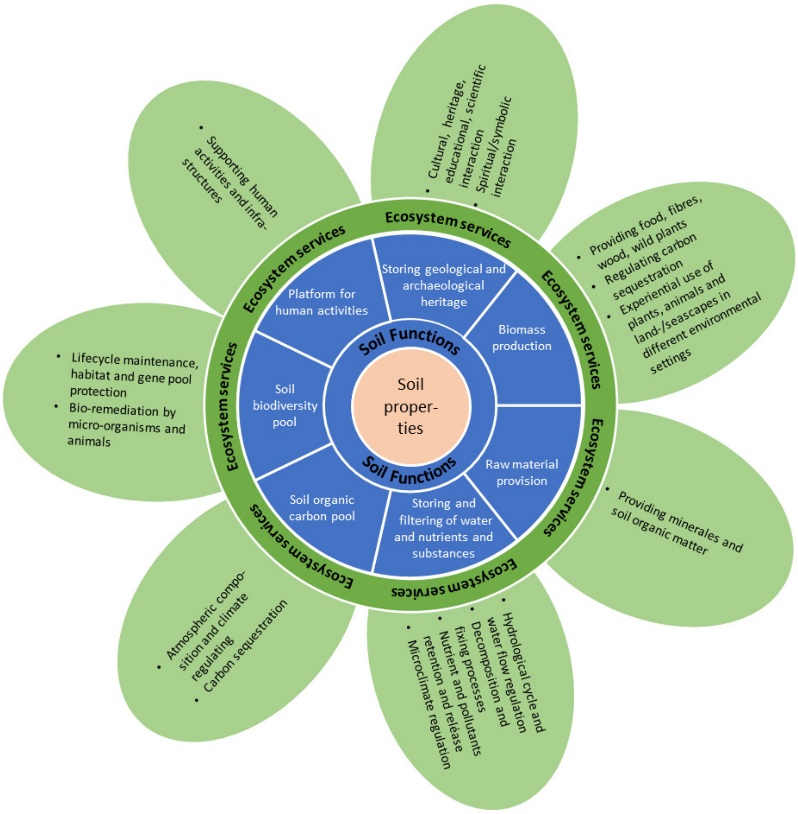
Accordingly, it is essential in the context of local and national policymaking and environmental planning to link soil functions to the general ecosystem service concept and its categories. Nevertheless, an assessment at European scale is not the most appropriate to deliver this link for a single soil function. Figure 2.5 shows specific ecosystem services that are based on soil functions, following the Common International Classification of Ecosystem Services (CICES) system (Haines-Young and Potschin, 2013).

Several soil functions, including the provision of a soil organic carbon and biodiversity pool, and storing and filtering water and substances, are related to ecosystem services of the CICES section 'Regulating & Maintenance' (see Figure 2.5 and Table 2.2). These services include regulation of carbon sequestration and atmospheric carbon dioxide (CO2), regulation of water and nutrient availability, and crop pollination and pest control. Provisioning services are closely linked to the soil functions of biomass production potential and raw material provision, highlighting biomass and food provision as well as mineral and soil organic matter provision. Finally, the soil functions of providing a platform for human activity and storing geological and archaeological heritage are the basis of cultural ecosystem services.

As highlighted by Dominati at al. (2010), the inherent and manageable soil properties constitute the soil natural capital and allow soil functioning and the provision of ecosystem services to fulfil human needs. They are subject to external drivers, both natural and anthropogenic. In our analysis, the latter are of major interest and include land-use changes and farming practices. The type of disturbance is governed by the type of land use, while management and the degree of intensity (i.e. inputs, compaction) are linked to farming practices.

Based on this understanding, the impact of the land processes discussed earlier on soil functions and related ecosystem services can be tracked.

Figure 2.5 Correspondence between soil functions and ecosystem services



Sources: Modified from Adhikari and Hartemink (2016), based on Dominati at al. (2010) and Haines-Young and Potschin (2013).

2.2.2 Soil functions: data foundation and data coverage

This study used modelled pan-European soil function data (4); four out of seven soil functions possess a varying number of sub-functions (see Table 2.2).

While some soil (sub-)function data are available for the EEA-39, most of the data are only available for subsets of the 28 Member States of the EU (EU-28), due to the different availability of input data used to model the suitability of soils to provide the various soil functions (see Table 2.2).

(4) The map for substances transforming capacity map has not been produced.

Table 2.2 Soil functions, their sub-functions and related ecosystem services

Related ecosystem service category [a]	Main soil function [b]	Sub-function	Coverage [c]
Provisioning	Biomass production (Tóth, 2012; Tóth et al., 2013)	− Arable crops − Grass − Forest	EEA-39
			EU-28 (except Croatia, Cyprus, Malta)
	Raw material provision (Tóth et al., 2013)	−Organic materials −Construction materials	EEA-39 (except Cyprus, Iceland, Malta, Turkey)
Regulating & Maintenance	Storing and filtering of water and nutrients/substances (Weynants, 2015; Makó et al., 2017)	−Substances storing −Substances filtering −Water storing: wilting point, field capacity	EU-28 (except Croatia, Cyprus)
			EEA-39 (except Cyprus, Iceland and Turkey)
	Soil organic carbon pool (sequestration) (Lugato et al., 2014a, 2014b)		EEA-39 (except Iceland, Malta, Switzerland, Turkey)
	Soil biodiversity pool (Aksoy et al., 2017)		EU-28 (except Croatia, Cyprus, Malta)
Cultural	Platform for human activities (Tóth and Hermann, 2015)		EEA-39 (except Turkey)
	Storing geological and archaeological heritage (Kibblewhite, 2015)	−Bones/teeth −Metals −Organics −Stratigraphic evidence	EU-28 (except Cyprus, Malta)

([a]) Based on CICES v.4.3 (Common International Classification of Ecosystem services) (http://cices.eu/), used in the Mapping and Assessment of Ecosystems and their Services (MAES) context (http://biodiversity.europa.eu/maes/common-international-classification-of-ecosystem-services-cices-classification-version-4.3).

([b]) Further information on and access to the soil function data is available at http://esdac.jrc.ec.europa.eu/resource-type/soil-functions-data.

([c]) 'EEA-39' refers to the full coverage of EEA member and cooperating countries (https://www.eea.europa.eu/about-us/countries-and-eionet), while 'EU-28' refers to the 28 Member States of the European Union.

The soil function data reveal the potential or suitability of a given soil to supply a specific function, independent of the current land cover or land use. No land use mask is applied. For instance, soils with good forest biomass potential can be found in areas with arable or grassland. Good potential or suitability means that the soil has the capacity to provide specific soil functions based on soil properties and climatic, geomorphological and land use-related characteristics. Thus, even though current land use may not be aligned with the soil function potential, that soil function potential might be capitalised upon on in the future (e.g. soil with good potential for arable biomass production but currently under forest use).

This potential or suitability is modelled in a spatially explicit manner based on soil-inherent information (such as texture or pH, taken from the European Soil Database (JRC, 2001)), climate and topographic data, and land cover information. The final data usually come as a grid layer with a spatial resolution of 1 km^2. All original soil function data are scaled to index scores ranging from 1 to 10, where 10 represents the most suitable conditions for a particular soil function and 1 the least suitable.

The index scores show the relative capacity of soils expressed in index values without units, allowing better comparison between the various soil functions. For easier interpretation of the results, the soil function data were classified into three classes of soil function capacity: 'good', 'average' and 'poor'. This classification is based on the value range of the data, i.e. the mean value and standard deviation. Concretely, this means that all values above +1 standard deviation are classified as good, and all values below –1 standard deviation as poor. All values between the two thresholds (i.e. +/- 1 standard deviation) are of average potential. This classification in three quality classes thus allows differentiating impacts of land-cover/land-use changes on soils with good, average and poor capacity. If the potential for a specific soil function is poor, assessment of the effects of land processes on that potential becomes less relevant; the analysis therefore focuses on good and average soils.

Considering key global and European environmental and agricultural policies, and the related delivery of ecosystem services, the hotspot assessment in this study takes account of all biomass production potential sub-functions as well as the soil organic carbon pool and soil biodiversity pool functions. The biomass production potential is related to provisioning services such as food and fibre, crucial in the context of local and regional food security. The soil organic carbon pool is essential to national actions to comply with the United Nations Framework Convention on Climate Change (UNFCCC) objectives of stabilising greenhouse gas concentration and preventing anthropogenic interference with the climate system. Finally, the soil biodiversity pool is of growing interest regarding all biodiversity-related policies (EC, 1992; EC, 2011), since it represents capacity to act as a habitat and gene pool. Even though the other soil functions are also related to crucial European environmental policies (e.g. EC, 1991; EC, 2000), their scope and delivery of ecosystem services is more localised compared with the regional or global effect of impact on the previously mentioned soil functions. Nevertheless, the impact on soil functions such as storing and filtering of water and nutrients/substances is much broader and can have effects downstream of river basins, in terms of both water quantity and quality.

2.2.3 Spatial distribution of soil function suitability in Europe

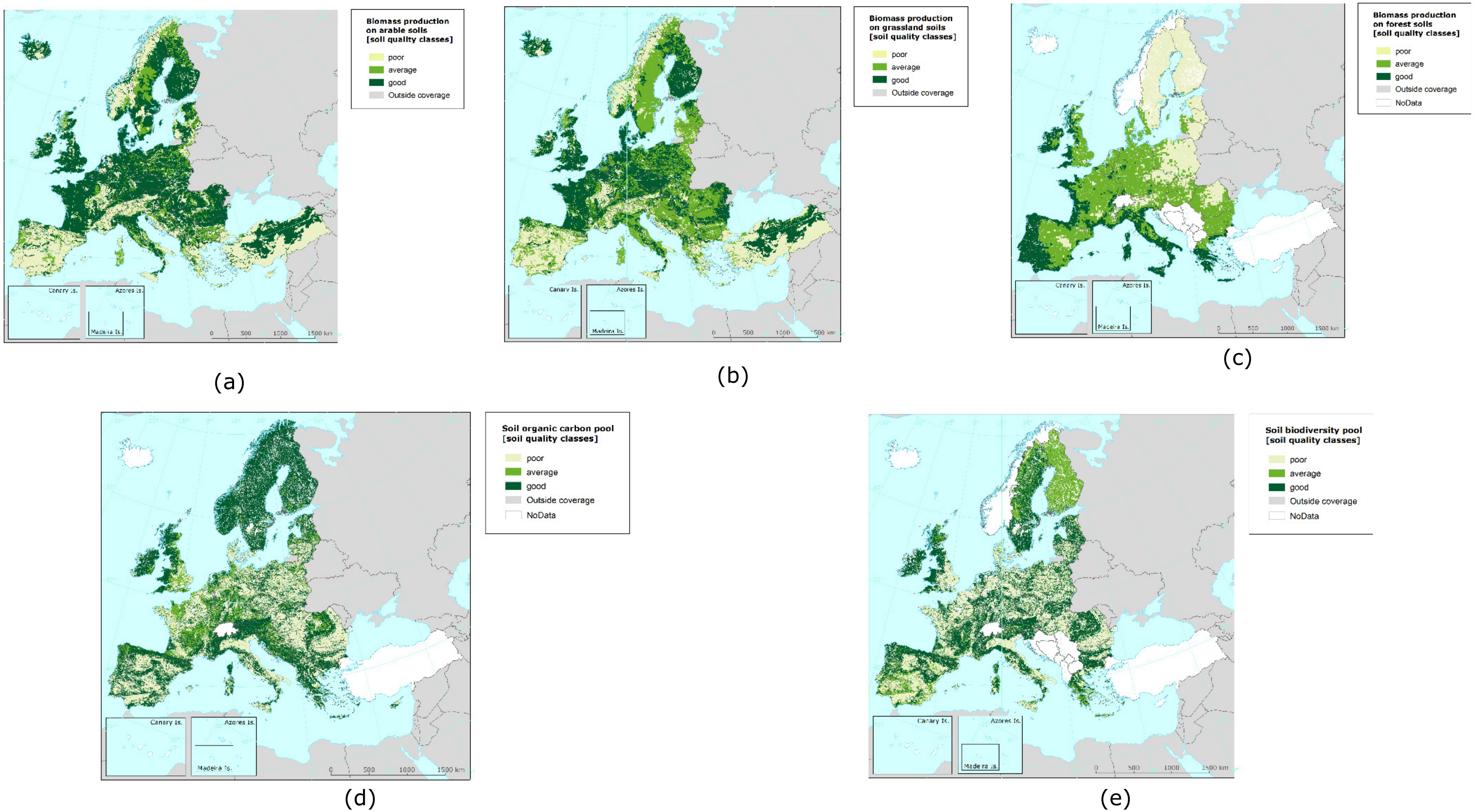
The spatial distribution of soil function suitability depends on the input parameters considered in the modelling of the various soil functions (see references in Table 2.2). Map 2.3 provides "Quick Look" images of suitability maps for some of the aforementioned soil functions: arable biomass production potential, grass biomass production potential, forest biomass production potential, soil organic carbon pool potential and soil biodiversity potential. The reclassified maps indicate good, average and poor capacity for soil function provision.

For those soil functions in which climatic factors prevail, including biomass production, a clear biogeographical distribution can be observed. This is particularly true for the forest biomass production potential, since Tóth et al. (2013, p. 10) have argued that '*the net ecosystem productivity (NEP) of a forest can be limited by two main factors: the air temperature, which determines the length of the vegetative season, and the amount of water from soils that the plants can evapo-transpire. Accordingly, the northern latitude forests are limited by the relatively short vegetative season, while the Mediterranean forests will be limited by the relatively low water availability, which in turn is related to both climate and soil characteristics*.' This gradient is also visible in Map 2.3**(c)**. The biomass production potentials for arable crops and grass show a similar geographical distribution, even though local management factors or the soil's response to such factors also play a role in the distribution of these functions.

Land cover/land use is a determinant factor for the soil functions soil organic carbon and biodiversity pool. For soil biodiversity, Aksoy et al. (2017) highlight that the highest potentials in soil biodiversity levels are found in pasture and grassland, followed by forests. For both functions, maps (Map 2.3 (c) and (d)) show a clear difference between the potential levels in areas dominated by arable land and those characterised by grassland, pasture and forest.

Finally, the soil functions storing and filtering of water and nutrients/substances, provision of a platform for human activities, and raw material provision are determined to a high degree by inherent soil properties such as texture, pH, rock/gravel content and soil type, and show a heterogeneous distribution at a European scale. For instance, Makó et al. (2017, p. 1) state for the storing and filtering potential maps that '*those soils are characterized by good storing capability that have thick topsoil and subsoil layers and these layers are free from the effects of groundwater. As the content of clay and humus content increases and the stone or gravel content decreases, the storage capacity increases simultaneously*.' On the other hand, the distribution of the raw material provision (organic material) function corresponds quite well with the topsoil peat content map presented in the Soil Atlas of Europe (JRC, 2005). The map relating to construction material illustrates the sand and gravel resources that coincide with river floodplains and channels, as well as glacial deposits, which are the most important commercial source areas.

Map 2.3 Soil function suitability maps for biomass production potential on (a) arable soils, (b) grassland soils and (c) forest soils, as well as potential to act as (d) soil organic carbon and (e) soil biodiversity pool, reclassified into good, average and poor suitability



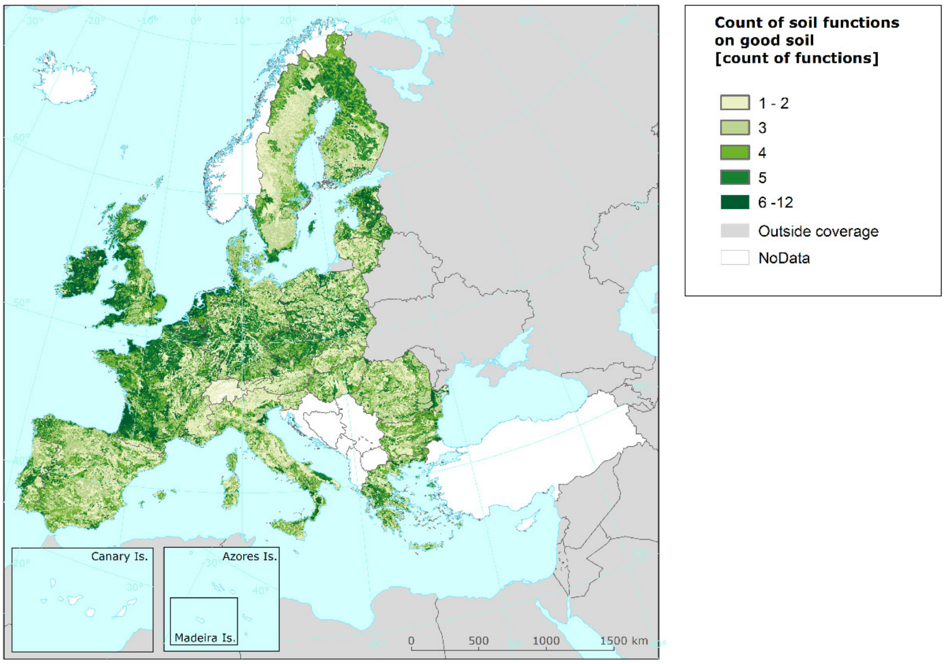
2.2.4 Multi-functionality of soils

Ecosystems and landscapes have multiple dimensions and roles, which means that they simultaneously provide, or should be able to provide, multiple functions (Raudsepp-Hearne et al., 2010; Berry et al., 2015). Of course, functions occurring in the same location can either support or interfere with each other. The former is referred to as synergy, i.e. where the use of one service or function directly increases the benefits supplied by another (positive association), while the latter is considered to be a trade-off, i.e. where the use of one service or function directly decreases the benefits supplied by another (negative association) (Mouchet et al., 2014; Turkelboom et al., 2015).

Map 2.4 and Map 2.5 give a first indication of the potential multi-functionality of soils by showing the presence of relevant functions and sub-functions (see full list in Table 2.2) per grid cell, based on the modelled soil function data described earlier: the higher the count of (sub-)functions, the greater the chance that two or more soil functions support or interfere with each other. The maps are provided separately for soils with a good and an average capacity: in each of the soil (sub-)function maps, the good and average soils (on classifications see Section 2.2.2) for the provision of this function have been selected and overlaid to obtain the count of (sub-)functions per grid cell. The results are illustrated at grid cell level, but discussed at an aggregated (NUTS 3 regional) level. Soil (sub-)functions are treated separately rather than grouped. However, data coverage across all European countries is incomplete for some soil functions. The count values are therefore only comparable for the EU-28 countries, minus Croatia, Cyprus and Malta, and are therefore only presented at that level.

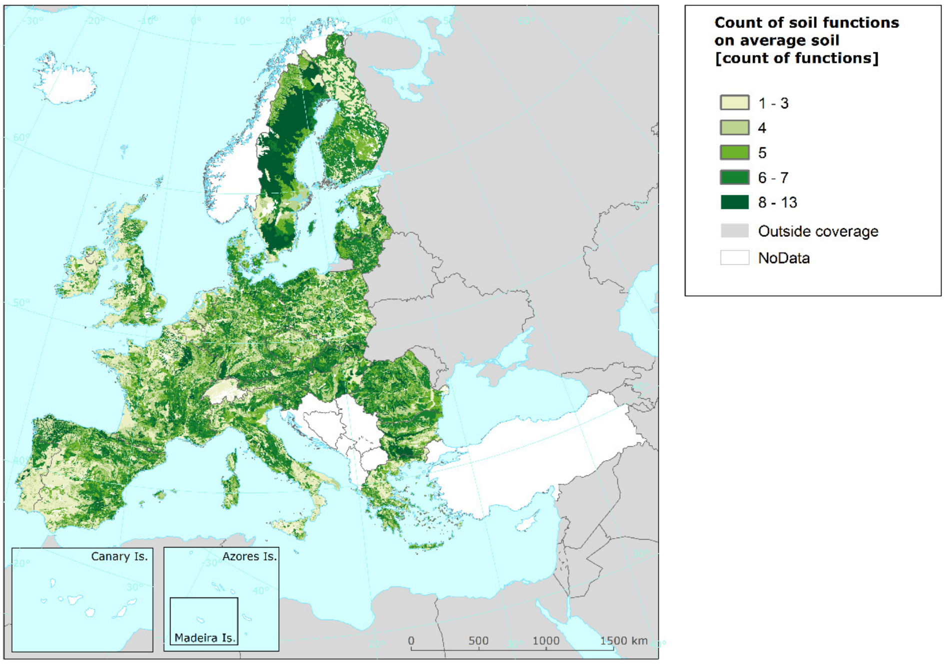
For interpreting the maps, it needs to be kept in mind that the classification of soils into good or average is based on the modelled JRC data (again see Section 2.2.2). This means that their classification as 'good' or 'poor' is based on the input parameters that went into the model. This also means that the maps do not represent the real situation in the various countries and regions, but rely on the modelled data. This also implies that multi-functionality is provided based solely on the overlay of good or average soils for the provision of soil functions.

Map 2.4 Count of functions (on soils with a good potential to provide soil functions) per grid cell (note: the maximum number of soil functions is 12)



Note: The theoretical maximum number of soil functions per grid cell is 15 (see Table 2.2). This map must be interpreted as though no grid cell contains all soil functions, but the maximum is 12 functions.

Map 2.5 Count of functions (on soils with an average potential to provide soil functions) per grid cell (note: the maximum number of soil functions is 13)



Note: The theoretical maximum number of soil functions per grid cell is 15 (see Table 2.2). This map must be interpreted as though no grid cell contains all soil functions, but the maximum is 13 functions.

The map of the number of soil functions on good soils for each of the functions (see Map 2.4) shows no clear pattern of regions with higher values. The maximum number of functions in a grid cell is 12 (found within the borders of three Dutch and two Estonian NUTS 3 regions). Clusters of regions with a high number of functions are visible, mainly in north-western Europe, including parts of Belgium, northern France and the Netherlands. These are regions characterised by generally very good river delta soils and high population pressure. In addition, regions along the Czech-Polish border, and in Bulgaria, south-western France and Hungary show higher values.

At the lower end of the value range, plenty of regions across Europe show low function counts. This includes larger clusters in Scandinavia and the Baltic countries, north-eastern Germany, and many of the more mountainous regions in the Alps (Austria, south-eastern France and northern Italy), the Carpathians, the Pyrenees, the Apennines, and the more elevated regions in northern Portugal and Spain.

On average soils, there are not many differences concerning the maximum values, but there are differences in the distribution across regions (see Map 2.5). The maximum number of functions per grid cell is 13 (found in three NUTS 3 regions in France, Germany and Spain). Although there is no clear pattern or gradient, clusters of regions with high values are more concentrated in north-eastern Europe. This particularly relates to regions in Finland and Sweden, but also to some regions in the Baltic countries, Denmark, and parts of northern Germany and Poland. Other clusters are visible in southern Bulgaria, western and southern Germany, Hungary and Slovakia.

At the other end of the spectrum, clusters of regions with low values are located in Belgium and the Netherlands, the British Isles and the south-western part of the Iberian Peninsula.

2.3 Impacts of land processes on soil functions: the impact matrix

To evaluate the impact of land processes on soil function potential, the grouped LCF data and the soil function potential data are spatially analysed. The outcomes of this analysis subsequently lead to information on the loss of soil function potential at various spatial levels. However, the impact of a land process is not necessarily negative. To support interpretation of the results, an evaluation matrix was created with the support of thematic experts, drawn mainly from the Eionet National Reference Centres for Soil, and the National Reference Centres for Land Use and Spatial Planning.

The matrix presented in Figure 2.6 indicates the quality of the impact of a group of LCFs (representing the major land processes) on soil functions. In this matrix, the impact of a specific land process on a particular soil function can be predominantly positive (it increases the potential of the soil to provide a function), predominantly negative (it decreases that potential), or neutral. Positive impacts are marked in green, negative impacts in red. Impacts that are considered to be neutral or highly uncertain with regard to the effect on the soil function potential are left blank. Admittedly, whether an impact is positive or negative may depend on the local or regional context. Single LCFs within a land process may also have slightly different impacts. However, evaluation of the impact still shows the predominant effect of the respective land processes on various soil functions at the EU level.

During the development of the evaluation matrix, four main guiding principles were applied:

- Focus is on the soil function potential as opposed to the actual land use (e.g. although a piece of land is used agriculturally, it still has the potential to provide forest biomass).
- Focus is on the impact of land-cover changes as opposed to using land according to its potential (e.g. although a piece of land has the potential to provide forest biomass, the land cover does not change into forest, but into something else).
- Focus is on assessing the impact within the time frame of the analysis, i.e. 2000-2012; possible long-term effects are not considered.

- Focus is on soil function potential sustained by the natural capital; maintenance of potential by physical resources (e.g. fertilisers, irrigation) is indicated where relevant.

In this report, the matrix is used (1) as a qualitative guide for the interpretation of the impact maps (see hotspot analysis in Chapter 4), and (2) mathematically, in the calculation of net balances (see Chapter 5), to demonstrate how a certain area fares in terms of predominantly positive or negative impacts of land processes on the prevalent soils, i.e. whether or not analysis indicates issues in relation to potentially problematic land use.

Although red colours dominate, suggesting a predominantly negative impact of the major land processes on soil functions, there exist a number of land processes that have an almost entire or partial predominantly positive impact. Urban expansion, which mostly causes the irreversible sealing of soils and the permanent loss of the soil functions underneath (see Section 1.1), leads to negative effects on most soil functions. However, its impact on the platform function remains unclear, to the extent that one could argue that urban expansion is the 'optimal' use of land with good soil to provide a platform for human activities.

Agricultural intensification as well as agricultural expansion have predominantly positive effects on the biomass provision function, as it is those land processes that aim to increase production and, eventually, productivity (yield). However, agricultural intensification makes use of physical assets, such as machinery, fertilizers and irrigation, to increase productivity, rather than using the natural potential of the soil (Matson et al., 1997; Hazell and Wood, 2008). In consequence, their impact is predominantly negative on the regulating and maintenance functions, including the soil organic carbon and soil biodiversity pool functions, as well as the storing and filtering of substances and water.

Unlike the two other agriculture-related processes, agricultural extensification has predominantly positive impacts on almost all soil functions, as this process leads in general to reduced pressure on soils and the landscape, and enables a more natural soil behavior, which improves its functioning. Likewise, forest expansion, i.e. the growth and replanting of new trees and forests, is predominantly positive for soil functions.

Although forest fellings has predominantly negative effects on most soil functions, it favors forest biomass production in the first 20-30 years of the 70- to 100-year forest cycle, due to the regeneration of forests after clearing. During forest management, particular attention should be given to maintaining good soil quality, to enable the forest soils to support the various services they can provide for society (Rauland-Rasmussen et al., 2011).

Figure 2.6 Matrix showing the impact of major land processes (groups of land cover flows) on the potential of specific soil functions

Ecosystem Service Category	Provisioning					Regulating and maintenance					Cultural	
Supply	Biomass production arable land	Biomass production grassland	Biomass production forest land	Raw material provision organic material	Raw material provision construction material	Storing substances	Filtering substances	Storing water	Soil organic carbon pool	Soil biodiversity pool	Platform for human activities	Storing geological / archaelogical heritage
Urban expansion				**	**							
Agricultural intensification	*	*	*	**	**							
Agricultural extensification				**	**							
Agricultural expansion				**	**							
Forest expansion				**	**							
Water bodies expansion					**							
Forest fellings	***	***	***	**	**							

Impact

predominantly negative

neutral/unclear

predominantly positive

* Productivity is mainly supported by use of physical assets (fertilisers, irrigation, etc.) rather than the natural potential of soils.

** In the reverse direction, the impact of extracting peat, sand and gravel strongly depends on aftercare.

*** Forest fellings and subsequent regeneration favour biomass production on forest land in the first 20-30 years of the (70-100 year) cycle.

Source: EEA and ETC-ULS, reviewed by participants at the 2016 Eionet thematic workshop ‘Land resource efficiency‘.

3 Distribution of land cover changes on soil function potential

This chapter will address the following questions:

- Which are the most important land processes for the various soil functions in the EEA-39 countries?
- How are the impacts of land processes on soil functions spatially distributed at a European and country level?

3.1 Distribution of land processes' impacts on soil functions on a European scale

This section summarises the impact of the major land processes on the various soil functions on a European scale. The graphs and tables presented in this section show the share of the impact of various land processes on soil functions and their respective sub-functions. The impact is only assessed for soils with good and average potential to provide soil functions (see Section 2.2.2), since only a combined assessment can provide a realistic picture of the situation. If, for example, only good soils (from a European perspective) had been considered, half of the European regions would not be visible in most assessments, even though large shares of their best soils (from a regional perspective) were affected.

For the calculation, the area values of soils with good and average soil function potential are summed up for each soil function, and a spatial overlay is made between the soil function (average and good potential) area values and the land processes area values. The proportion of soils with average and good potential to provide soil function on a European scale is presented in Table 3.1.

Table 3.1 Proportion of soils with average and good potential to provide soil function at European scale ([5])

Soil function	% area of soils
Biomass production (arable)	61.4
Biomass production (grass)	68.8
Biomass production (forest)	62.7
Raw material provision (organic materials)	19.0
Raw material provision (construction materials)	43.3
Storing and filtering of water and nutrients (substances storing)	69.2
Storing and filtering of water and nutrients (substances filtering)	68.2
Storing and filtering of water and nutrients (water storing)	46.6
Soil organic carbon pool	38.3
Soil biodiversity pool	51.3
Platform for human activities	74.6
Storing geological and archaeological heritage (bones/teeth)	35.4
Storing geological and archaeological heritage (metals)	22.1
Storing geological and archaeological heritage (organics)	29.1
Storing geological and archaeological heritage (stratigraphic evidence)	9.5

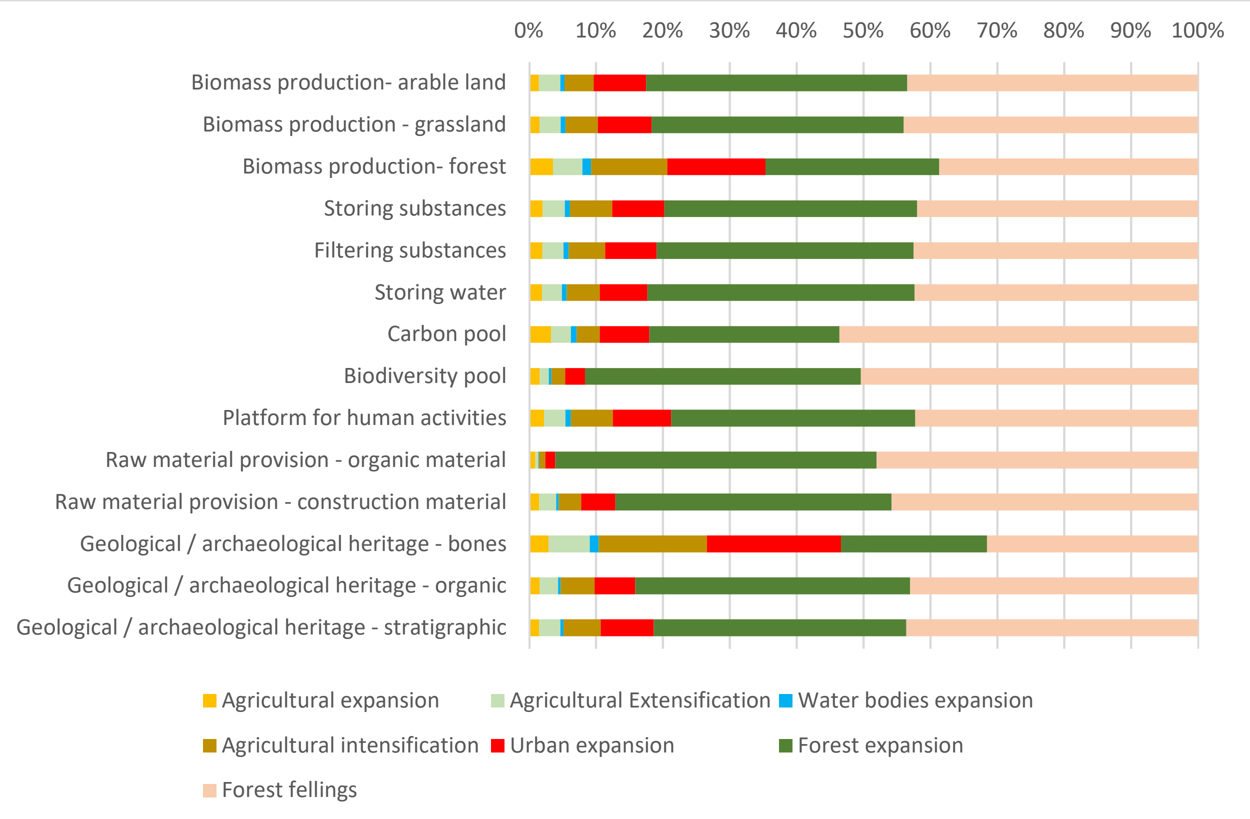
In terms of impact, forest fellings exerts the largest and most important impact of all land processes on soil function potentials (see Figure 3.1), which is in line with the findings in Section 2.1.2. Forest expansion is the second most important land process. Land processes related to forest management therefore account for more than 60 % of the impacts (see Section 2.1.2), with more than 90 % in the case of the raw material provision and biodiversity pool functions.

([5]) Data at country level are presented in Annex 3.

The raw material provision function (organic material) is the only function where forest fellings is not the most significant land process in terms of impact. Combining the forest management-related land processes, urban expansion and agricultural intensification come second and third as major land processes affecting soil functions. These flows are particularly relevant for forest biomass production potential (27 % of all impacts) and archaeological heritage (bones) (37 %).

It should be highlighted that the impact of land processes on the potential for delivering certain soil functions is independent of actual land use. This is the reason that forest fellings, for example, is the most important land process even on soils with good and average levels for grass biomass production potential, or for providing a platform for human activity.

Figure 3.1 Share of impact of major land processes on soil functions with good and average capacity



3.2 Land processes' impacts on soil functions at country level

The shares of impacts of land processes at country level provide a more detailed picture.

Map 3.1 ([6]) shows an example of the shares of impacts of land processes on the biomass production potential for arable crops. The colour of the country area illustrates the land process with the highest share of impact. The relevance of the impacts depends on the total area of impact and the share of soils affected by the impact. This information is listed per country in Annex 2.

Forest expansion (11 countries) and forest fellings (18 countries) are considered to be the most important land processes when it comes to impact on soils with good and average potential for biomass production for arable crops. The map provides evidence that urban expansion is highly relevant for several central European countries, including Denmark, Germany, the Netherlands and Switzerland, as well as some

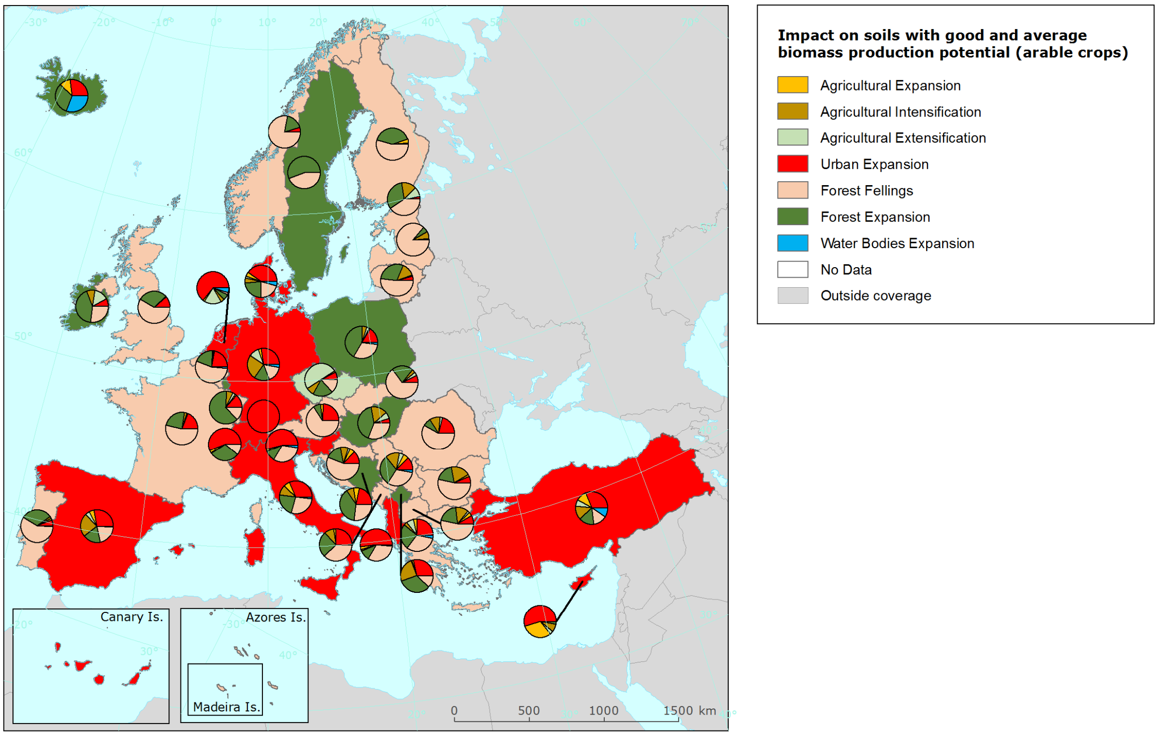
([6]) Background tables of these maps are provided in Annex 2.

Mediterranean countries such as Albania, Cyprus, Italy, Spain and Turkey. The Czech Republic is the only country where impact on this soil function is dominated by agricultural extensification.

The sum of impacts of forest fellings and forest expansion add up to more than 50 % of all impacts in 24 out of the 39 EEA countries. In the other countries, the share of the various land processes regarding their impact on biomass production potential is more equally distributed, with urban expansion and agricultural intensification playing a major role alongside the forest management-related processes.

There are some exceptions. Iceland has a very high share of water body expansion (30 % of all shares) and no forest fellings affecting this soil function; in Cyprus, urban expansion dominates, followed by agricultural expansion; and in Turkey, there is an almost equal distribution of all land processes affecting soil function.

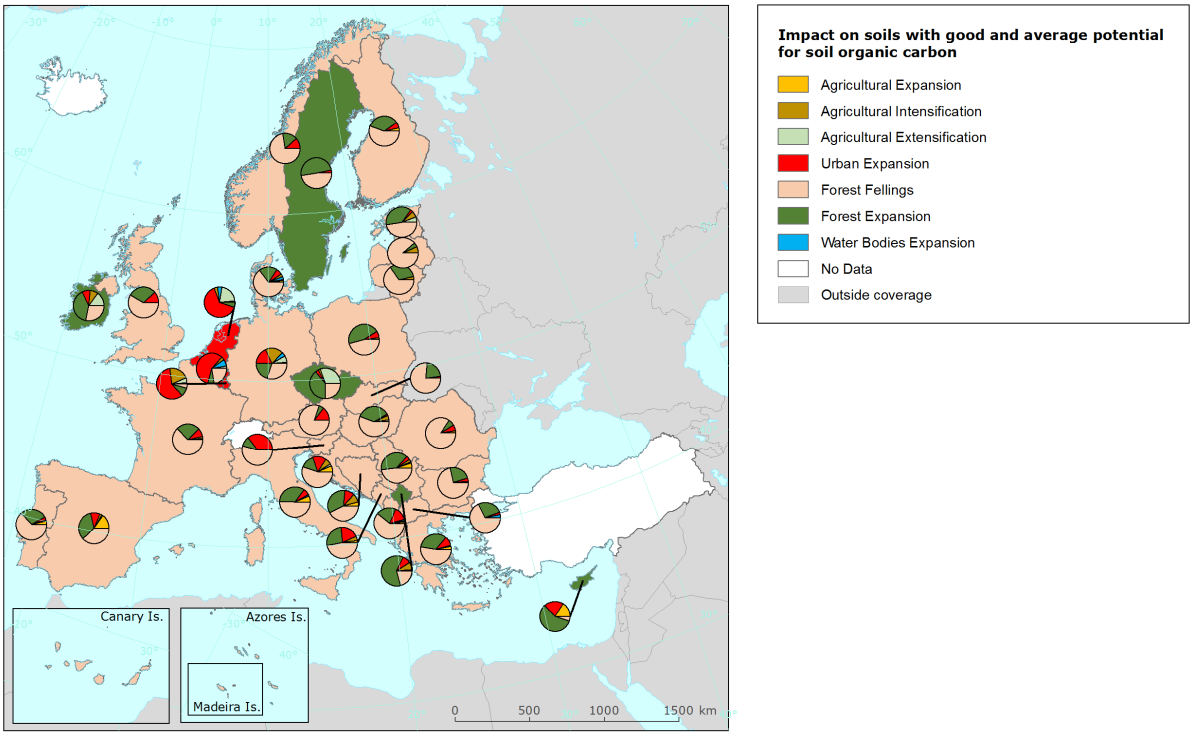
Map 3.1 Impact on soils with good and average biomass production potential (arable crops) ([7])



Since the carbon pool function is much more land cover related (i.e. land cover is a major parameter in the calculation of the carbon pool function), and is positively correlated with forest land, the average and good soils are even more sensitive to forest-related land processes. The major changes that affect average and good soils for the carbon pool function are therefore forest fellings and, to a lesser degree, forest expansion (see Map 3.2). Only a few countries' impacts are dominated by forest expansion (the Czech Republic, Ireland, Cyprus, Macedonia and Sweden), while the Benelux countries (Belgium, the Netherlands and Luxembourg), Switzerland, Liechtenstein and Malta have their impacts dominated by urban expansion.

([7]) Land process with the highest impact (represented by country colour) and proportional impact of various land processes (represented in pie charts) on soils with good and average potential for biomass production (arable crops) per country (EEA-39).

Map 3.2 Impact on soils with good and average potential for soil organic carbon pool function (8)



Countries differ hugely in the share of good and average soils in their territory — an indicator of the relevance of these functions in a country's territory — as well as in terms of absolute and relative impacts of land processes (measured respectively in hectares and as a percentage of total area of good and average soils affected by a particular process). Figure 3.2 and Figure 3.3 illustrate these differences for biomass production potential (arable) and soil organic carbon pool functions, respectively. The figures compare the percentage of soils with good and average quality to provide a given soil function (x-axis) with the share of good and average soils affected by all land processes (y-axis). Hence, in the upper right corner are those countries with a high percentage of soils with good and average quality, and a large share of these soils affected by land processes; in the lower left corner are countries with a low percentage of good and average soils, and a small share of them affected by land processes. In addition, the size of the circle indicates the absolute area of good and average soils (in hectares) affected by land processes. This provides a good overview of the relative and absolute relevance of the impact in the various countries, compared with the overall share of good and average soils.

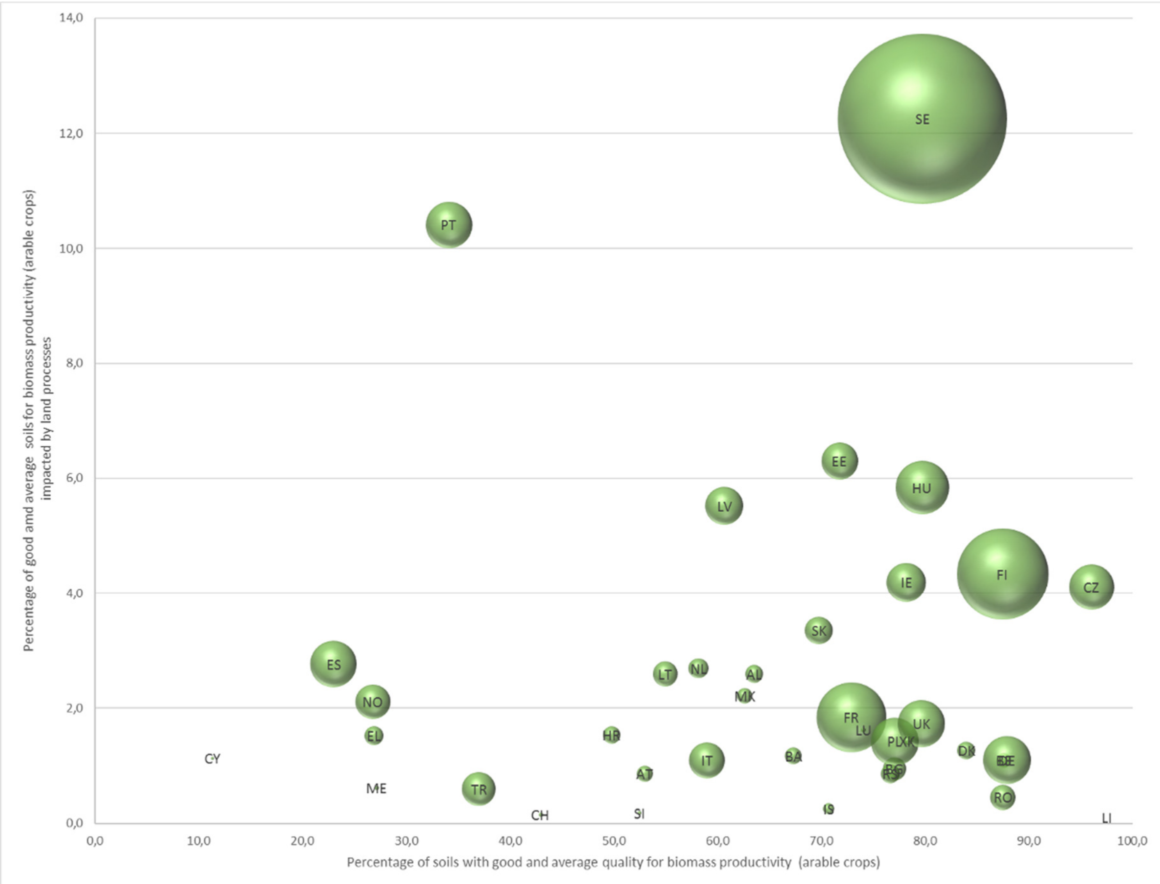
In the case of biomass production potential for arable crops (see Figure 3.2), Sweden stands out with high values in both relative and absolute terms, and also with a very high portion of good and average soils. Germany, Poland and the United Kingdom are among other countries that have very similar shares of good and average soils (around 80-90 % of all soils), but the absolute and relative impact is much lower (e.g. less than 2 % of all good and average soils are affected). This means that the situation in Sweden is much more critical, since a substantial part of the soils with good and average potential for arable crop biomass production (i.e. around 12 %) are subject to land processes, predominantly with a negative impact on soil functions.

(8) Land process with the highest impact (represented by country colour) and proportional impact of various land processes (represented in pie charts) on soils with good and average potential for soil organic carbon pool function per country (EEA-39 with the exceptions of Iceland, Malta, Switzerland and Turkey).

At the other end of the scale are countries such as Greece, Norway and Spain, on the one hand, and Portugal, on the other. The first group of countries show both small relative and absolute impacts, with a small share of soils with good and average potential. In Portugal, the share of soils with good and average potential is also relatively small (below 40 %), as is the total impact, but the relative impact amounts to more than 10 % of all soils with good and average potential. This is a critical situation in a country with a relatively low share of these types of soils, particularly because of the negative impact of the dominant land processes, which include urbanisation and forest fellings.

When looking at the most important land processes behind these impacts (see Map 3.1 and Annex 3), some questions arise regarding the reversibility of these impacts, or whether they are positive or negative. The impacts in Sweden and Portugal, for instance, are due mainly to forest management (fellings, replanting), as is the case in many other countries. In Greece, Spain and Cyprus, to name but a few countries with low shares of good and average soils, urban expansion plays a major role (28 %, 24.6 % and 55.1 %, respectively). This expansion leads to soil sealing and the unavailability of potential biomass production at these specific spots.

Figure 3.2 Comparison of percentage of soils with good and average biomass production potential (arable crops) (x-axis), with share of good and average soils impacted by all land processes (y-axis) ([9])

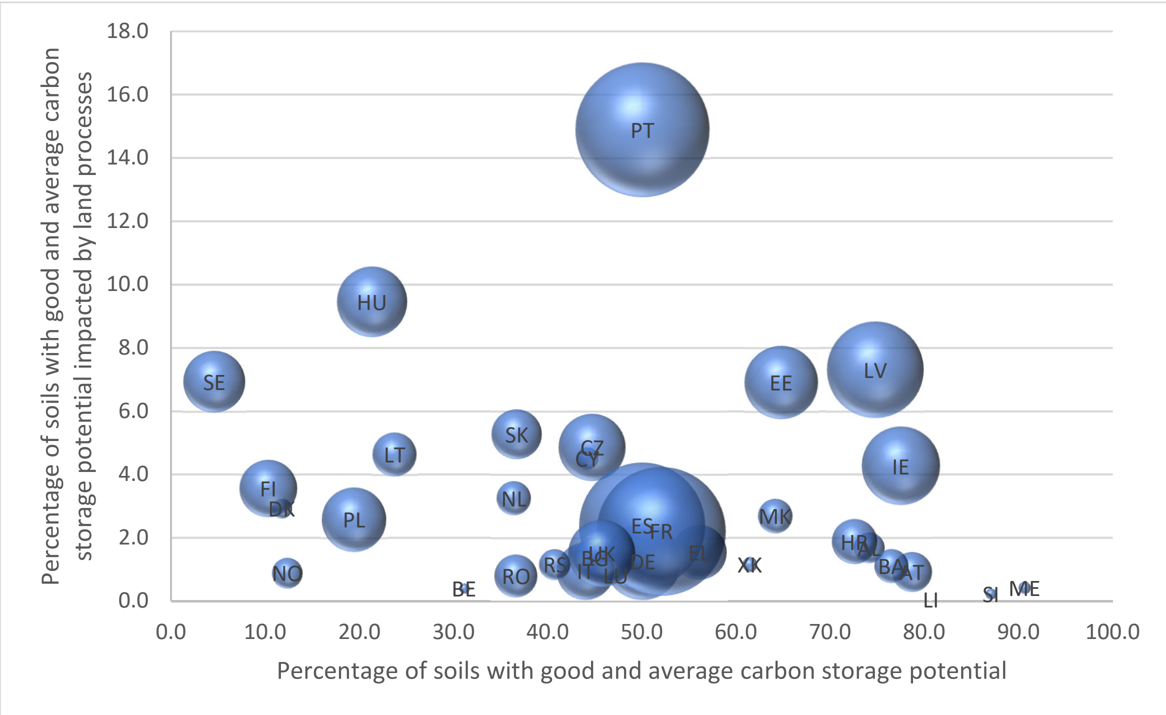


The carbon pool potential shows a different distribution (see Figure 3.3). Various groups of countries can be distinguished. One group of countries around the Baltic Sea (Denmark, Finland, Lithuania and Poland) has low shares of both good and average soils and shares of impacts. A large group of countries from central, south-eastern and western Europe shows low shares of good and average soils affected by impacts, and medium shares of good and average soils. Finally, there are two clusters with high shares of good and average soils: on the one hand, several western Balkan countries (and Austria) show low relative

([9]) Bubble size represents the total area (in hectares) of good and average soils affected. The bubble size for some countries is very small and not visible behind the country code.

impact, and on the other hand two Baltic countries (and Ireland) show medium relative impact. In Portugal, the share of good and average soils is relatively small (below 40 %), with a relatively high total impact (almost 700 000 ha), but the relative impact amounts to more than 10 % of all good and average soils, a critical situation in a country with a relatively low share of these types of soils. This situation corresponds mainly with the high impact of land processes related to forest management and disturbance (see Box 4.5 for details on forest fires in Portugal). Good and average soils for the carbon pool function are found mainly in forests, and the impact of forest management processes in Portugal affect a relatively large share of these types of soils. In the case of carbon pool potential, therefore, the forest-related land processes are dominant for major impacts on this soil function (see Map 3.2). Again, the question of the irreversibility of this impact is relevant. In six countries with intensive use of land and high population density (Belgium, Liechtenstein, Luxembourg, Malta, the Netherlands and Switzerland), urban expansion is the land process with the biggest impact, but the Netherlands has very small total absolute impacts and low shares of relative impact.

Figure 3.3 Comparison of percentage of soils with good and average carbon storage potential and percentage of soils with good and average carbon storage potential affected by all land processes (y-axis) ([10])



The situation within countries is much more differentiated, with some regions evincing major impacts by specific land processes that do not have the same relevance at country level. In this context, the hotspot analysis in the next chapter will provide a spatially explicit and more detailed overview of the regional differences within the countries.

([10]) Bubble size represents the total area (in hectares) of impacted soils with good and average carbon storage potential. The bubble size for some countries is very small and not visible behind the country code.

4 Assessing impacts at NUTS 3 level: hotspot analysis

This chapter will:

- present the results of the hotspot analysis on the impacts of the three major land processes, urban expansion, agriculture and forest management, on soil functions at NUTS 3 level; and
- discuss the results indicating potential drivers as far as possible.

LCFs can have predominantly negative, positive or neutral impacts on soil (see Section 2.3). Therefore, the term 'hotspot' should not be interpreted as negative per se, since land cover changes can also improve soil functions.

At the outset, the assessment considered 1 492 NUTS regions, 7 LCF groups (i.e. land processes) and 15 soil (sub-)functions. In order to structure the assessment, LCFs were bundled into the topics 'urban expansion', 'agriculture' and 'forest management'. For each topic, affected soil functions were prioritised and only those deemed relevant were considered.

In the various assessments that follow, 'hotspots' were fixed as those regions that ranked among the top 5 % of the data distribution for a specific LCF and a defined soil function (see definition and justification in Table 4.1). Furthermore, the assessment considered the combined impacts on 'good' and 'average' soils, as only the combination generates a clear overview at the European level. If, for example, only 'good' soils (from a European perspective) were considered, half of the European regions would not be visible in most assessments, even though large shares of their best soils (from a regional perspective) were affected. This has recently been confirmed in a research project by the Austrian Environment Ministry, which revealed that food sovereignty requires a regional approach and preservation of the best regional soils (DaFNE research programme, Project 100975 BEAT — Bodenbedarf für die Ernährungs-sicherung in Österreich ('Soil demands for food sovereignty in Austria')).

4.1 Calculation of hotspots

For the identification of the hotspot regions, the land cover change information was combined with the soil function data to obtain a quantitative assessment of the impacts of those land processes on the potential of the soils to provide the functions. Table 4.1 illustrates the approach selected for the three major processes, i.e. which LCFs were used, which soil functions were considered and how the impact was calculated.

Table 4.1 Description of hotspot calculations

Definition of 'hotspot'	A hotspot is an area with significant activity, in this case of land-cover/land-use change activity. Regions that rank among the top 5 % of the data distribution for a specific land process and a defined soil function qualify as hotspots. Various methods were applied: top 5 %, top 20 regions and weighted values. The selection of the top 5 % produced the best results for this assessment (Calzolari et al., 2016).

Land process	Calculation
Urban expansion	Considered land process: urban expansion. Considered soil function: biomass production function for arable crops, grass and forest, covering soils with good and average potential to provide the function. For each NUTS 3 region, the largest impact of urban expansion on either arable crop biomass production potential, grass biomass production potential or forest biomass production potential was selected (result in hectares). The result was expressed as a 'percentage of productive land' compared with the total stock of soils with average and good potential for biomass production. The top 5 % of all NUTS 3 regions were computed with regard to urban expansion at the expense of soil productivity potentials. Subsequently, an assessment was carried out with regard to urban expansion and population growth between 2000 and 2012. A distinction was made between hotspot regions with growing population, stagnant population and shrinking population.
Agricultural land use	Considered land processes: agricultural expansion and agricultural intensification. Not considered: agricultural extensification (see justification at the end of Section 4.3). Considered soil function: biomass production function for arable crops and grass, covering soils with good and average potential for providing the function. For each soil function, the impact of agricultural expansion and intensification on good and average soils was calculated (in hectares). For each region, the highest value was selected and expressed as a 'percentage increase of agricultural land' intensification or 'intensification of agricultural land' compared with the total stock of average and good soils combined. The calculated values 'percentage increase of agricultural land' and 'intensification of agricultural land' were combined. The top 5 % were defined as hotspots.
Forest management	Considered land processes: forest fellings and forest expansion. Considered soil function: biomass production function for forest, covering soils with good and average potential for providing the function. The impact of forest fellings and forest expansion on soils with good and average forest biomass potential was calculated (in hectares). The two LCFs were balanced against each other, by deducting forest fellings from forest expansion. The result was expressed as a 'percentage of forest land' compared with the total stock of average and good forest land and can have a positive but also a negative value. The top 5 % were defined as hot spots.

4.2 Urban expansion

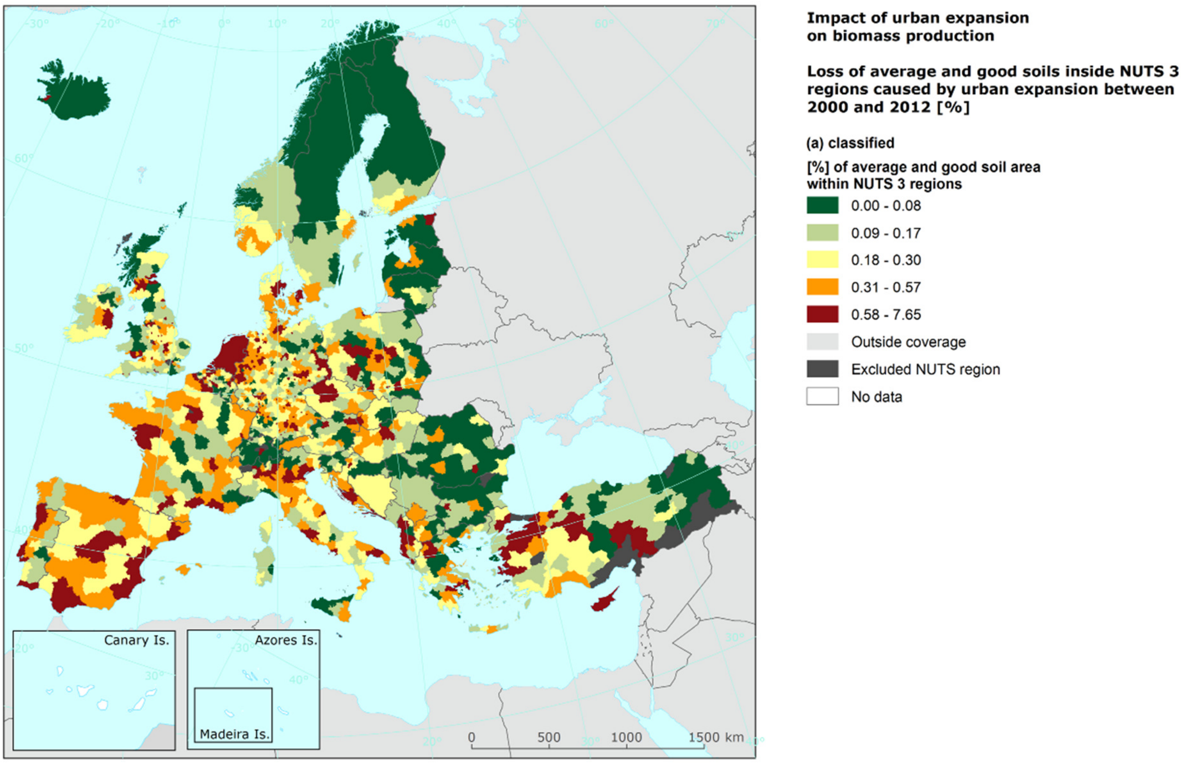
The land process urban expansion has predominantly negative impacts on all soil functions (see Section 2.3).

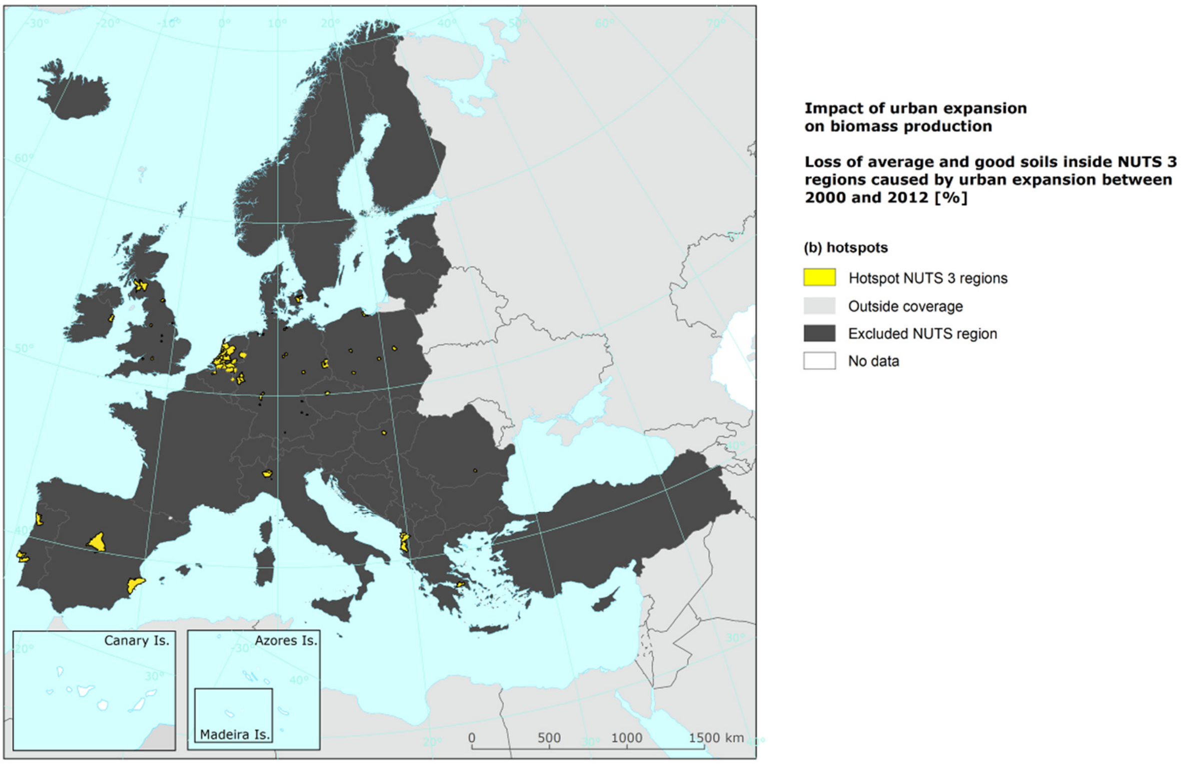
Population growth and economic development are key drivers of urban expansion. More people need more housing, commercial units, streets, and infrastructure for education and health services. Higher living standards lead to larger house sizes and more commercial development. In some cases, urbanisation occurs irrespective of population growth. This is the case in regions where major infrastructure (e.g. high-speed roads, railway lines or airports) is being built to improve accessibility.

Most European cities are surrounded by fertile soils, because settlements were founded in places that allowed optimal self-sufficiency. Today, urban expansion is mostly realised at the fringes of towns and cities, which results in losses of fertile land. The following assessments considered biomass production potential versus urban expansion, as this is a common European issue.

Map 4.1 (a) below shows urban expansion on land with 'good' and 'average' potential for biomass production. Urban expansion leads to a decline of the biomass production potential. Urban expansion on good and average soils affected 93 % of European regions.

Map 4.1 Urban expansion on 'good' and 'average' soils, classified map (a) and hotspots (b)





Hotspot areas of urban expansion have lost more than 1.4 % of soils with good and average biomass production potential (value corresponding to the highest 5 % of all regions concerned). A total of 72 such regions were identified and are presented in the map (see the yellow regions in Map 4.1 (b)). The largest cluster can be observed in the Netherlands, including 21 regions. Hotspot areas are scattered across Europe and correspond to metropolitan areas. Many countries do not include any hotspots of urbanisation; they include the Scandinavian countries, the Baltic countries, Austria, France, Iceland, Slovakia, Switzerland and the Balkan countries, with the exception of Albania.

The situation in the United Kingdom is remarkable. Average population growth there amounted to 7.7 % between 2000 and 2012, and yet many regions managed to contain their losses of agricultural land despite considerable population growth. This can be attributed to the United Kingdom's planning policy (see Box 4.1).

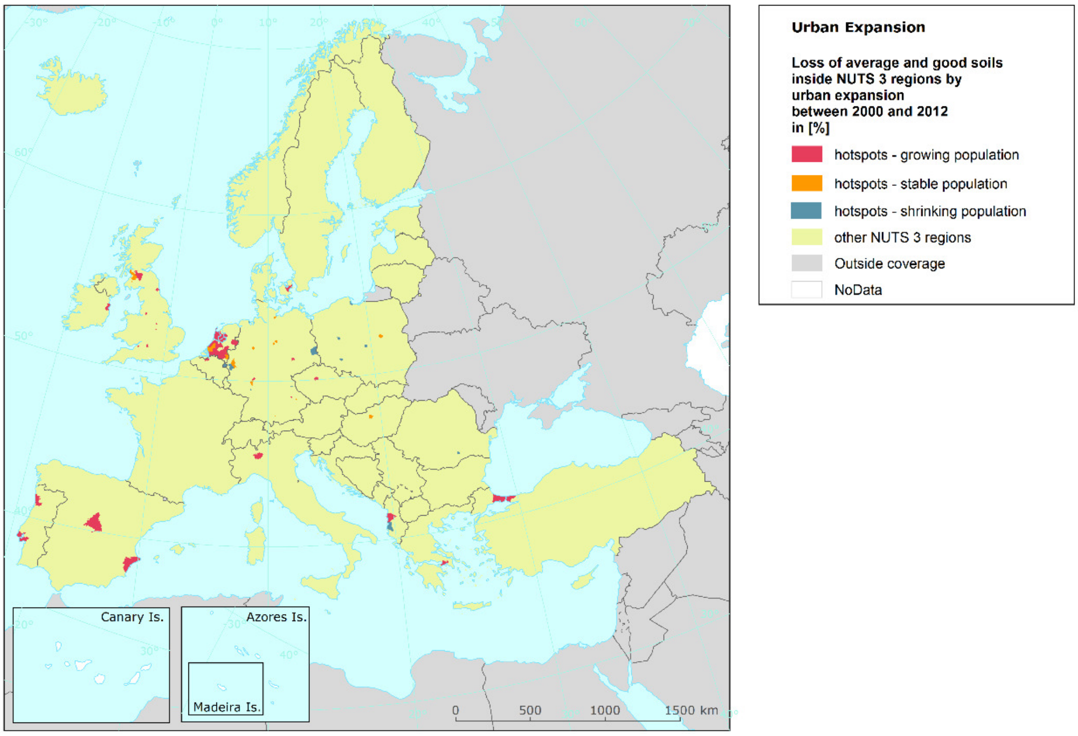
Box 4.1 Outstanding planning policy in the United Kingdom

The assessment reveals that United Kingdom regions are very efficient with regard to urban expansion, in particular in England where 77 % of new homes built in 2008 were constructed on brownfield land, up from 57 % in 1996. In the United Kingdom, new developments are restricted by urban containment policy dating from the 1940s, and by the use of green belts. The latter restrict development on a band of countryside surrounding a town or city. In addition, planning policy statements prioritise the redevelopment of brownfield sites. This policy seems to have been a success.

Source: Schulze Baing (2010)

In Map 4.2, hotspots of urban expansion are further presented by distinguishing between growing population, stagnant population and shrinking population. Hotspots of urban expansion with shrinking populations can be detected in 14 regions (coloured blue). Four such regions can be found in Poland, and two on the German side of the Polish-German border. Urban expansion in these regions can be attributed to highway construction. The network of motorways and expressways in Poland expanded by a factor of four between 2000 and 2012. Furthermore, 47 large transport infrastructure projects were realised between 2004 and 2012 (Lubieniecka-Kocoń, 2016). Bucharest is also a 'shrinking' hotspot, but has to be considered in conjunction with its surrounding region, Ilfov, which has experienced a population growth rate of 42 %. The Bucharest metropolitan area was the only area in Romania with a growing population in the period 2000-2012. Bucharest has experienced a 'doughnut effect' (see definition in Box 4.2), meaning that because of higher incomes people moved out of the city centre to suburban regions (see also Box 4.2). In western Germany, there is a cluster of three hotspot regions with stable or shrinking populations. They are characterised by the extension of several open-cast mining sites.

Map 4.2 Hotspots of urban expansion compared with population dynamics



Hotspots of urban expansion with growing populations are scattered all over Europe, and include large urban agglomerations such as Athens, Copenhagen, Dublin, Lisbon, Madrid, Milan and Porto, but also smaller cities such as Alicante, Glasgow and Regensburg. Within this category, the cities of Tirana, Alicante, Istanbul and Madrid, and the region of Flevoland, stand out with population growth of more than 20 %.

Box 4.2 The doughnut effect

Definition
This describes the abandonment of a downtown or city centre area as people and activities move out to the suburbs, leaving a hole in the middle like that of a doughnut (Urban Design Collective, 2014).

Urban expansion in Madrid
The Madrid metropolitan area experienced a population growth rate of 20.6 % between 2000 and 2012, compared with 18 % national and 2.4 % European average rates (according to the Eurostat regional database). It is noteworthy that there was hardly any population growth in the city centre, and that it mainly happened in suburban regions. Key reasons for this phenomenon were above all increasing housing prices and increasing mobility. As a consequence, urban land surface grew at a rate in excess of 4 % per year (Díaz-Pacheco and García-Palomares, 2014). According to Tóth (2012), urban sprawl occurred to a large extent on agricultural land. According to an EEA report (EEA, 2006), major drivers are: (1) growing demand for first and second homes caused by economic growth and low interest rates and in spite of rather modest population growth; (2) increased mobility; (3) increasing housing prices, which force more people to move further and further into the city's hinterland; and (4) a weak planning framework. Moreover, the Organization for Economic Co-operation and Development (OECD) reports rapid development that led to urban sprawl in the Madrid region (OECD, 2007).

Suburbanisation as a result of post-Soviet housing demand
The regions of Stredoceský kraj (in the Czech Republic) and Ilfov (in Romania) share many features. Both surround large cities, namely Prague and Bucharest. These cities are surrounded predominantly by very productive soils and agricultural regions. Many middle-class people who previously lived in multistorey buildings (German Plattenbauten) in the city centres have moved to the outskirts, to acquire single family houses. Furthermore, new residents from rural regions have settled in suburban areas around both cities, due to the good job opportunities. In addition, industry and the service sector have constructed several new sites around the two cities within the given period. As both agglomerations are surrounded predominantly by soils of outstanding productivity, all new construction activities come at the expense of good soils. As a result, agricultural regions surrounding Prague and Bucharest are more and more being transformed into low-density settlement and commercial areas.

4.3 Agriculture

Land cover flows related to agriculture include three land processes with the following impacts on soil functions (see also Section 2.3):

- agricultural intensification has a positive impact on the biomass production potential of land (following the use of physical inputs), whereas all other soil functions are predominantly negatively affected;
- agricultural extensification results in positive impacts on all soil functions; and
- agricultural expansion also results in negative impacts on all soil functions except biomass production.

For the agriculture sector, four assessments were carried out. The land processes related to agricultural expansion and agricultural intensification were combined, since both processes have the same impacts on soil functions:

(1) impacts of agricultural expansion and agricultural intensification on the biomass production function, which are predominantly positive;

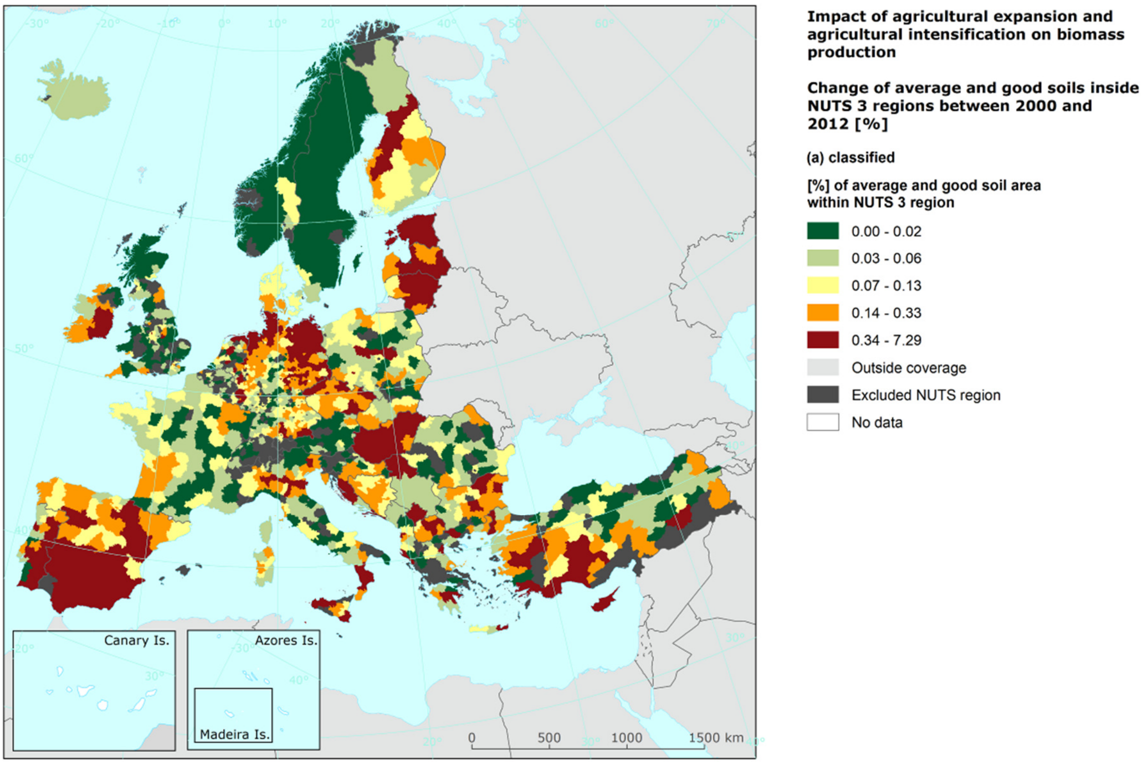
(2) impacts of agricultural expansion and agricultural intensification on the soil carbon potential, which are predominantly negative;
(3) impacts of agricultural expansion and agricultural intensification on the soil biodiversity potential, which are predominantly negative; and
(4) impacts of agricultural extensification on the biomass production function, which is predominantly positive.

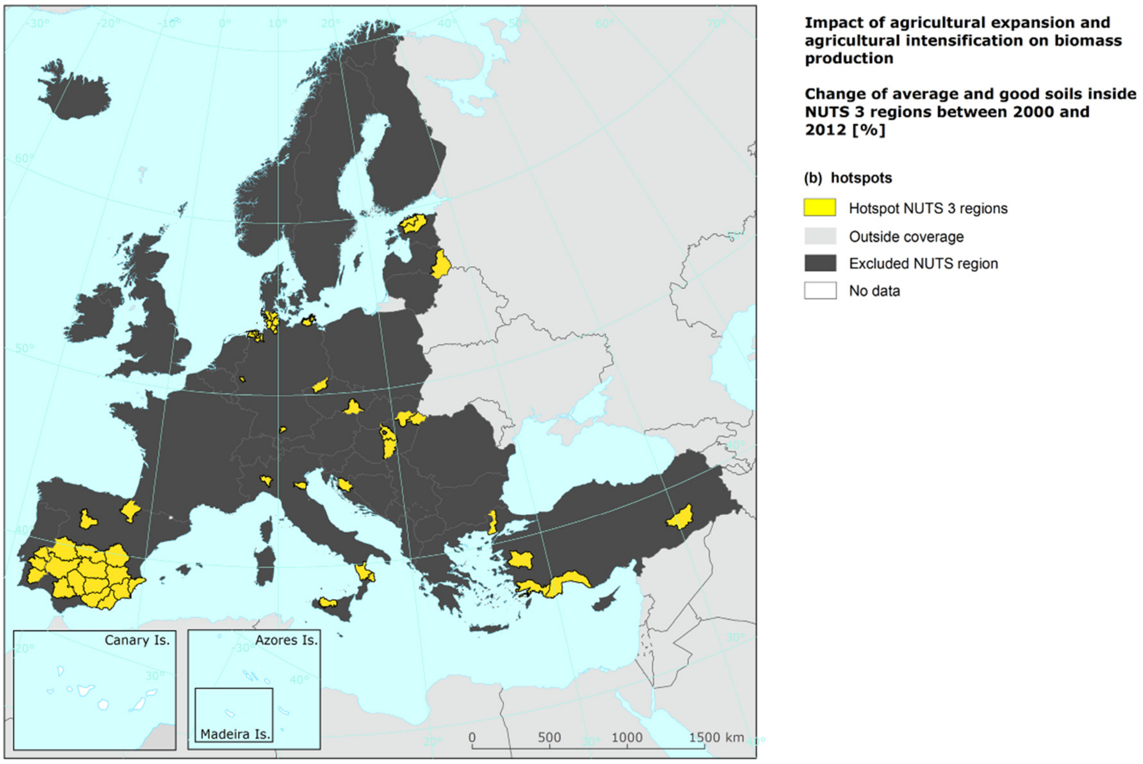
4.3.1 Agricultural hotspots of biomass production due to agricultural intensification and expansion

This assessment considers the positive impact of agricultural intensification and expansion on the biomass production potential (see Map 4.3). Generally, it can be observed that 75 % of European regions have experienced an increase in the biomass production potential of good and average soils due to agricultural expansion or intensification. Among the regions concerned, agricultural intensification dominates in 62 % of regions and agricultural expansion in 38 %.

Hotspots for this assessment are affected in a range of 0.9 % to 7.3 % of their available stock of good and average agricultural soils, corresponding to the first 5 % of relevant regions. In total 56 hotspot regions were identified (see Map 4.3 (b)). Hotspots of intensification and expansion can above all be found on the Iberian Peninsula and on the Mediterranean coast of Turkey. Single regions can also be found in the Czech Republic, Germany, Hungary and Italy.

Map 4.3 Hotspots of agricultural intensification and expansion, classified map (a) and hotspots (b)





In Andalusia, Spain, the traditional importance of olives as the main product for internal consumption and export (2 litres in every 5 litres of olive oil sold in Europe are from this region) led to the expansion of olive groves between 2000 and 2006. This policy was supported by the regional government and by the reformed common agricultural policy (CAP), and realised mainly by replacing rain-fed olive groves with irrigated olive groves, even in areas with steep slopes (Scheidel and Krausmann, 2011). Irrigation expansion and intensification (based on national and regional irrigation plans between 2000 and 2008) are also major drivers for internal conversion of other crop types (Calatrava and Garrido, 2010).

4.3.2 Hotspots of soil organic carbon impairment due to agricultural intensification and expansion

This assessment considers the negative impacts of agricultural intensification and agricultural expansion on the soil organic carbon potential. In total 59 % of European regions are not relevant to this assessment, due to their lack of good or average soils for the relevant soil function, or the lack of relevant LCFs (see Map 4.4).

Hotspots refer to regions where agricultural intensification and expansion affected more than 0.9 % of the available stock of good and average agricultural soils, corresponding to the first 5 % of relevant regions. In total 30 hotspot regions were identified (see Map 4.4 (b)), of which 26 are situated in Germany: five regions in Mecklenburg-Vorpommern, seven in Niedersachsen (both north-eastern Germany), and 13 regions clustered in northern Germany (Schleswig-Holstein, Lüneburg and Weser) (see also Box 4.3).

Generally, it can be concluded that the impacts observed in this assessment are much lower than those of urban expansion and forest management. A relatively low number of regions are concerned and hotspot values are also relatively low.

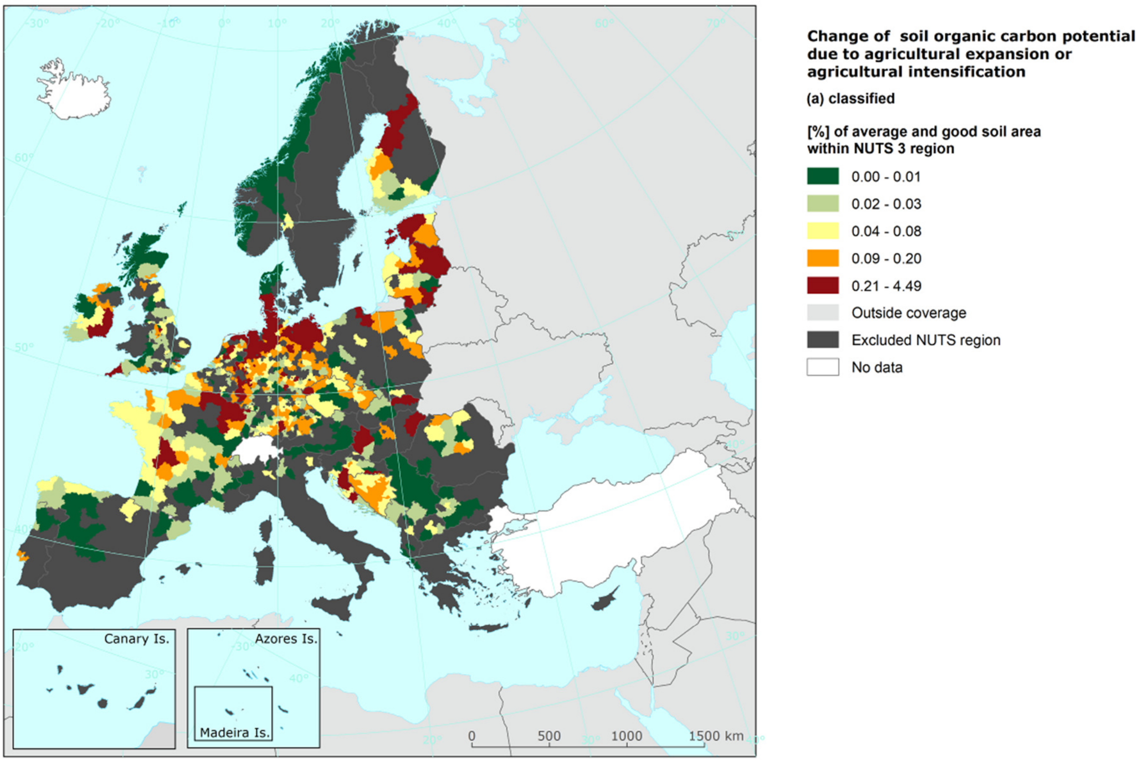
Box 4.3 Grassland conversion for biomass-based energy production in northern Germany

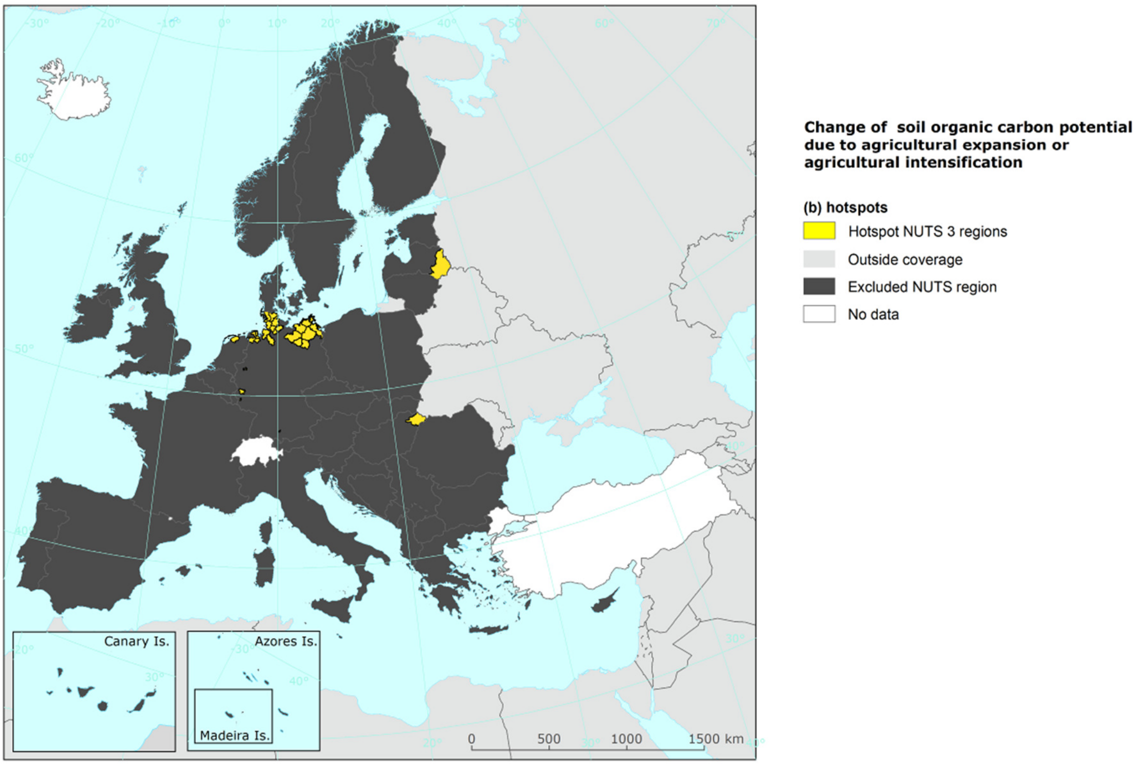
In the context of the German policy of energy transition (Energiewende), energy crops such as maize and rapeseed and the construction of biomass energy plants have been widely supported. One side effect is that grassland has been converted to cropland for energy crops. It has been shown in particular that maize is used on more than 50 % of former grassland areas now converted to cropland (Nitsch et al., 2009).

The problem with the conversion of grassland to cropland lies in the consequences regarding the soil carbon pool. Due to conversion, the carbon fixed in the soil is mineralised and largely released as CO2 during the first year of the conversion. There is an additional release of nitrous oxide (N2O), a greenhouse gas with an even greater negative effect than CO2. Carbon can be fixed again by creating grassland. Nevertheless, the yearly fixing rate of carbon is only half of the release rate from the conversion of grassland to cropland (von Haaren et al., 2010). Poeplau et al. (2011) reach the same conclusion, showing modelling results where, in contrast to the slow and steady accumulation of soil organic carbon that follows the establishment of grassland, carbon loss after cultivation of former grassland occurs more rapidly. For a mean sampling depth of 27 cm, a new equilibrium was already reached within 17 years of conversion, with a predicted loss of −36 ±5 % of the initial soil organic carbon stock. Matzdorf et al. (2010) calculated the costs of CO2 emissions from the conversion of grassland to cropland at nearly EUR 1 500 per hectare per year. For the time being, more than 12 % of Germany's utilised agricultural area is occupied by energy crops, compared with 2.5 % in 2000. A significant proportion is devoted to plants for biogas production (1.15 million ha) and rapeseed (0.75 million ha) for biofuel production.

There are two main drivers of this situation: the subsidies for energy crop production (e.g. maize, rapeseed) and the legal support for the construction of biogas energy plants. Even though the construction of biogas energy plants was stopped due to new energy legislation in Germany (2014), the existing plants have a 'right of continuance' for the next 20 years, which at least maintains the status quo. Some specific legislation at the state (Länder) level has halted further conversion from grassland to cropland and helped to keep the reduction of grassland in Germany at only 9 000 ha annually in 2012 and 2013 (BFN, 2014). Future energy policy and land management regulations should be in line with the good agricultural and environmental conditions (GAECs) for land included in the cross-compliance system of the CAP; i.e. to maintain soil organic matter and soil structure, and therefore to maintain the level of soil organic matter by avoiding this kind of conversions.

Map 4.4 Hotspots of soil organic carbon impairment due to agricultural intensification and expansion, classified map (a) and hotspots (b)



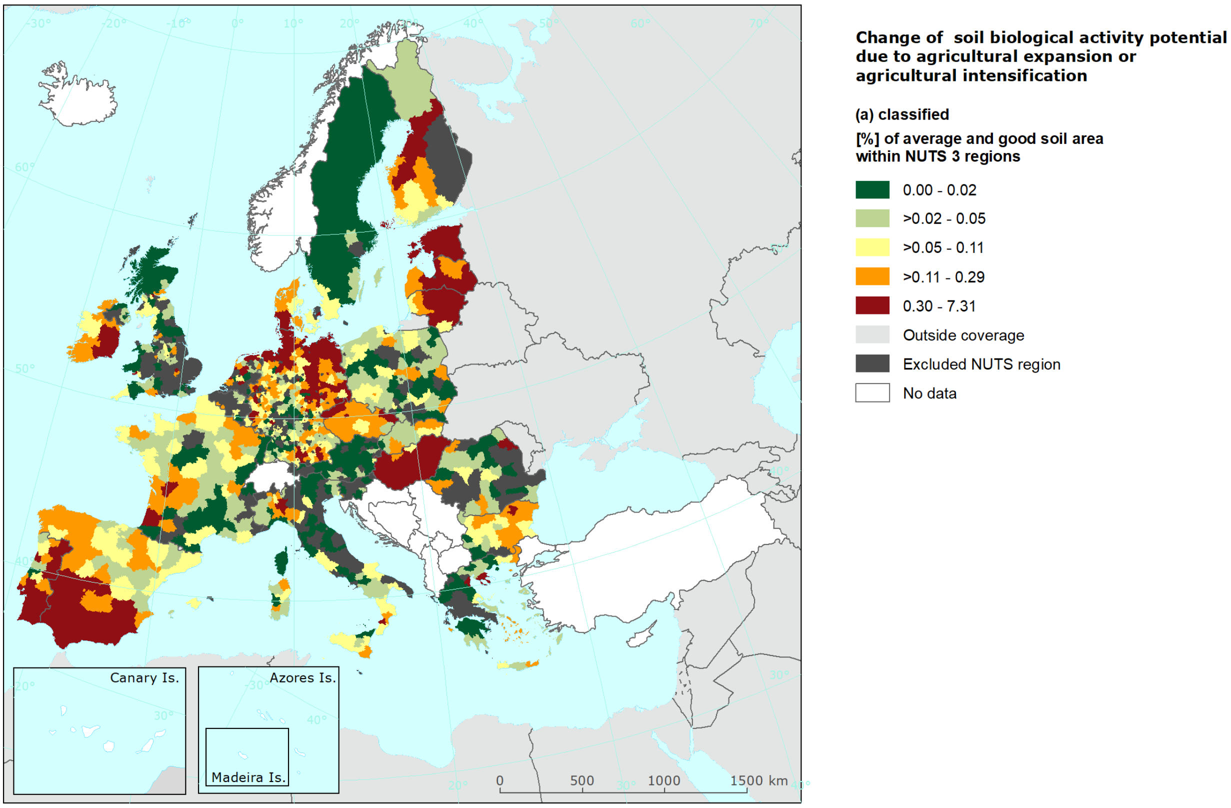


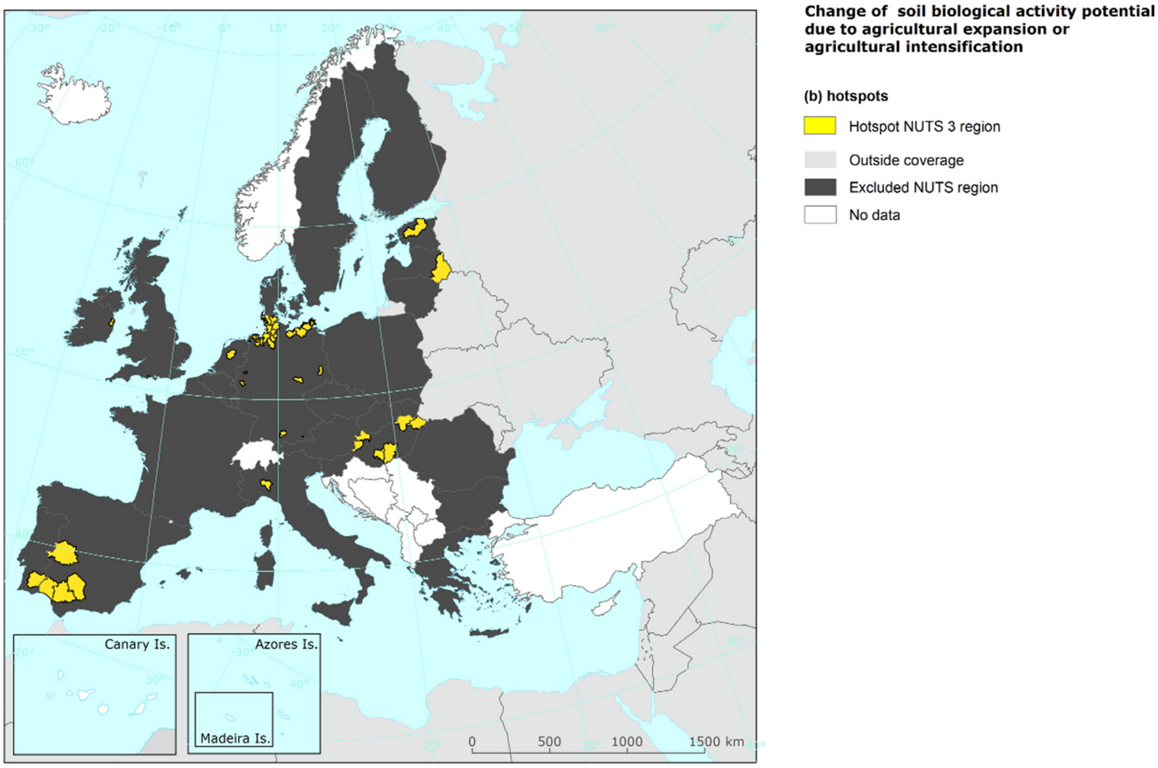
4.3.3 Hotspots of soil biodiversity impairment due to agricultural intensification and expansion

The assessment considers the LCFs agricultural expansion and agricultural intensification between 2000 and 2012 on good and average soils for the soil biodiversity function. Fifty-eight per cent of European regions are relevant for this assessment, because they are equipped with good or average soils for the soil function concerned and are affected by the relevant LCFs (see Map 4.5). For the period assessed, agricultural intensification is the dominant LCF for 60 % of regions concerned.

Hotspots of soil biodiversity impairment refer to regions where agricultural intensification and expansion affected more than 1 % of the available stock of soils with good and average potential for soil biodiversity, corresponding to the first 5 % of relevant regions. Of the 44 such regions identified (see Map 4.5 (b)), 27 are located in Germany, and predominantly in the northern parts of Germany. The rest are scattered all over Europe. Remarkably, six hotspot regions are assembled in Hungary and south-eastern Austria. Similar conclusions can be drawn as for the above assessment, namely a high share of unaffected regions and relatively low regional values concerning the percentages of affected soils.

Map 4.5 Hotspots of soil biodiversity impairment due to agricultural intensification and expansion, classified map (a) and hotspots (b)




Change of soil biological activity potential due to agricultural expansion or agricultural intensification
(b) hotspots
Hotspot NUTS 3 region
Outside coverage
Excluded NUTS region
No data
Canary Is.
Azores Is.
Madeira Is.
0 500 1000 1500 km

Box 4.4 Pros and cons of agricultural expansion on soil function potential in Almeria (Spain)

The region of Almeria experienced very rapid agricultural expansion through the installation of huge numbers of greenhouses to allow for year-round growth of produce (fruits and vegetables). This development led to a rise in living standards in this previously impoverished region. Between 1994 and 2005 Almeria's growth in gross domestic product (GDP) nearly quadrupled relative to the regional and national averages; in 2012 the region of Almeria ranked amongst the top third of all Spanish provinces in GDP per capita (Giagnocavo, 2012). However, negative environmental impacts threaten the region's ecosystems.

Figure 4.1 Growth of greenhouses in Almeria between 1977 and 2013

Source: Left: National photogrammetic flight (Spain) 1977-1978 (scale 1:18 000). Right: Orthophotography of the Spanish Orthophotography Plan 2013 (scale: 1:70 000). White spots on the right photo represent greenhouses.

From the mid-1970s, rural agricultural areas have typically been developed into intensive greenhouse agriculture (see Figure 4.1). As the area is arid, rain-fed agriculture is impossible and irrigation water cannot be sourced from local rainwater or surface water. Therefore, immense over-exploitation of the groundwater layer has led to an increase in the salinity of the aquifer (Mota et al., 1996). Additionally, intense agricultural activity in Almeria has had a strong impact on greenhouse soils due to the addition of agrochemicals to soils and crops, to improve nutrient supply or for crop protection and disease control (Ramos-Miras et al., 2014).

The massive extension of the agricultural surfaces has greatly affected the capacity of poor, average and good soils in Almeria for storing and filtering substances and nutrients. This impairment of all chemical and physical functions is expected to eventually lead to a reduction in the capacity of these soils to store, filter and transform nutrients.

Agricultural extensification has a positive impact on all soil functions. From a quantitative perspective, the storing and filtering function is most affected. Results show that 47 % of European regions are affected by agricultural extensification. Hotspots are above all located in the Czech Republic and the Netherlands. At the regional scale, agricultural extensification cannot be considered as a major influencing LCF, as only 27 regions were affected with more than 1 % of their stock of good and average agricultural soils. Therefore, this LCF is not further discussed.

4.4 Forest management

Forests present a significant global carbon stock accumulated through growth of trees and an increase in soil carbon. Estimates made for the Global Forest Resources Assessment 2015 (FAO, 2015) show that the world's forests and other wooded lands store more than 485 gigatonnes (1 Gt = 1 billion tonnes) of carbon: 260 Gt in biomass (53 %), 37 Gt in dead wood and litter (8 %) and 189 Gt in soil (39 %). While sustainable management, planting and rehabilitation of forests can conserve or increase forest carbon stocks, deforestation, degradation and poor forest management reduce carbon stocks. Globally, carbon stocks in forest biomass decreased by an estimated 0.22 Gt annually during the period 2011-2015. This was mainly because of a reduction in the global forest area.

Forest management is considered as a cycle of forest fellings and afforestation. A full cycle takes 70 to 100 years, in which the first 20 to 30 years are dominated by biomass production. The following assessment considers both forest fellings and forest expansion within a time span of 12 years. Thus, results by no means represent a full forest cycle.

Three assessments were carried out. In all assessments, forest expansion and forest fellings were balanced against each other:

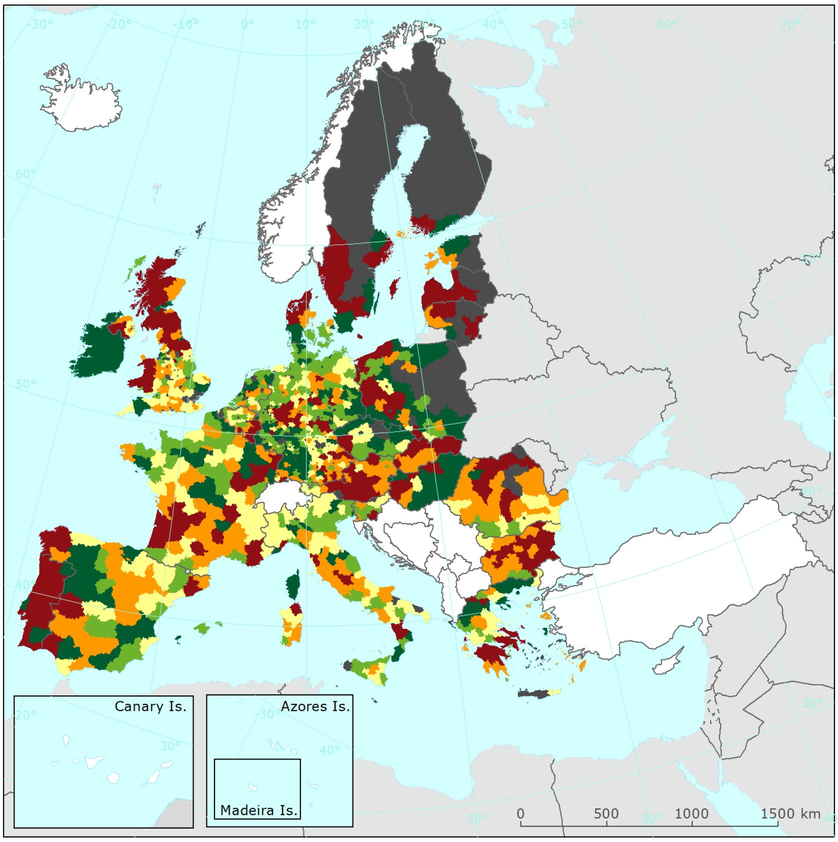
- impacts of forest expansion and forest fellings on the biomass production function;
- impacts of forest expansion and forest fellings on the soil carbon potential; and
- impacts of forest expansion and forest fellings on the soil biodiversity potential.

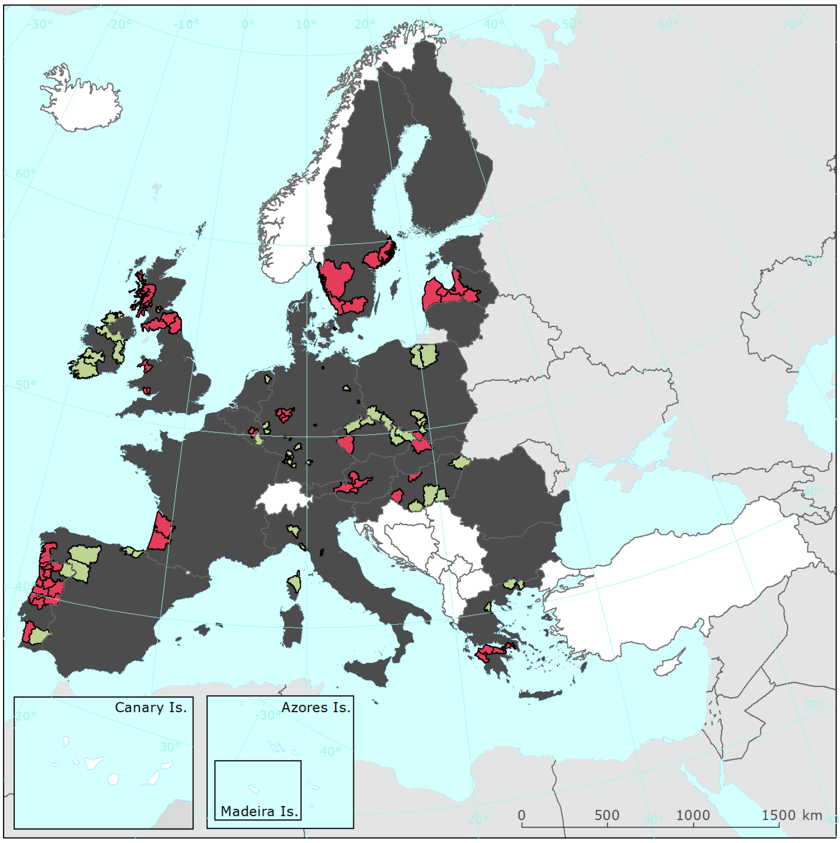
4.4.1 Hotspots of biomass production and biomass loss due to forest management

Forest expansion is considered as an increase of the biomass production potential, and forest fellings as a decrease (see Map 4.6). For each NUTS 3 region the land processes 'forest fellings' and 'forest expansion' were counter-balanced for the relevant soil function. The resulting sum was expressed as a percentage of the total stock of soils with average and good potential to deliver the respective soil function combined.

For the calculation of hotspots, regions were ranked according to their increase or loss of soil function potential (expressed as a percentage). The top 5 % at both ends were defined as hotspots, referring to regions with highest values of loss or increase of soil function potential. The assessment excludes regions that lack good or average soils for the relevant soil function, or where neither forest expansion nor forest fellings occurred between 2000 and 2012. In total, 31 % of European regions were not considered in this assessment.

Map 4.6 Hotspots of biomass changes due to forest fellings and forest expansion, classified map (a) and hotspots (b)





Forest management affects 69 % of European regions; 31% of European regions are affected by neither forest fellings nor forest expansion. In the period 2000-2012, forest fellings was clearly dominant, affecting 61 % of relevant regions, compared with 39 % for forest expansion.

Forest management is a key economic sector in Scandinavian countries, where a continuous increase of forest biomass can be observed.

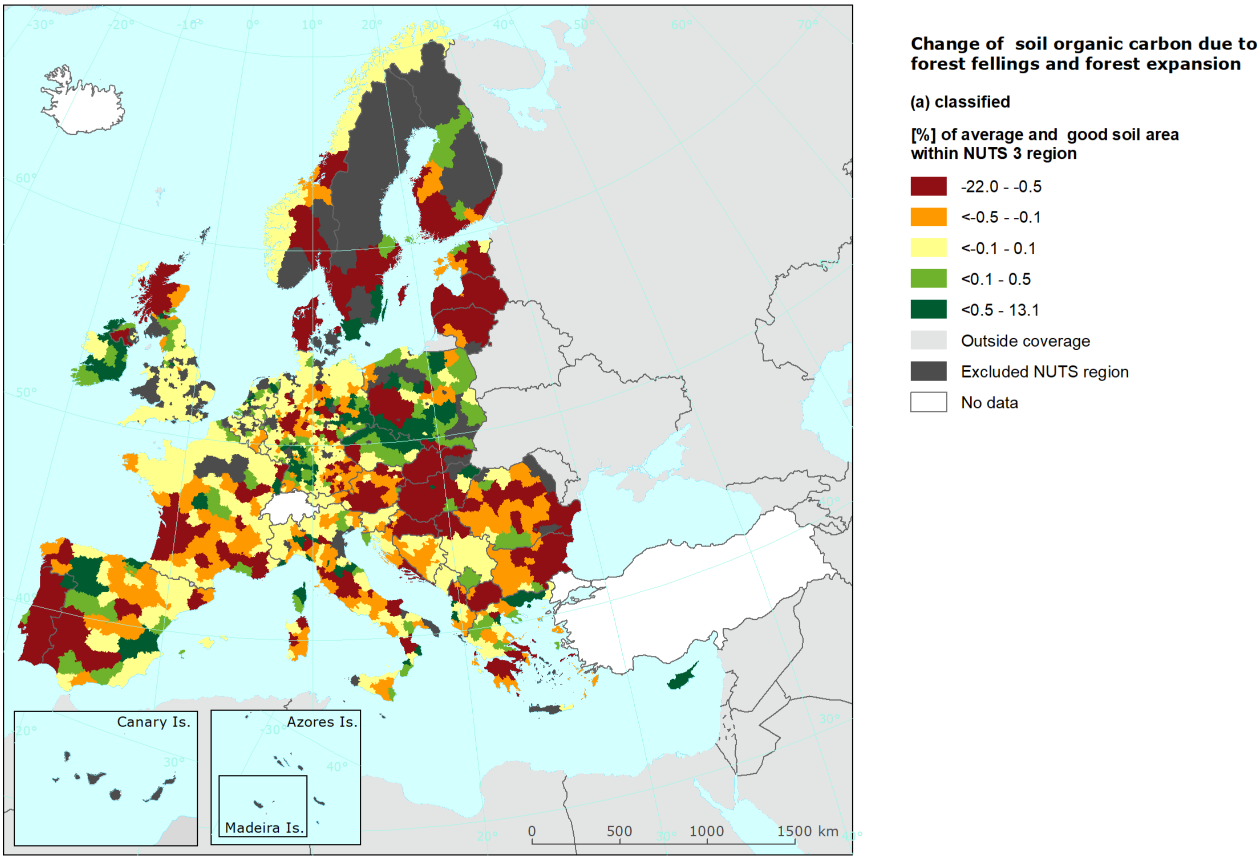
Regions with high losses of forest stock were above all affected by exceptional events. Forest fires are one cause, and regularly affect many European regions (see Box 4.5). This was the case in the Portuguese regions of Médio Tejo (−14 %) and Beira Beixa (−10 %), and in the Latvian region of Kurzeme (−7 %). The French region of Landes (−17 %), on the other hand, was affected by a storm (see also Box 4.5). Hotspots of forest expansion can be observed with values up to 5.4 % of the forest stock. Germany dominates in this category, but many French and Polish regions are also dominated by forest expansion.

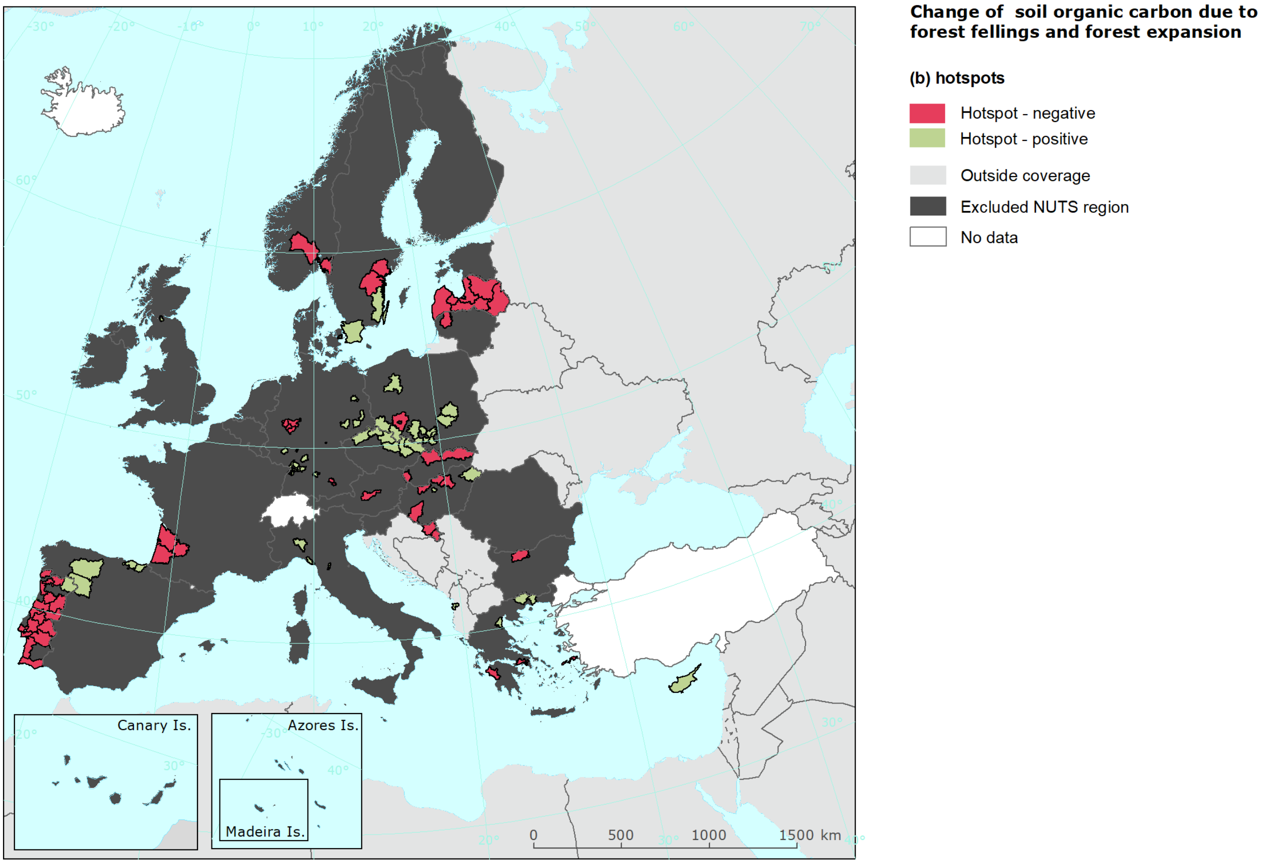
4.4.2 Hotspots of changes in soil organic carbon potential due to forest management

The assessment considers the LCFs forest fellings and forest expansion between 2000 and 2012 on good and average soils for the soil organic carbon pool function. Seventy-two per cent of European regions were affected by either forest fellings or forest expansion on good and average soils (see Map 4.7). Forest fellings is the dominant LCF for 62 % of relevant regions. Hotspots are defined as the top 5 % of those regions where forest fellings or forest expansion has the highest impact on soils with good and average potential to serve as a soil organic carbon pool. On the negative side, 54 hotspots range from −3 % to −22 % predominantly negative impact on these soils due to forest fellings (see Map 4.7 (b)). Two big clusters can be observed, one in Portugal with 16 regions, and the other in the Baltic region, with seven regions.

On the positive side, 54 hotspots range from 1 % to 13 % predominantly positive impact on soil organic carbon potential on good and average soils due to forest expansion. The largest cluster includes 12 regions in the south of Poland and in the Czech Republic.

Map 4.7 Hotspots of soil organic carbon changes due to forest fellings and forest expansion, classified map (a) and hotspots (b)





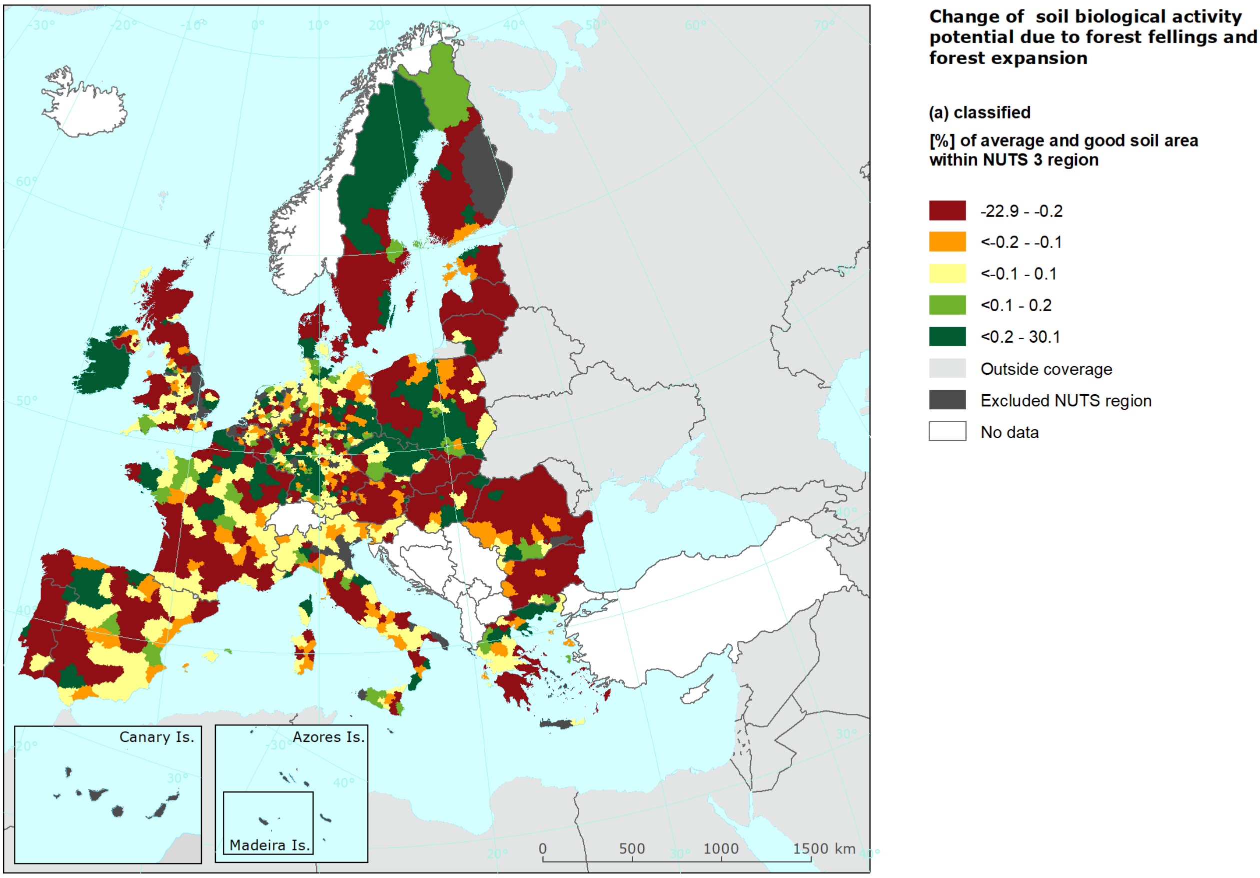
4.4.3 Hotspots of soil biodiversity changes due to forest management

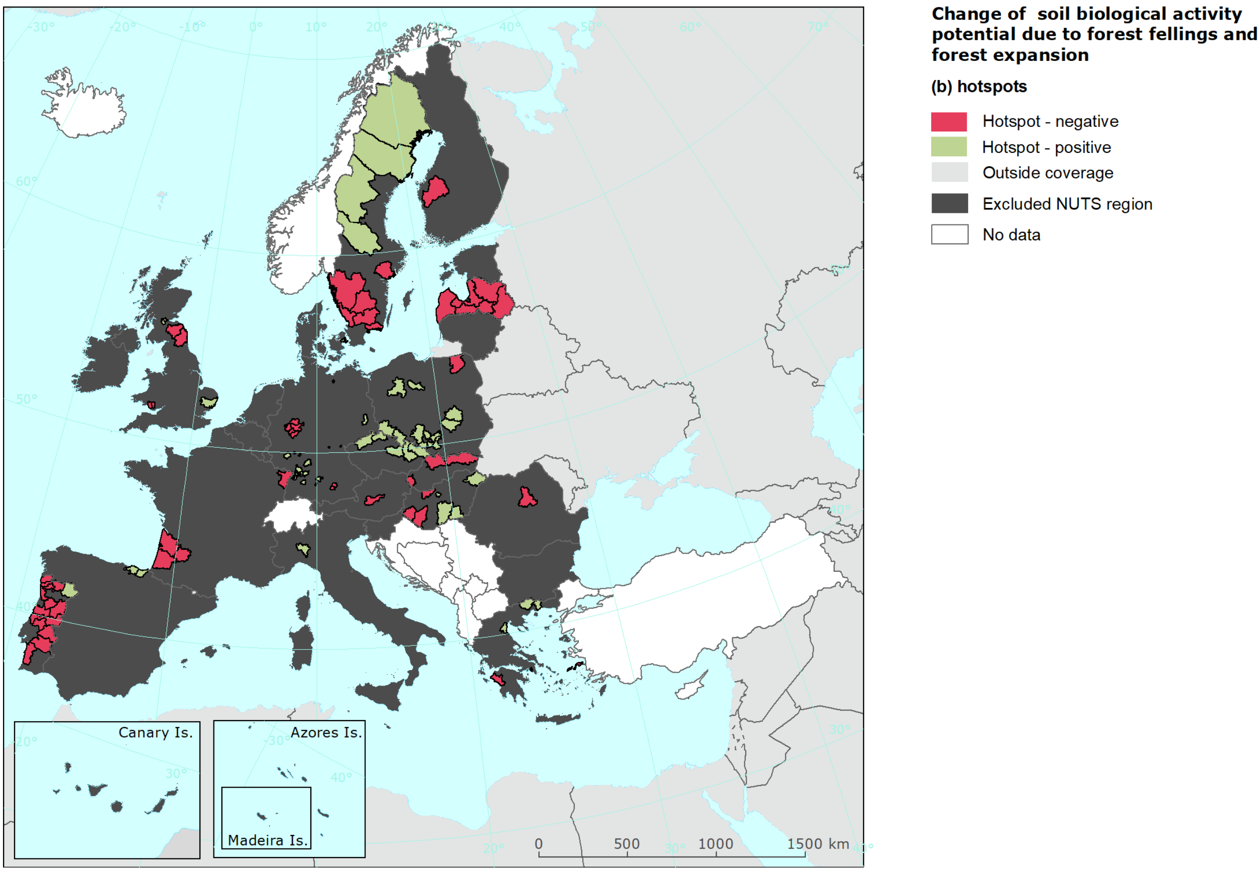
The assessment considers the LCFs forest fellings and forest expansion between 2000 and 2012 on good and average soils for the soil biodiversity function. Seventy-two per cent of European regions were affected by either forest fellings or forest expansion on soils with good and average potential for soil biodiversity. Forest fellings is the dominant LCF for 63 % of regions concerned.

On the negative side, 55 hotspots range from −2 % to −23 % predominantly negative impacts on the soil biodiversity potential of 'good' and 'average' soils due to forest fellings. Three major clusters can be observed, in Portugal with 14 regions, in Latvia with five regions, and in the south of Sweden with five regions (see Map 4.8 (b)). On the positive side, 55 hotspots range from 1 % to 30 % predominantly positive impact on the soil biodiversity potential of 'good' and 'average' soils due to forest expansion. The largest cluster in terms of surface can be observed in the north of Sweden, with four very large regions. The second largest cluster is spread over the Czech Republic and Poland, with 13 regions.

Forest management affects soil biodiversity and soil organic carbon in a very similar way, as can be observed through this and the previous assessment.

Map 4.8 Hotspots of changes in soil biodiversity potential due to forest fellings and forest expansion, classified map (a) and hotspots (b)



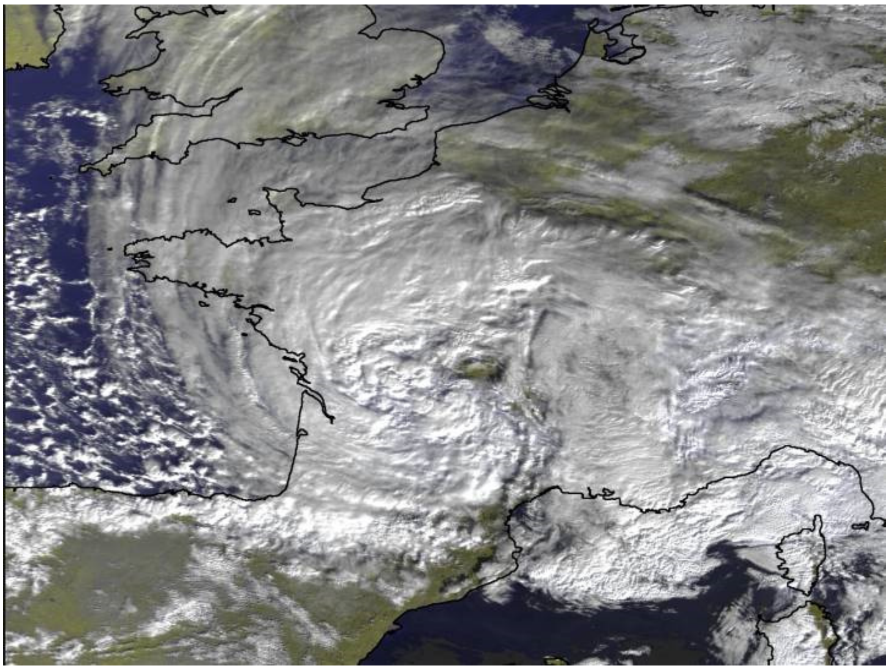


Box 4.5 Storms and forest fires as causes of major forest losses

Storm Klaus devastates Atlantic coast

In January 2009, Windstorm 'Klaus' damaged around 300 000 ha of pine forest, most of which was located in the Landes forest. In 2010, trees were devastated by a bark beetle infestation. Now the affected area hosts the biggest reforestation project in Europe, with 220 000 ha to be reforested by 2017. This devastating storm and the subsequent reforestation programme are probably the major reason why the data for the Landes region exhibits more forest expansion (i.e. afforestation) than forest fellings (devastation by the storm) compared with other regions (Global Forest Watch, 2009; The Guardian, 2012).

Figure 4.2 Satellite image of Windstorm Klaus in 2009



Source: Météo France.

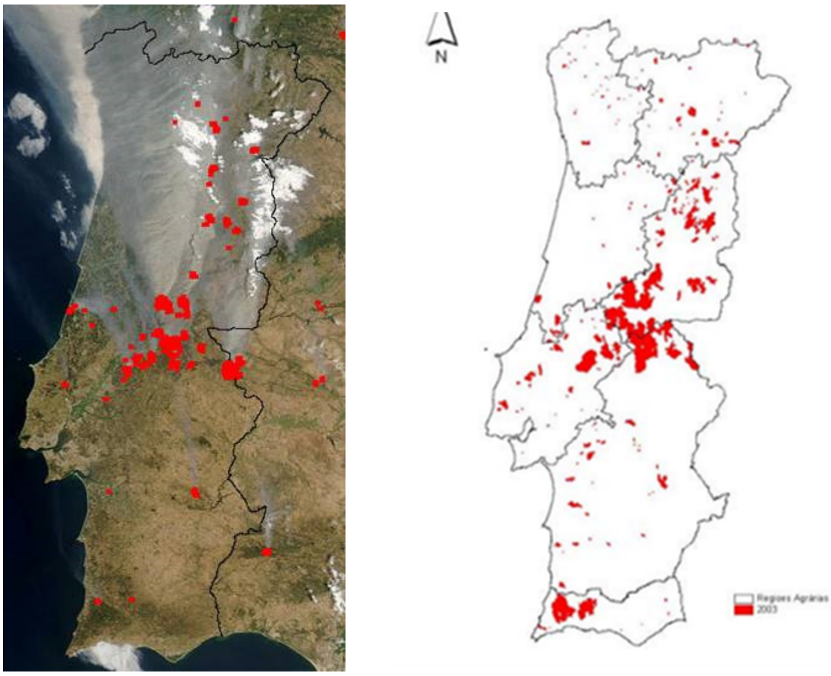
Forest fires in Portugal

Since the end of the 1980s, Portugal has regularly been affected by forest fires and wildfires, which destroy large areas of forest. In 2003 alone, more than 400 000 ha of forest, shrubland and agricultural land were burnt, more than half of the entire burnt area in all European Mediterranean countries that year. While other Mediterranean countries recorded around average burnt areas, this area quadrupled in Portugal, while at the same time the number of fires increased only slightly. In other words, while accounting for 38 % of all forest fires in 2003, Portugal recorded 58 % of the burnt area in Mediterranean Europe, meaning that the average area covered or burnt by a forest fire in Portugal was bigger than in the other Mediterranean countries (JRC, 2004). An image of the situation is provided by the NASA Earth Observatory, showing the location of the various fires at the beginning of August 2003 and the huge smoke clouds over the north of the country (see Figure 4.3, left) ([11]).

The dramatic expansion of the burnt area during the summer months of 2003 was unprecedented (see Figure 4.3, right). 2017 was then the next year during which devastating fires caused burnt

([11]) http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=11856 areas of a similar size than 2003 (around 440 000 ha) and more than 100 casualties ([12]). The reasons for this situation were, and still are, on the one hand, an abnormally hot and dry weather period (as happened in large parts of Europe in 2003), and on the other hand conjunctural and structural causes (such as the absence of a sustainable long-term national forest policy or a rather poor education of the population regarding forest fire risks). The decrease of the rural population, together with the abandonment of cultivation and reduced animal grazing on forest and shrublands, left many areas unguarded and unmanaged; moreover, afforestation focused mainly on eucalypt and pine species, which are highly flammable, and, in the event of fire, aggravate its intensity and increase the speed of propagation. After 2005, several actions and measures have been taken to improve the situation; the approval of the National Strategy for Forests in particular was an important step. ([13])

Figure 4.3 Areas burnt by wildfires in Portugal in 2003. Left: Satellite image (MODIS) showing the smoke cloud; maps of fire locations superimposed. Right: Mapped forest fires in 2003.



Sources: NASA, 2003 (left); IFFN, 2006 (right).

In any case, the consequences of such devastating fires are the destruction of forests and their conversion into burnt areas and subsequent transitional woodland. This also has economic repercussions, taking into account that the forest sector, based on the forest biomass production potential, contributed USD 3.3 billion (1.6 % of GDP) to the Portuguese economy in 2011 ([14]). In addition to the environmental impact, therefore, the economic losses are of major importance in Portugal (as in other Mediterranean countries).

([12]) http://www2.icnf.pt/portal/florestas/dfci/relat/rel-if/2017, https://www.publico.pt/2017/11/10/sociedade/noticia/2017-foi-o-ano-em-que-mais-ardeu-nos-ultimos-dez-anos--quatro-vezes-mais-que-o-habitual-1792180

([13]) personal communication from the NRCs land use and spatial planning as well as land cover.

([14]) http://www.globalforestwatch.org/country/ESP, http://www.globalforestwatch.org/country/PRT

5 Three-dimensional land cover accounts: balances at pan-European, country and NUTS 3 level

This chapter will:

- provide balances of the impacts of the selected land processes on soil functions on a pan-European, national and regional level; and
- describe and analyse those balances, with a particular focus on the total balance at NUTS 3 level.

5.1 Calculation of balances

By definition, a balance in the financial world is 'a figure representing the difference between credits and debits in an account; the amount of money held in an account' [15]. However, balances are not only used in an economic context, and have also been applied in nature and soil sciences, for instance concerning soil water balances, nutrient balances in soils, or soil carbon and soil microbial activity.

In the context of this study, looking at the impacts of land processes on the various soil functions (predominantly positive or negative; neutral or unclear impacts were left out — see Figure 2.6), it is possible to create balances that provide an indication of whether or not one of these impacts prevails. The balance can be produced for various reference units, such as single or multiple soil functions (is the impact of the sum of all land cover changes positive or negative?), and for different spatial units, such as countries or NUTS 3 regions (is the country/region overall affected in a predominantly positive or negative way?). Furthermore, the balances can be calculated for all the land processes together, for separate land processes or for land processes merged to meaningful categories (such as agriculture- or forest-related flows).

For the calculation of balances, the impact values for all areas affected by the land processes (grouped according to major topics/sectors — see Chapter 2) are given their proper prefix according to their impact on the soil function, being predominantly positive (+) or negative (−). These weighted (following the area affected) values are then summed up for all soil functions and given in relation to the NUTS 3 reference area. In this calculation, the reference unit had to be changed from share of good and average soils within the NUTS 3 regions, which is used in the analysis of the single soil functions, to the total surface area of the NUTS 3 regions. This was necessary because grid cells (of the soil function data) can contain multiple soil functions (see Section 2.2.3), so that the total sum of good and average soils within a NUTS 3 region can easily exceed the total area of that region. Moreover, all impacts were treated equally without accounting for their severity (see further elaboration on this in Section 5.4).

As a consequence, the values presented in the graphs and maps in the following sections indicate the percentage of all NUTS 3 areas that have been affected by the land process(es) and for the soil function(s) under consideration. Those values can be either positive (when predominantly positive impacts prevail) or negative (when predominantly negative impacts prevail).

[15] https://en.oxforddictionaries.com/definition/balance

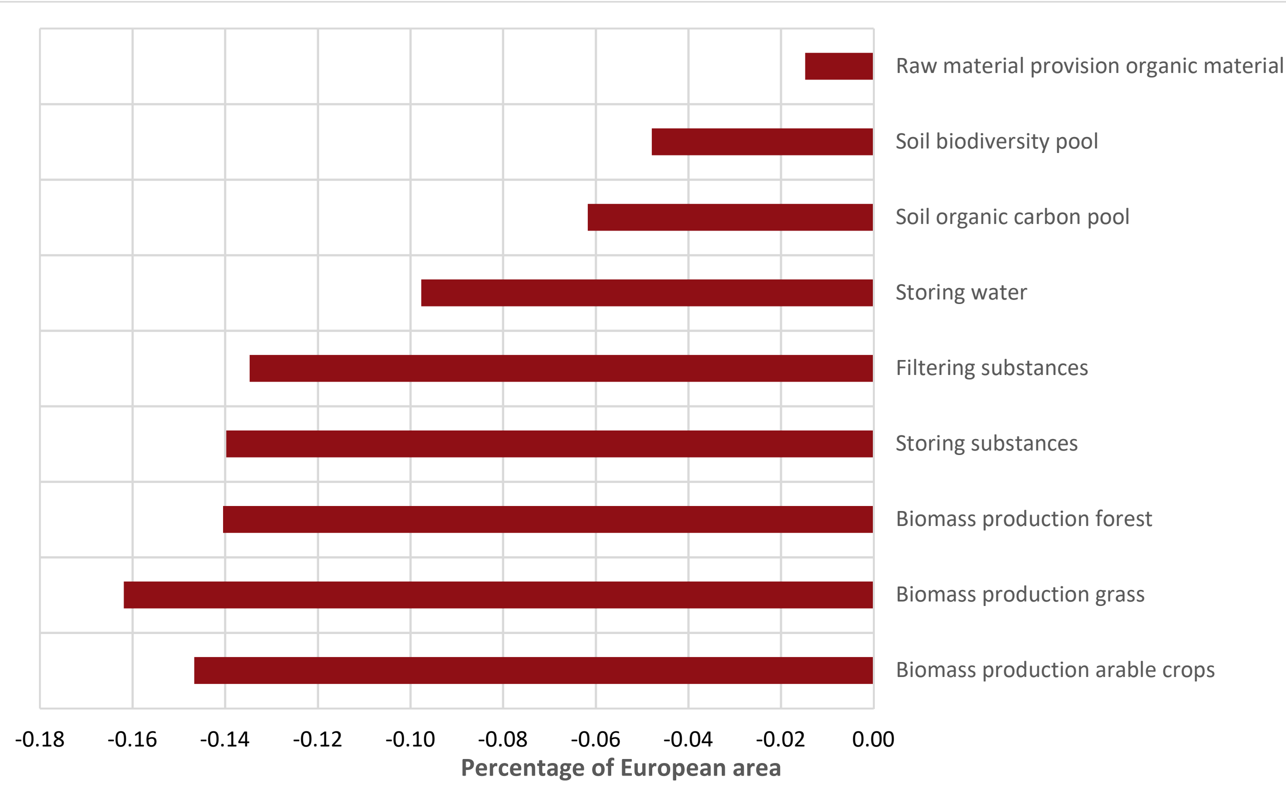
5.2 Balances at European level

This first section analyses the balances at the European level for each of the three important land processes separately per soil function. It is obvious that the graphs reflect the direction of the impact (positive or negative), which is given by the evaluation matrix (see Section 2.3 and the description of calculation methods in the previous Section 5.1). It is interesting to see the size of the impact when comparing the different soil functions, however.

5.2.1 European soil function balance for urban expansion

The biomass provision functions, along with the storing and filtering substances functions, are most affected by urban expansion (see Figure 5.1). However, to properly evaluate the maximum value of the impact it needs to be kept in mind that urban expansion (1) consists of only one land process, while the other two illustrations (agriculture and forest management) are made up of two processes, and (2) covers much less surface area than, for example, forest-related processes.

Figure 5.1 Impact of urban expansion (2000-2012) on the relevant soil functions, EEA-39



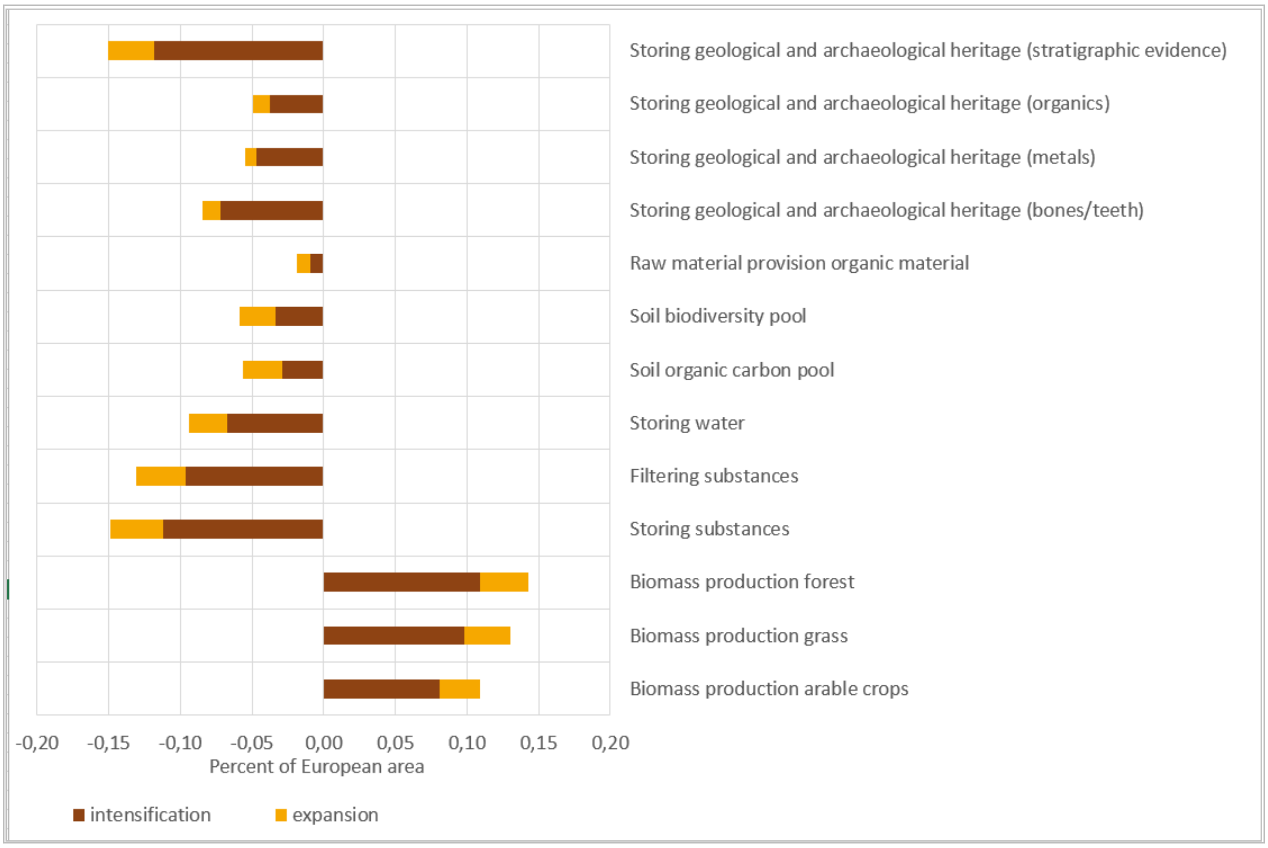
Note: The platforms for human activities, provision of construction material, and storing geological and archaeological heritage functions are not displayed, as their impact is unclear or neutral.

5.2.2 European soil function balance for agriculture

The illustration of the agriculture-related processes 'agricultural intensification' and 'agricultural expansion' (see Figure 5.2) demonstrates that the three biomass production functions (arable crops, grass, forest) have a positive balance (i.e. the capacity for producing biomass improves), whereas all other functions are negatively affected, but to varying degrees.

Moreover, for most of the functions intensification dominates over expansion, i.e. the positive as well as negative impact of agricultural expansion is higher than that of agricultural intensification. Exceptions are the soil organic carbon pool function and construction material provision, for which the impact is similar.

Figure 5.2 Impact of the agricultural processes 'agricultural intensification' and 'agricultural expansion' (2000-2012) on the relevant soil functions, EEA-39



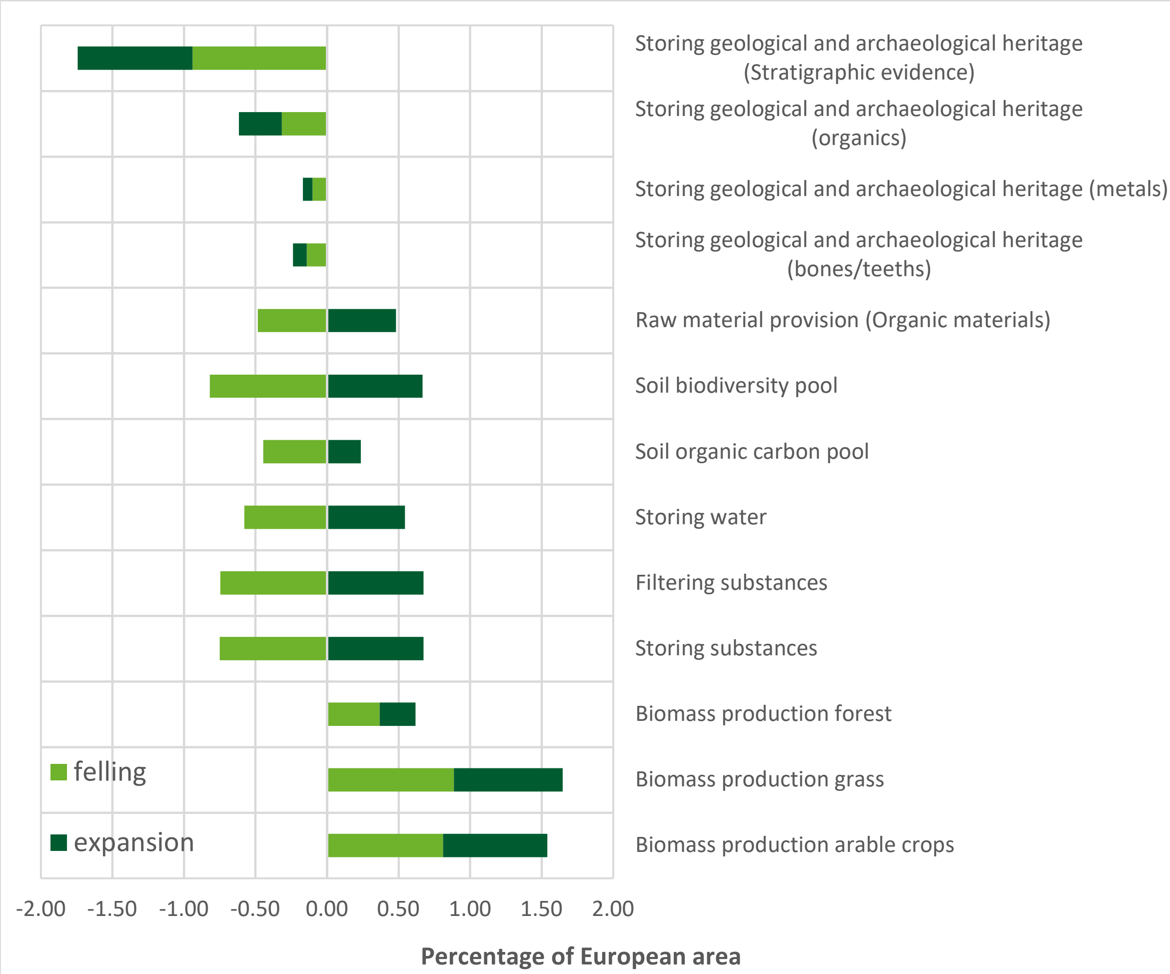
Note: The platform for human activities and provision of construction material functions are not displayed, as their impact is unclear or neutral.

5.2.3 European soil function balance for forest management

Analysing the balance of the forest management-related processes (see Figure 5.3), the overall picture is less clear, but also reflects the evaluation matrix (see Figure 2.6 in Section 2.3). This is because forest expansion and forest fellings are two processes with opposing impacts on the soil functions. While forest expansion is predominantly positive for all functions (except storing geological and archaeological heritage), forest fellings is, in the framework of the forest management cycle, positive only for the biomass production function, and has predominantly negative impacts on all other functions.

The most interesting finding here is that for most functions forest expansion and forest fellings level each other out, i.e. they are of the same magnitude in opposite directions. However, for the soil organic carbon pool and the forest biomass production functions in particular, the predominantly negative impact dominates, which indicates a slight deterioration of the potential of good and average soils to provide those functions. In general, the proportions of impacts (i.e. the percentages) are much larger (by a factor of around 10) than those for agriculture-related processes.

Figure 5.3 Impact of the forest management processes 'forest fellings' and 'forest expansion' (2000-2012) on the relevant soil functions, EEA-39



Note: The platform for human activities and provision of construction material functions are not displayed, as their impact is unclear or neutral.

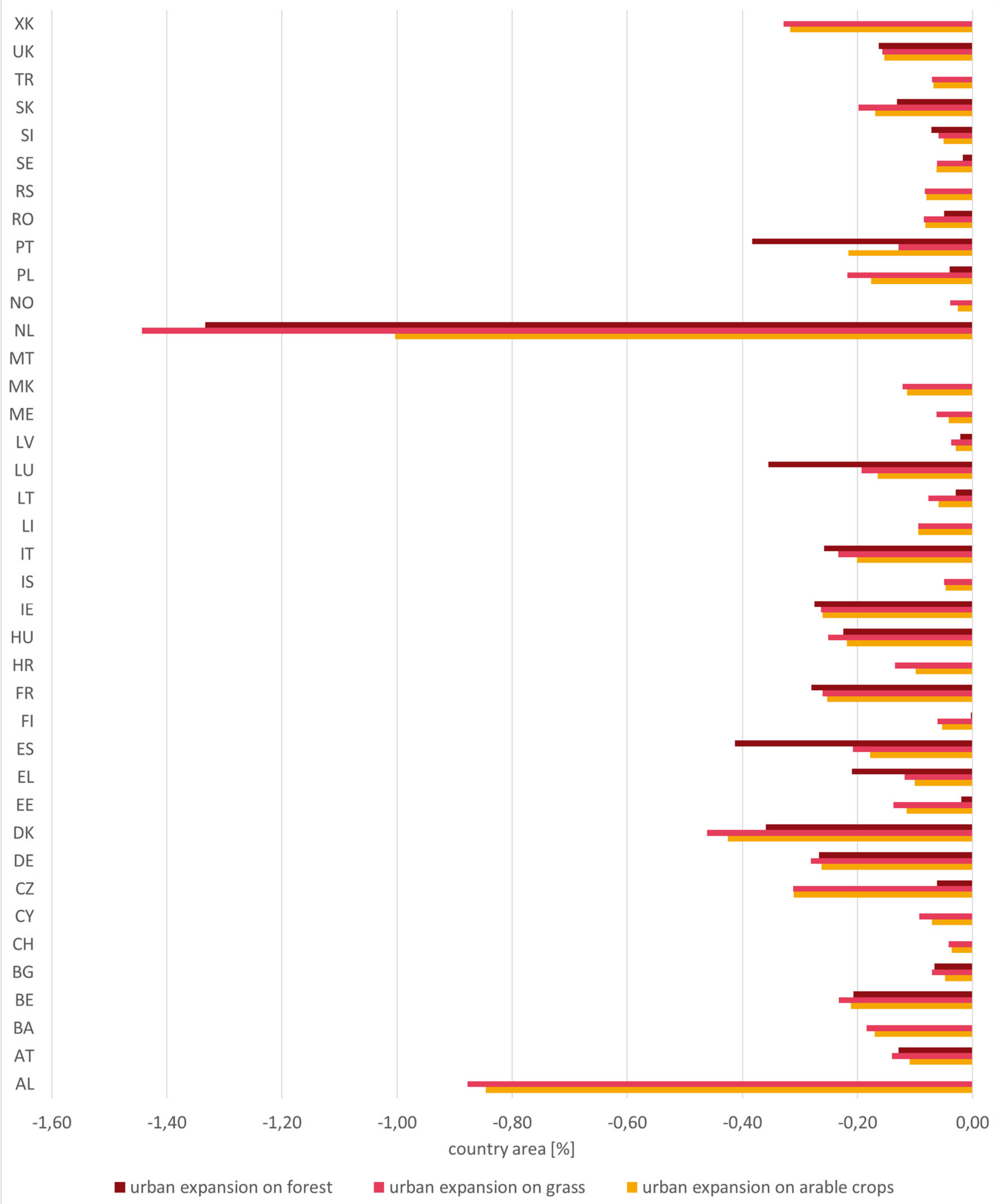
5.3 Country balances

The country balances combine the impacts of the land processes with a specific soil function and are displayed as percentages per country.

5.3.1 Soil function balance for urban expansion at country level

The impact of urban expansion on the capacity of soils to produce arable, grass and forest biomass is predominantly negative, i.e. affected soils and their functions are often irreversibly lost. However, the overall balance shows high variations in Europe (see Figure 5.4). The Netherlands has the highest impacts from the expansion of buildings and infrastructure on soils with production potential for grass, crops and forest (−1.42 % for grass, −1.33 % for forest and −1 % for arable crops). This position of the Netherlands reflects the general distribution of urban expansion in Europe (see Section 2.1.2). The other countries reveal different pictures when the impact of urban expansion on the three soil (sub-)functions is analysed. While the impact on soils with production potential for crops and grass is almost always in a similar range, with a slightly higher impact for grass, the impact on soils with a production potential for forest biomass differs substantially between countries. Spain, Portugal and Luxembourg are the three countries in which the impact on the forest production potential is significantly higher than on arable land and grassland soils. Only Denmark has a similar value, but it does not exceed the other two values.

Figure 5.4 Impact of urban expansion (2000-2012) on soils with the capacity to provide biomass (arable crops, grass and forest)



Note: Data for soils with a potential to provide biomass (arable crops and grass) cover the EEA-39, while forest biomass provision data cover the EU-28, except Croatia, Cyprus and Malta; Malta does not possess good and average soils.

5.3.2 Soil function balance for agriculture at country level

By far the highest combined impact of the two processes ‘agricultural intensification’ and ‘agricultural expansion’ is on the provision of arable crop biomass (see Figure 5.5). Both processes have a predominantly positive impact on the capacity of soils to provide arable crop biomass, as can be found in Hungary and Estonia with values of 0.732 % and 0.657 %, respectively. In both countries, agricultural intensification clearly dominates over expansion. This is generally the case for almost all countries except Finland, which is almost exclusively affected by agricultural expansion. Although it seems to be surprising to find Finland here, this situation is probably caused by the Nordic Aid Scheme agreed upon in the Act of Accession to the European Union. This allowed specific national support schemes for maintaining and extending agricultural production north of 62° latitude (EC, 1994, 1995). But the general picture confirms the overall prevalence of the land processes in Europe (see Section 2.1.2), with Hungary and Estonia having the highest values in terms of intensification and shows expansion to be almost non-existent. It should be recognised, however, that the values are in general relatively low, and all stay well below 1 %.

Figure 5.5 Impact of the agriculture-related processes 'agricultural intensification' and 'agricultural expansion' (2000-2012) on the biomass production potential for arable crops, EEA-39

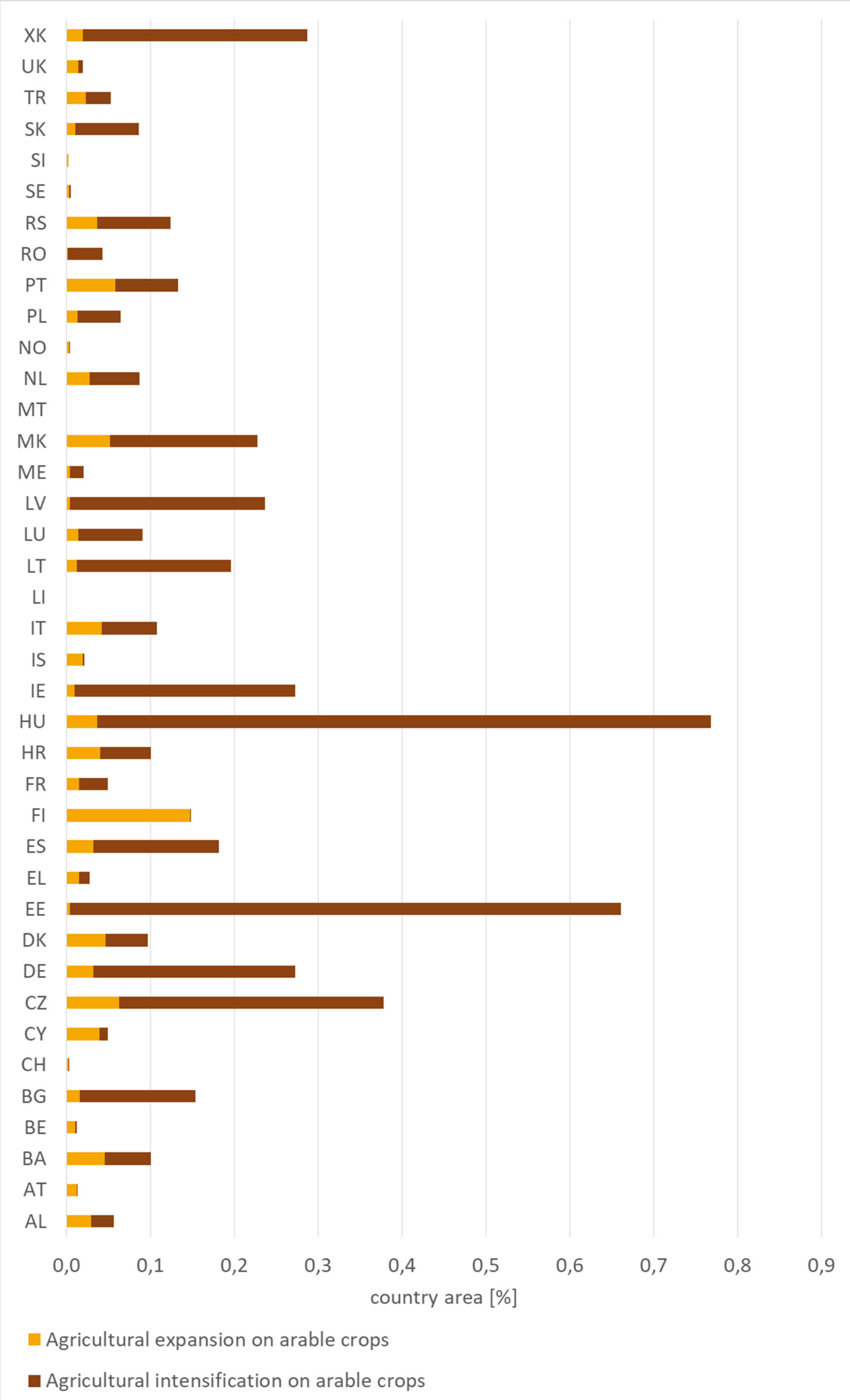
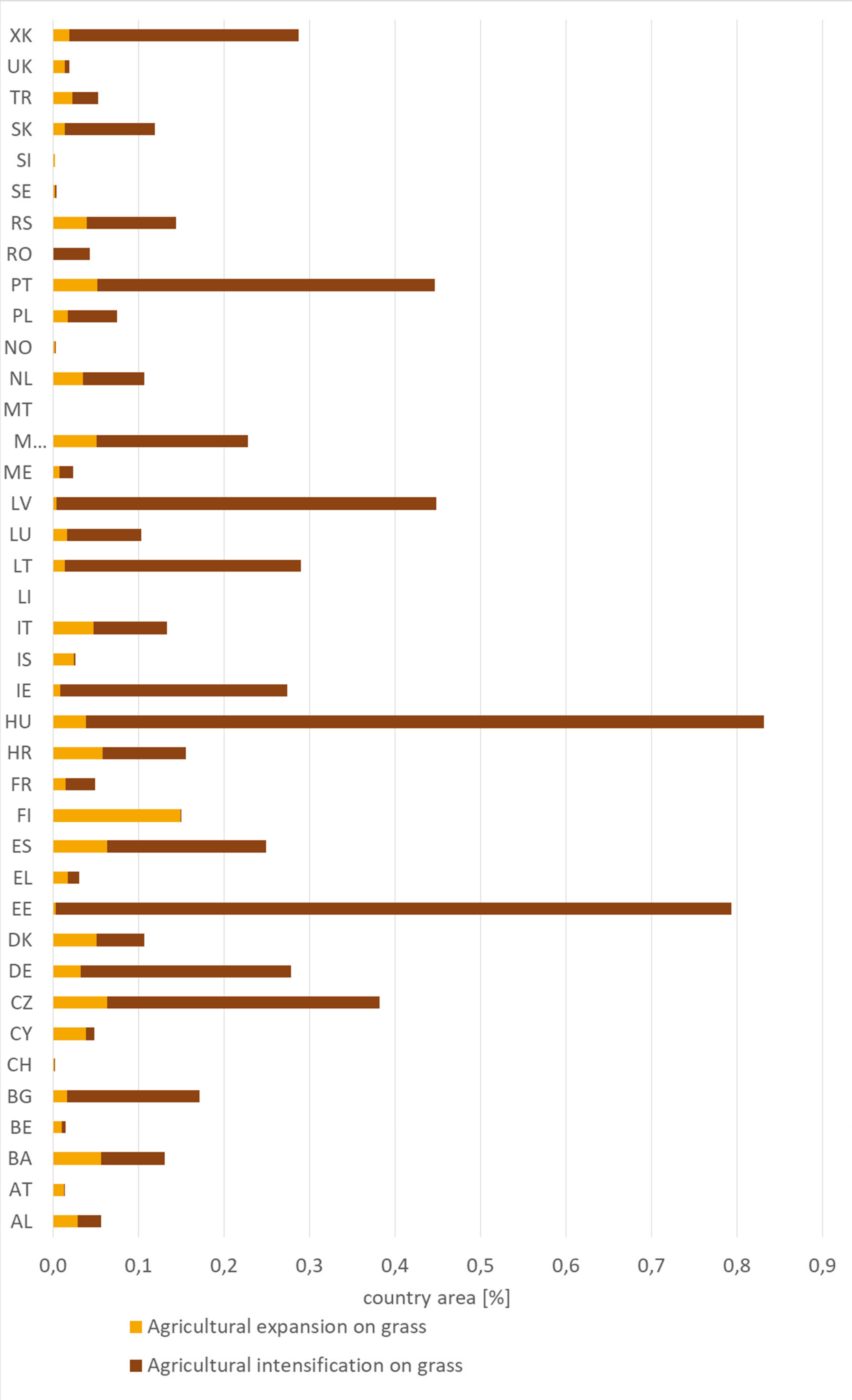


Figure 5.6 Impact of the agriculture-related processes 'agricultural intensification' and 'agricultural expansion' (2000-2012) on the grass biomass production potential, EEA-39

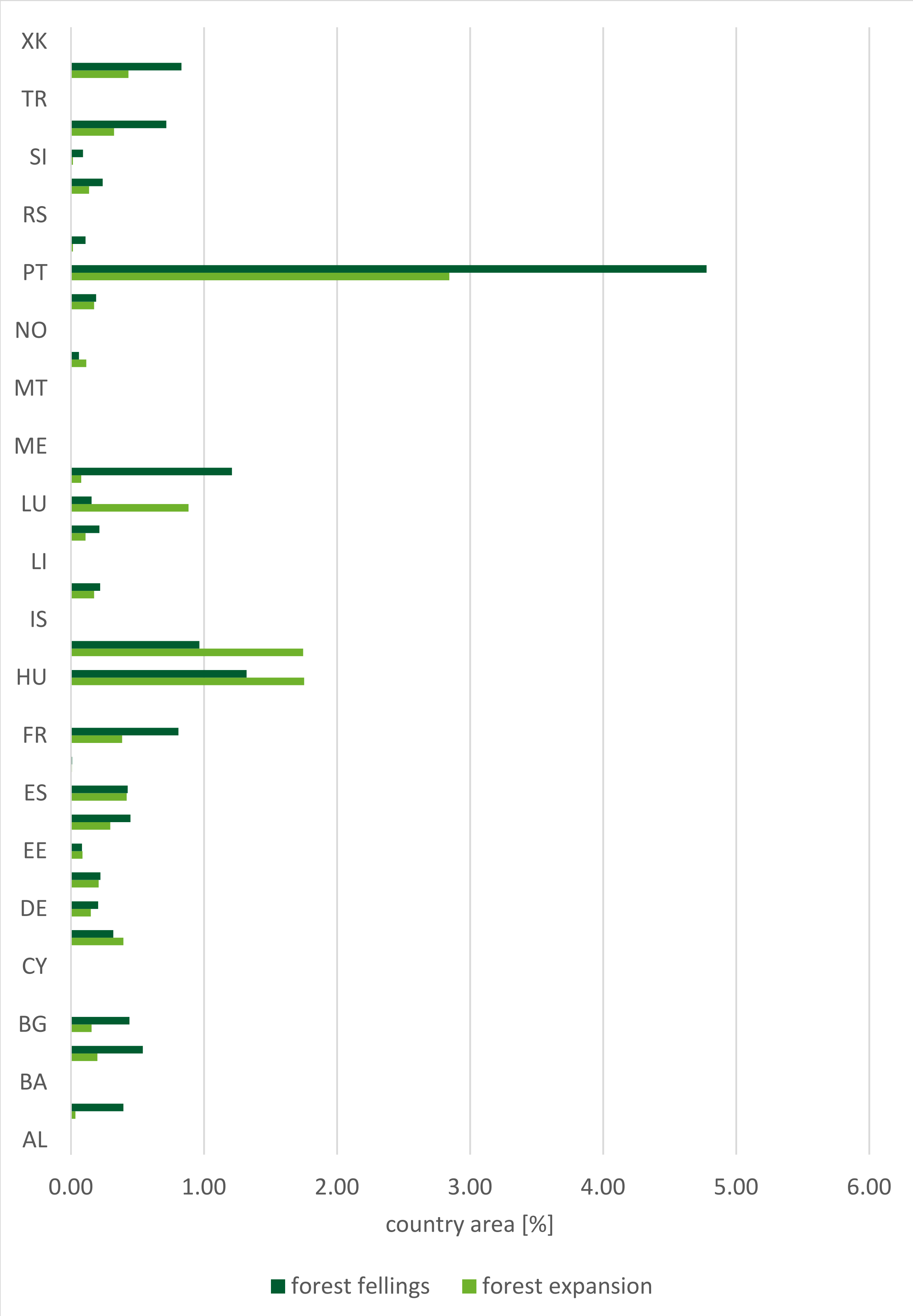


The overall picture is relatively similar for the impact of the two agriculture-related processes on the production potential for grass biomass (see Figure 5.6). Hungary and Estonia have the highest values, almost twice as high as the values for the next countries in the list (Latvia and Portugal). As with the impact on arable land, agricultural intensification is clearly the dominant process, and again only Finland is represented, mainly by agricultural expansion.

5.3.3 Soil function balance for forest management at country level

Unlike the previously discussed biomass production function for arable crops and grass, the total impact of the forest management-related processes ‘forest expansion’ and ‘forest fellings’ on the capacity of soils to provide forest biomass covers only the EU-28, with the exceptions of Croatia, Cyprus and Malta. Both processes have predominantly positive impacts; forest fellings and subsequent regeneration favour forest biomass production in the first 20-30 years of the forest management cycle (see Section 2.3). The graph (see Figure 5.7) shows the varying importance of the two processes for each country, with some countries having more forest expansion and others more forest fellings. For both processes, Portugal possesses the highest values (4.78 % of its area has undergone forest fellings and 2.84 % forest expansion). Hungary and Latvia follow with respect to forest fellings (1.32 % and 1.21 %, respectively), while Hungary and Ireland have the next highest impacts from forest expansion (both 1.75 %). Comparing those values with the distribution of the land processes across Europe (see Section 2.1.2), Portugal and Latvia also show the highest proportions of forest fellings, whereas Portugal and Hungary are runners-up when it comes to forest expansion.

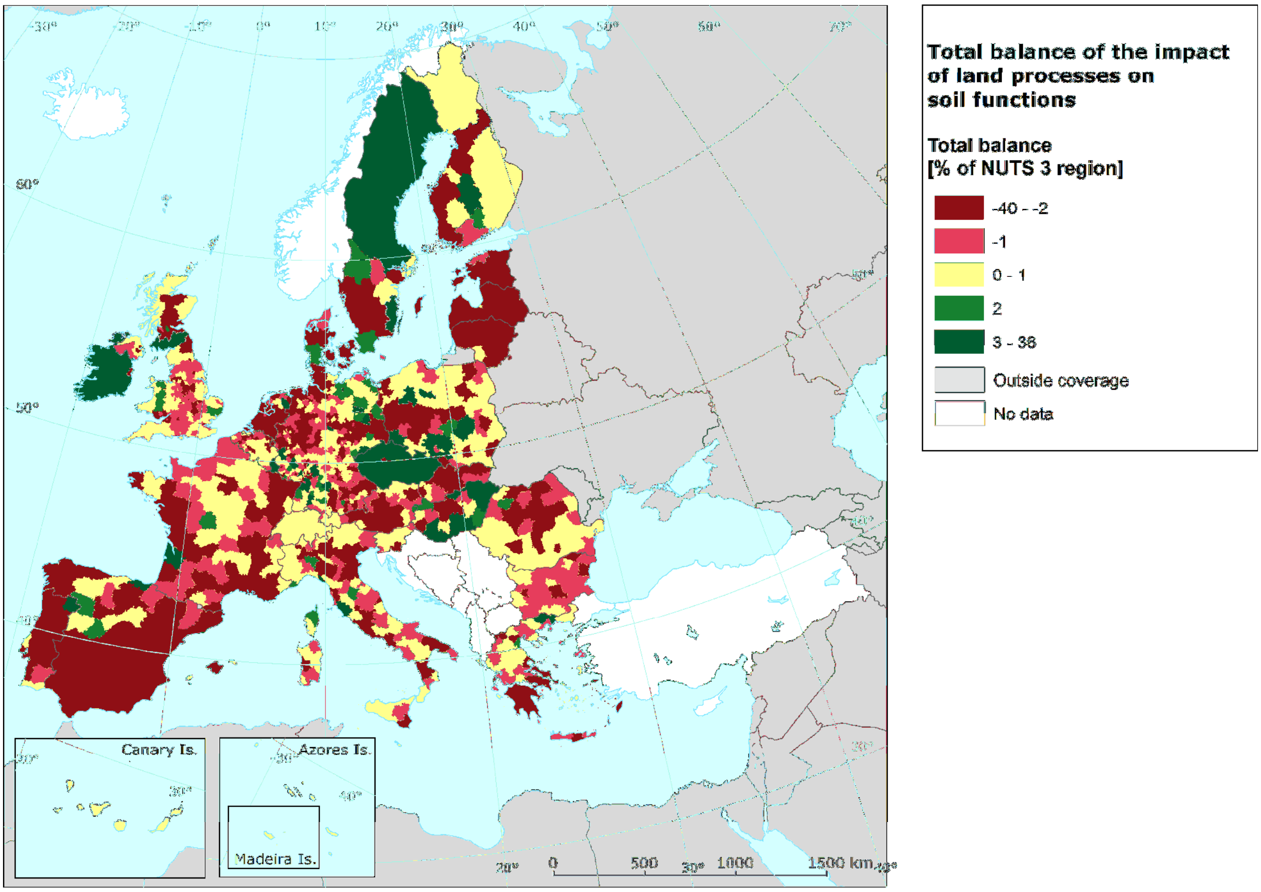
Figure 5.7 Impact of the forest management-related processes 'forest expansion' and 'forest fellings' (2000-2012) on the forest biomass production potential, EU-28 (except Croatia, Cyprus and Malta)



5.4 Balances at NUTS 3 level

The balance at NUTS 3 level goes beyond the more sectoral balances shown so far and presents the total balance, i.e. the impact of all land processes on all soil functions, displayed as a percentage of each NUTS 3 region (see the detailed description of the calculation of the balances in Section 5.1). This representation allows for an analysis of the situation within the NUTS 3 regions regarding the multi-functionality of soils, i.e. whether predominantly positive or negative impacts prevail, or the impact is more or less in equilibrium.

Map 5.1 Map of the total balance of the impact of all land processes per NUTS 3 level



The red areas in Map 5.1 represent the regions that are characterised by predominantly negative impacts, whereas the green regions have, in the main, predominantly positive impacts. In the yellow regions, predominantly positive and negative impacts level each other out. Overall, there are more regions with predominantly negative impacts than there are with predominantly positive impacts. Geographically, there is a corridor from the Netherlands and western Germany, running in a south-western direction across France (mainly through coastal regions and the Rhône valley) and covering almost the entire Iberian Peninsula, which is characterised by predominantly negative impacts of land processes on all soil functions combined. In addition, the Baltic countries, several parts of eastern and south-eastern Europe (south-western Poland, Slovakia, Romania, Bulgaria and Greece), Italy, Austria, southern Sweden, western Finland and parts of the United Kingdom also show these conditions. At the other end of the spectrum, Ireland, the Czech Republic and most parts of Sweden are clusters of regions with predominantly positive impacts. Other more isolated regions are located in southern Hungary, Germany, France and Spain.

Looking in more detail at the two extremes of the value ranking and taking the relative importance of the single land processes on the aggregated soil functions into account, it becomes clear that the regions with the highest positive values are mostly affected by forest expansion and agricultural extensification, i.e. the two land processes that are to a large extent predominantly positive. Baden-Baden in Germany possesses the highest value (35.6 %), which stems almost exclusively from forest expansion activities, presumably reforestation activities after Storm Lothar devastated large areas of the German Black Forest in 1999. The next regions are all located in Sweden and the Czech Republic (with impacts ranging from 27.6 % to 21.3 %). The Czech regions are characterised in particular by agricultural extensification, but also forest expansion, which is counteracted, but to a lesser degree, by forest fellings, urban expansion and agricultural intensification. The Swedish regions are less diverse, but almost exclusively affected by forest expansion over-balancing forest fellings; some minor urban expansion can be detected as well.

On the negative side, the Portuguese region of Médio Tejo has the highest proportion of predominantly negative impacts (almost 40 %). This is mainly caused by the very high impact of forest fellings (i.e. the aforementioned forest fires, which are subsumed under forest fellings processes — see Box 4.5 and Box 5.1 for further details). The next regions are largely in Portugal, but also in Latvia (values ranging from −30.9 % to −20 %). Both the Portuguese and Latvian regions are characterised by forest fellings and some urban expansion, which cannot be counter-balanced by the predominantly positive impact of forest fellings on the biomass production function, forest expansion and agricultural extensification. Interestingly, the Kronobergs region in southern Sweden has the second highest value, which is largely determined by forest fellings and therefore stands in contrast to the other Swedish regions. This could be due to a major storm event (Cyclone Gudrun) that took place in January 2005 and caused the destruction of 160 000 ha (75 million m3) in southern Sweden alone ([16]).

Multi-functionality is characterised as a condition in which an ecosystem is able to perform multiple functions simultaneously (see Section 1.1; Berry et al., 2015). Land use and management are important factors for land multi-functionality; processes that lead to the loss of productive land need to be controlled. The impact of such processes on the underlying soil functions is case-dependent, e.g. agricultural intensification has a positive impact on the biomass production function (through increased yields), but negative impacts on the other functions (e.g. through decreased water storing and soil biodiversity; see Figure 2.6). From that perspective, urban expansion can be considered as the land process with the most critical impact on the capacity of soils to provide functions, as its impact across the functions is predominantly negative (with the exception of the two functions for which the impact is unclear), and it is an irreversible process (see Box 5.2 as an illustration of the impact of urban expansion in the Madrid region). Agricultural intensification also has predominantly negative impacts on most functions, but is reversible. Even less critical are the forest-related land cover changes, as most of them are part of the forest management cycle and therefore cause only short-term limitations to the capacity of the soils to provide their functions. Only where exceptional events such as storms and fires lead to widespread damage to forests could the subsequent disturbances lead to longer lasting negative impacts on the soil functions.

([16]) http://www.smhi.se/kunskapsbanken/meteorologi/gudrun-januaristormen-2005-1.5300

Box 5.1 What are the reasons for the strong negative balance in Médio Tejo (Portugal)?

The analysis of the multi-functionality is rather complex as there are many combinations of land processes affecting the various soil functions, and processes have differential impacts on the soil functions. In the following, the region with the highest percentage of negative impacts overall (the Portuguese region of Médio Tejo) has been selected as an illustration of the factors that play a role in the balance calculation.

It becomes clear that forest fellings, as the process with the largest impact on the total balance in that region (see Figure 5.8), can be found at the negative end of the range, with high negative impacts on the potential of soils to act as a carbon and soil biodiversity pool, and on the storing and filtering function, but also at the positive end of the value range, with the highest positive impacts on the potential of soils to provide biomass (crops, grass and forest; see Figure 5.9). As the negative impacts are in total substantially higher than the positive ones, the total balance is strongly negative. In this case, forest fellings is mainly related to fire damage, and hence the impact on the soil functions could be a long-term issue.

Figure 5.8 Total impact of the different land processes on the aggregated soil functions (hectares) in the NUTS 3 region of Médio Tejo (PT16I)

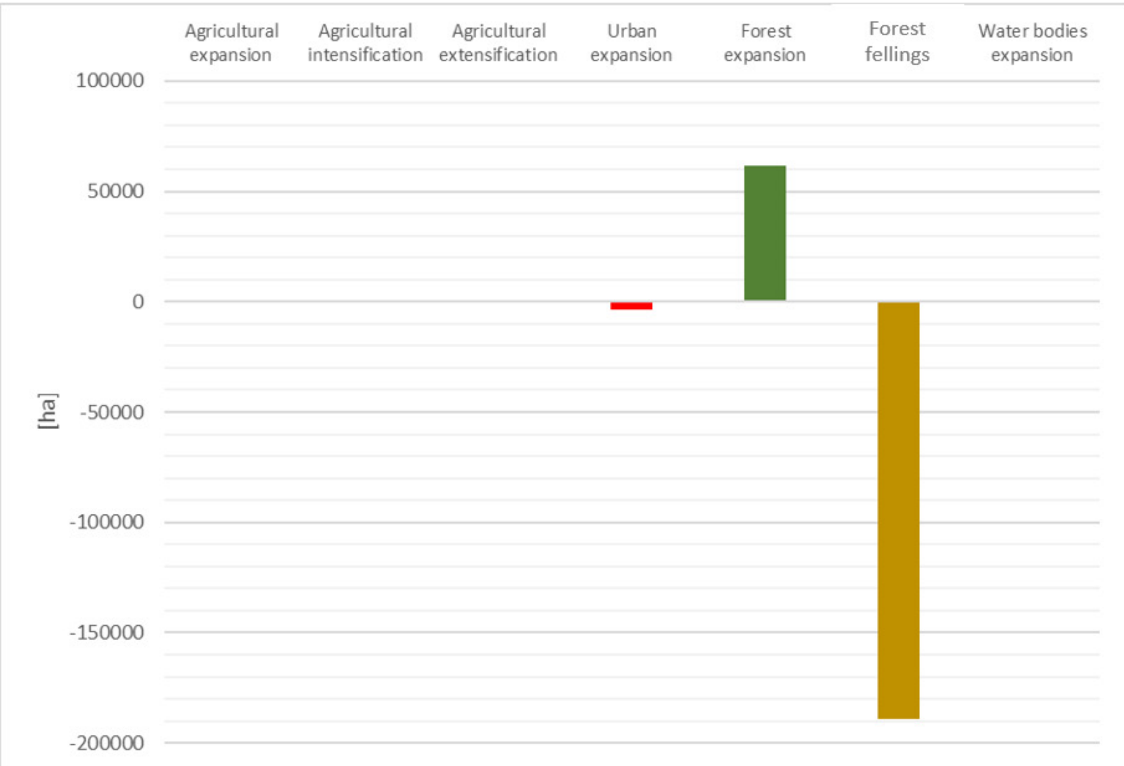
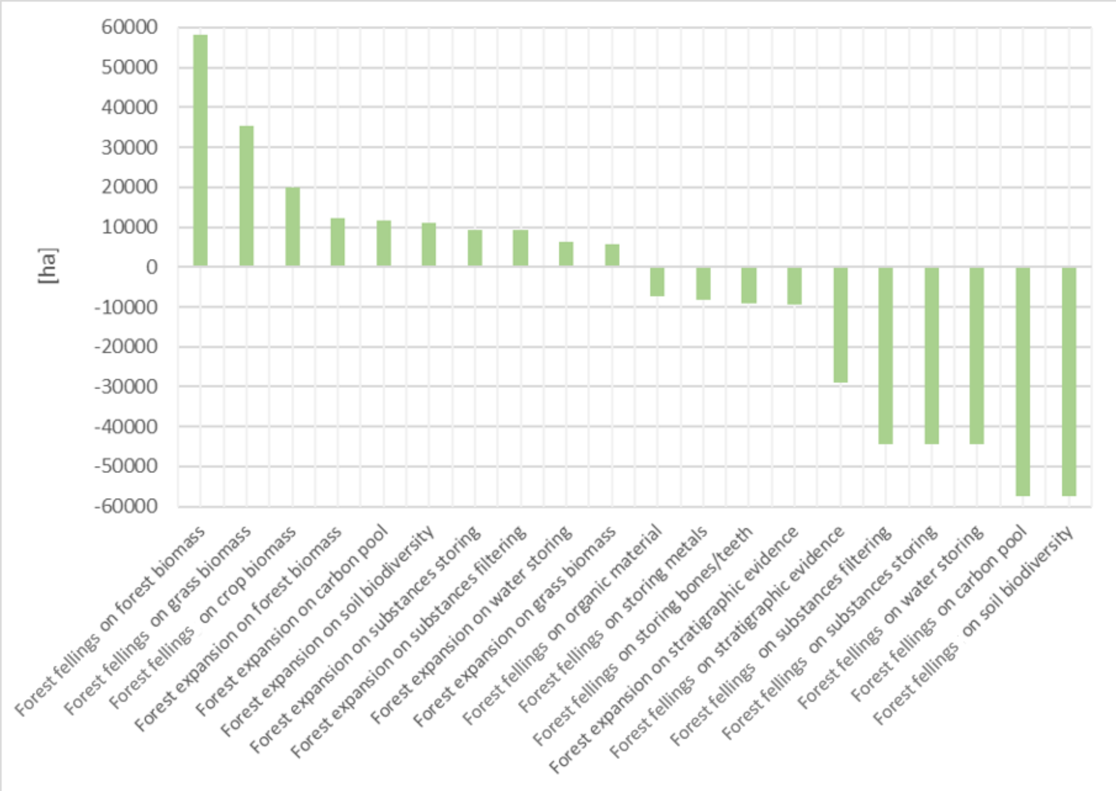


Figure 5.9 Impact of the different land processes on the disaggregated soil functions (hectares) in the NUTS 3 region Médio Tejo (PT16I)



Note: Out of the list of possible combinations, only the 10 highest positive and the 10 highest negative values were selected.

Box 5.2 The impact of urban expansion in Madrid (Spain)

It is worthwhile taking a closer look at what is generally the most critical of the land processes, urban expansion, and its impact on soil functions. For a more in-depth look at the impacts of urban expansion, the region with the highest impact was selected. This turned out to be Madrid, a region already mentioned in the hotspot chapter (see Section 4.2). The chart in Figure 5.10 clearly confirms that the negative impact of urban expansion is the dominant factor in the total balance of the Madrid region. The issue of urban expansion and urban sprawl in this region has already been discussed in an EEA report on urban sprawl in Europe (EEA, 2006a; see also Box 4.2) There is some predominantly positive forest expansion and agricultural extensification, but this is far too low to counter-balance urban expansion. The very strong dominance of negative impacts is also reflected in the values for the impact of the various land processes on the single soil functions (see Figure 5.11). While there is positive impact on several soil functions, mainly from forest expansion (e.g. forest biomass provision, soil organic carbon, soil biodiversity or water storing), the eighth highest negative impact is still higher than the highest positive one. It is also almost inevitable that nearly all of the negative impacts are caused by urban expansion, with the highest values relating to forest biomass provision, and substances storing and filtering.

Figure 5.10 Total impact of the various land processes on the aggregated soil functions (hectares) in the NUTS 3 region of Madrid (ES300)

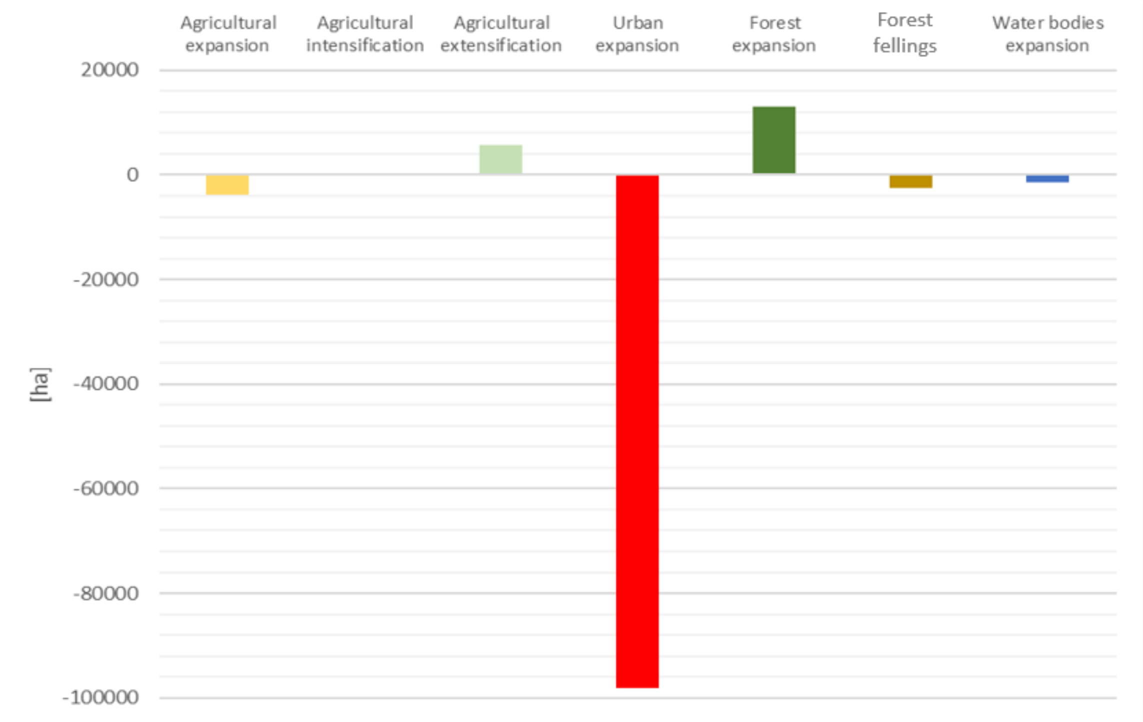
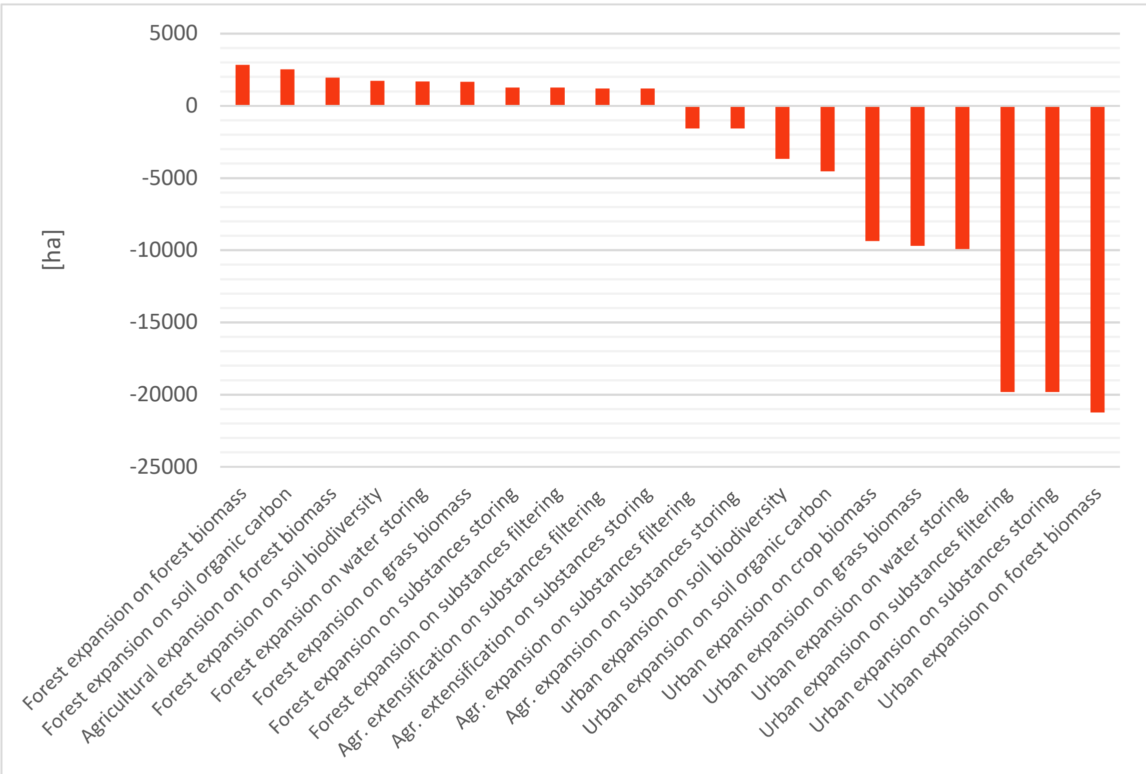


Figure 5.11 Impact of the various land processes on the disaggregated soil functions (hectares) in the NUTS 3 region of Madrid (ES300)

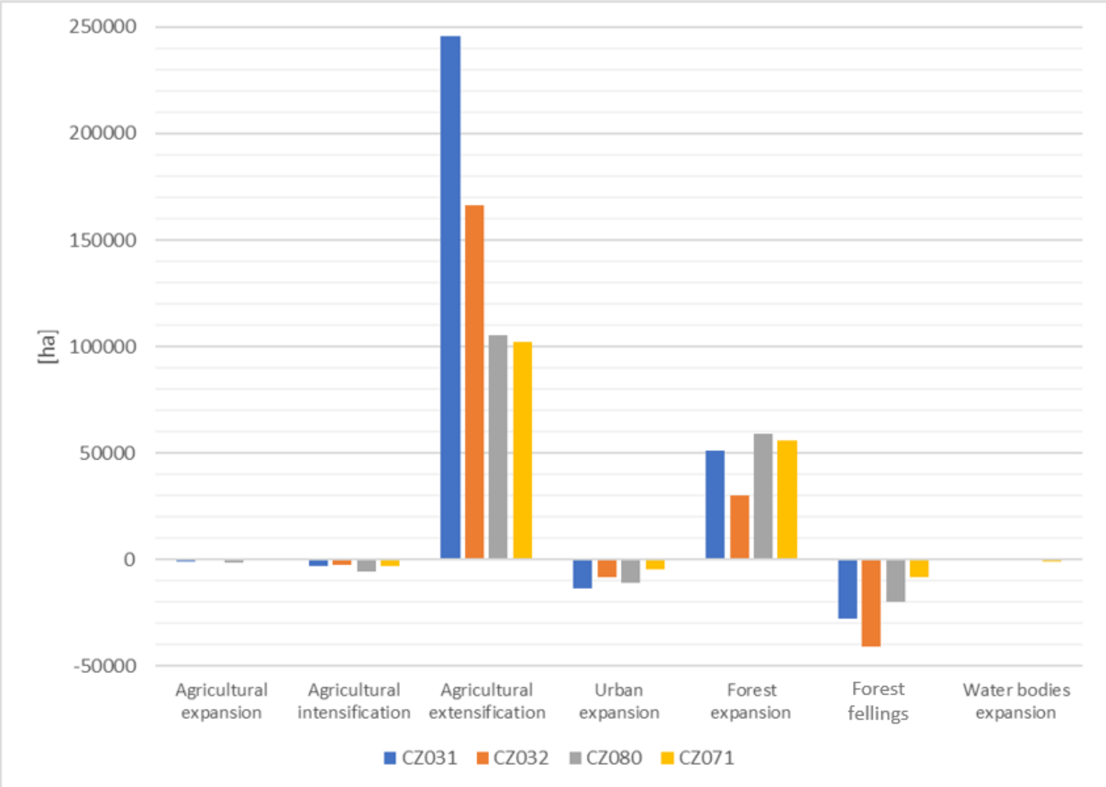


Note: Out of the list of possible combinations, only the 10 highest positive and the 10 highest negative values were selected.

Box 5.3 Improving soil functions in the Czech Republic

Next to the two rather negative examples of Médio Tejo (see Box 5.1) and Madrid (see Box 5.2), a positive case should also be illustrated. Regions in the Czech Republic dominate the list of regions in which the predominantly positive impact of agricultural extensification is largest. The four regions of South Bohemia (CZ031, Jihočeský kraj), Plzen (CZ032, Plzeňský kraj), Moravia-Silesia (CZ080, Moravskoslezský kraj) and Olomouc (CZ071, Olomoucký kraj) are the only ones with more than 100 000 ha of impact. Forest expansion adds to agricultural extensification as a positive influence on the total balance. Combined, these processes cannot be counter-balanced by the two negative processes that also occur, urban expansion and forest fellings. The dominance of forest expansion over forest fellings is probably because Czech forests were severely damaged by storms at the end of the 1990s and in the early 2000s, and subsequently reforested. Thus, in the observation period, 2000-2012, there was some time for forest to regrow.

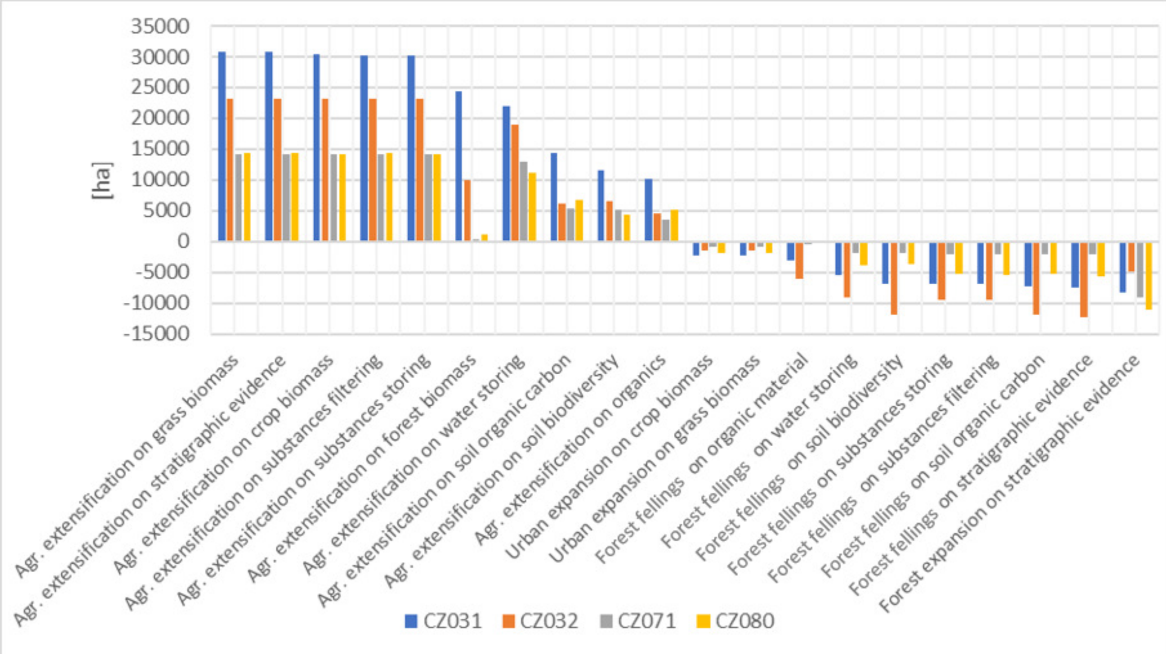
Figure 5.12 Total impact of the various land processes on the aggregated soil functions (hectares) in four Czech NUTS 3 regions



Note: The four Czech NUTS 3 regions analysed are South Bohemia (CZ031, Jihočeský kraj), Plzen (CZ032, Plzeňský kraj), Moravia-Silesia (CZ080, Moravskoslezský kraj) and Olomouc (CZ071, Olomoucký kraj)

Regarding the impact of the land processes on the single soil functions, forest expansion does not play a major role. It is only agricultural extensification that dominates and shows the highest impacts on the provision of grass biomass, preserving stratigraphic evidence and crop biomass. All four regions show a very similar situation for most of the impacts, except for forest biomass provision for which the two eastern Czech regions have almost no impact, probably because the storm damage was concentrated in the western part of the country. The negative end of the spectrum is dominated by forest fellings and its impacts on preserving stratigraphic evidence, soil organic carbon and substances filtering. But the highest impact is that exerted by forest expansion on the capacity of soils to preserve stratigraphic evidence.

Figure 5.13 Impact of the various land processes on the disaggregated soil functions (hectares) in four Czech NUTS 3 regions



Note: Out of the list of possible combinations, only the 10 highest positive and the 10 highest negative values were selected. The ranking follows the region with the highest overall balance for agricultural extensification (South Bohemia). The abbreviation “Agr.” stands for “Agricultural”.

Note: The four Czech NUTS 3 regions analysed are South Bohemia (CZ031, Jihočeský kraj), Plzen (CZ032, Plzeňský kraj), Moravia-Silesia (CZ080, Moravskoslezský kraj) and Olomouc (CZ071, Olomoucký kraj).

Taking the aforementioned cases and examples into consideration, it becomes obvious that discussing soil and land multi-functionality, and identifying the best options, is a very complex undertaking that needs specific, tailor-made approaches and solutions on a regional level. This report can support the process by providing a European baseline of the distribution of LCFs, which were combined into groups that reflect the major land processes, the availability of soil functions and the impacts of land cover changes on soil functions, both disaggregated (hotspots) and aggregated (balances).

Chapter 6 will take a closer look at the implications of the analysis in this report for land governance, with respect to the efficient use of the land resource.

6 Implications for land governance: land use resource efficiency

This chapter will:

- summarise the findings of the spatial analysis;
- provide some contextual explanations;
- shed some light on soil governance-related issues; and
- draw some conclusions.

This report presents a promising way to integrate the soil component into the assessment of land-cover/land-use developments and their accounting in Europe. By (1) combining the two-dimensional land-cover data (as a proxy for the major land processes) with spatial soil function data, and (2) evaluating the quality of the impact of land cover change processes (predominantly positive or negative) on the capacity of soils to provide specific functions, it became possible to identify hotspot regions across Europe, and to calculate balances that can be included in accounting frameworks.

Soil functions underlie a wide range of ecosystem services that are crucial for human wellbeing. The spatially explicit analysis of the impact of a major driver such as land-cover change helps us to understand which soil functions and their linked ecosystem services are affected both positively and negatively in the European regions, always taking into account the data that underlie the spatial analysis.

Land cover flows are an ideal indicator for impacts on soil functions, since they represent the final spatial expression of land use decisions triggered to a large degree by policies and regulations. EU policies and legislation and their national implementation play a fundamental part in this process (Vrebos et al., 2017). The picture of land processes and their impact on soil functions provided in this study therefore adds to our understanding of the ongoing processes of Europe’s land system.

6.1 Hotspots and balances

The analysis clearly reveals that, despite regional specificities, there are land processes that are more important than others in terms of their extent. Both water expansion and agricultural expansion are, on a European level, relatively insignificant. Together with agricultural intensification, however, they are responsible for negative impacts on a number of regulating and maintenance functions (such as storing and filtering of water and substances, and provision of a soil organic carbon and soil biodiversity pool). Despite possessing by far the largest impacts quantitatively, the forest management-related processes forest fellings and forest expansion are to a large extent related to the forest management cycle and are therefore planned and regulated activities. However, major unregulated disturbances of forest stock are often connected with natural events or human disturbances (see Box 4.5), such as forest fires as a consequence of heatwaves, water scarcity, bad management of landscapes, malicious arson (as in Portugal, Spain and Latvia), or windstorms (as with the Landes region in south-west France). In such cases, a sudden loss of forest stock occurs, which can only slowly be recovered. Yet such events also demonstrate the capabilities of the managing institutions to react appropriately and ensure maintenance of the capacity to deliver certain soil functions. Finally, Europe-wide but also globally, urban expansion is the process known to change landscapes most significantly, often by extending sealed surfaces and, as a consequence, irreversibly disrupting most of the soil functions.

Regarding the multi-functionality of soils, the number of soil functions occurring in a European grid with a 1 km2 size was calculated and mapped, for both good and average soils, to provide soil functions (see Map 2.4 and Map 2.5). The maps show that the highest multi-functionality can be found in north-western Europe (i.e. the Netherlands, Belgium, western parts of Germany, northern France), as well as in some other regions irregularly distributed across Europe. On average soils, the highest values are located largely in north-eastern parts of Europe. Knowledge about where which levels of multi-functionality can be found in Europe is important for the analysis of both the risk of regions losing functions and of regional synergies and trade-offs of soil functions. Looking at the proportion of soils with good and average potentials combined, the platform for the human activities function appears on around 75 % of European soils, whereas the biomass provision and the storing and filtering of substances functions can be found on between 60 % and 70 % (see Table 3.1).

Forest-related processes have the largest impact on most soil functions, followed by urban expansion and agricultural intensification (see Figure 3.1). This corresponds with the proportion of the land processes in relation to all land cover changes (see Figure 2.1). It needs to be kept in mind, however, that the impact is analysed on the potential of a soil to provide a certain soil function irrespective of current land use.

Urban expansion and its negative effects on the biomass production function (and all other soil functions) affect 93 % of all European regions (see Section 4.2). Most of these activities occur in and around large cities or densely populated areas. Another cluster of hotspot regions can be seen in the Netherlands (see Map 4.1), which is one of the (mostly small) countries that experience the highest impact of urban expansion (see Figure 2.2). Population pressure and the need for living and working space, as well as supporting infrastructure, is presumably the strongest driving force for urbanisation processes. This is in part confirmed by the finding that most of the hotspot regions experienced population growth between 2000 and 2012 (see Map 4.2). There are, however, other regions that have urban expansion activities despite a shrinking population. In several of those regions, the expansion of urban surfaces is related less to residential development than to infrastructure development (Poland) and industrial/mining activities (western Germany). These are driven by European and national policy and decision-making (the European TEN-T network in Poland, and energy policy in Germany).

Analysing the hotspots of the combined impact of agricultural intensification and agricultural expansion on the biomass provision, soil organic carbon and soil biodiversity functions, impacts are much more widespread on soils with a biomass provision potential (almost 75 % of European regions affected) than on soils with the potential to host soil biodiversity (around 60 %), and in particular soils that act as a carbon pool (41 %). While hotspots for the latter two soil functions are located mostly in Germany, for the biomass production function they are located mainly in southern Europe, in particular the southern part of the Iberian Peninsula and Turkey.

The combined impacts of forest fellings and forest expansion cause positive as well as negative hotspots, i.e. regions in which the effect is positive or negative because the two processes have mostly opposed impacts on the soil functions. The maximum value for the negative hotspot regions is greater than the positive one for the impact on the biomass production potential and the soil organic carbon potential. Although this value is in the same range for the impact on soil biodiversity potential (23 %), the positive impact maximum is higher in this case (30 %). The negative hotspots are concentrated in the fire-struck regions of Portugal and Latvia, whereas the positive hotspots can be found mainly in the Czech-Polish border region and in southern Sweden (in particular for soil biodiversity).

Comparing the hotspot locations with the data on the number of soil functions occurring in the various regions, it is the north-western part of the European continent that is most critically affected by urban expansion and that is most at risk of losing the potential of its soils to maintain their capacity to provide as many soil functions as possible. Likewise, regions in the Baltic countries of Latvia and Estonia, as well as certain other regions across Europe (many of which are located on the Iberian Peninsula), are at risk of reducing their soils' potential to provide a multitude of functions.

Finally, calculating balances is a means of assessing the combined impact of the major land processes on the potential of soils to provide soil functions. The total balances provide an indication of whether or not one of the predominantly positive or negative impacts prevails. If the balance in a region is negative, it means that the negative impacts dominate and the region is at risk of experiencing a decrease in the capacity of its soils to provide one or more soil functions. Looking more closely at the total balances (see

Map 5.1), they show the overall negative impact in specific regions and countries (such as large parts of Spain and Portugal, the Baltic countries, large parts of the Netherlands and north-western Germany, northern Italy, France, Finland, Romania and Greece), and positive signals from other regions (Ireland, Sweden, the Czech Republic and southern Hungary are the largest clusters).

Even though the study has shown that forest fellings and forest expansion are the flows with the largest spatial impact, it is the pattern of agricultural flows with negative impact on soil functions (i.e. agricultural intensification and expansion) that best overlay regions with negative total balances. Exceptions are the regions struck by forest fires or windstorms that damaged large areas of forest and led to strong negative impacts (Portugal, Latvia, south-western France, southern Sweden). It seems that agricultural uses, in combination with urban expansion processes, affect the overall functionality of soils in Europe more substantially, in particular when they relate to an ecosystem service (food production) crucial to food security and rural development.

6.2 Land governance

Multi-functionality means that an ecosystem can perform multiple functions at the same time (see Sections 1.1 and 5.4; Berry et al., 2015). Land use and management are important factors for land multi-functionality; processes that lead to the loss of productive land need to be controlled. However, the difficulty lies in the fact that the impact of such processes on the underlying soil functions is case-dependent, e.g. agricultural intensification has a positive impact on the biomass production function (through increased yields), but negative impacts on the other functions (e.g. through decreased water storing and soil biodiversity; see Figure 2.6).

Based on the evaluation matrix defined and used in this study, urban expansion can be considered as the land process with the most critical impact on the capacity of soils to provide functions. Its impact is almost exclusively predominantly negative (with the exception of the two functions for which the impact is unclear), and it is an irreversible process. Agricultural intensification also has predominantly negative consequences on most functions, but is reversible. Moreover, its predominantly positive impact on the biomass provision function helps to achieve an improved level of food security, even though it might be detrimental to environmental sustainability within a region. The forest-related land cover changes are to a large extent part of the forest management cycle and, therefore, already an element of land management. Moreover, they cause only short-term limitations to the capacity of the soils to provide their functions. Only where exceptional events such as storms and fires lead to widespread damage to forests could the subsequent disturbances lead to longer lasting negative impacts on soil functions.

The present study also provides a framework to discuss the functional land management concept (Schulte et al., 2014, 2015). Given the impacts on various soil functions by the main land processes that have been highlighted in this study, the response generated through land-related policies is crucial. When it comes to protecting land and soil from specific land processes, questions arise as to whether 'Functional Land Management, and the maximisation of soil functions, should or could be applied across national borders? […] While this will undoubtedly be challenging from a policy perspective, the application of "Functional Land Management" at a European level could represent a logical step towards meeting the global twin challenges of food security and environmental sustainability' (Schulte et al., 2014, p. 53).
On the other hand, studies have shown the degree to which various policy domains and levels of legislation have affected soil functions (Vrebos et al., 2017). This has not been addressed directly in the present study, but the patterns of agricultural expansion, extensification and intensification, as well as forest expansion, hint at individual land use decisions but are also related to overarching developments triggered by specific policies (see Box 4.1 and Box 4.3 as well as specific developments described in Chapter 4). Although soil governance is to a certain degree defined at a European level, the management and implementation of land use decisions will take place at a local level and often require tailor-made solutions. The reaction of local, regional and national authorities after the windstorms that caused severe damage in the Czech

Republic, France, Germany and southern Sweden provide such examples. Large reforestation programmes were established, involving many actors at various levels. A good example of an appropriate governance measure was the reaction of the French authorities after Windstorm Klaus hit south-western France. The authorities implemented the biggest reforestation project in Europe (Global Forest Watch, 2009; The Guardian, 2012). Next to these ad hoc actions that are prompted by catastrophic events, there are several (sub-)national planning policies in place that take soil conservation into account, i.e. the maintenance or improvement of the capacity to provide soil functions (see example in Box 4.1). It will be important to take balanced land use and management decisions so that the various needs that soils can cover or contribute to are duly accounted for. Policy-making and decision-making need to take into account the local context because the impact of specific land cover changes on the soil functions varies between regions.

For evaluating the efficient use of land and its capacity to ensure the supply of specific soil functions, it is also necessary to look at the demand side and the various drivers for landscape changes. Only the demand side converts the soil functions into soil-based ecosystem services. But the demand in urban areas is different from that in rural areas. While cities have a diverse range of demands, in rural areas the need is basically '*to protect, maintain and improve soil fertility on farmland*' (EEA, 2016c), to secure the availability of agricultural produce. In consequence, there is a necessity to establish (if non-existent) or optimise the balance between supply and demand. According to a recent EEA study, a soil governance system that emphasises the value of soil as an asset that is of use and benefit to society needs to be put in place, recognising the pivotal role of soil to a green economy (EEA, 2016c).

6.3 Limitations and perspectives

Next to the messages that can be derived from this analysis, the approach selected also has some limitations. With the use of data sets that are harmonised across Europe, information on certain land use changes that have an impact on soil functions cannot be integrated. This comprises information on landscape configuration and composition, for example, as well as detailed information on land abandonment, which is related to extensification. These elements would require spatial pattern analysis (landscape configuration/landscape composition), rather than statistical analysis, or the use of additional layers (other than land cover/land use). Moreover, the focus on the scale of European regions, determined to a large extent by data availability, means that the findings can only provide general indications on land governance; analysis based on local data sets is required to guide decision-making at local level.

The soil function data are largely dependent on the model input parameters and the underlying data used. Some of the distribution maps (see Section 2.2.3) reflect the input data with the highest influence on the outcome (see Section 2.2.2). Climate (water availability and sun exposure, as represented by temperature data), for example, largely affects the distribution of the biomass production functions, whereas land-use/land-cover data have the largest influence on the soil organic pool and soil biodiversity functions. Soil-inherent characteristics (such as texture or soil chemistry) strongly affect the distribution of soils with a potential to store and filter substances and water. Therefore, the need to revisit and refine some of the models could be expressed. Likewise, both the evaluation matrix and the grouping of the LCFs (see Figure 2.6 and Figure 2.1 in Section 2.1 and Section 2.3) could also be optimised by setting up a larger panel of experts from various countries, for example.

In conclusion, the outcomes of this study can support the process of identifying options for optimising or improving land use and management by providing a European baseline for the distribution of the major land processes, the availability of soil functions and the impacts of the land processes on the soil functions, both disaggregated (hotspots) and aggregated (balances). The study, therefore, contributes to filling a knowledge gap, as is requested by priority objective (PO) 5 of the 7th EAP. Likewise, the analysis also supports bridging knowledge gaps in the context of the land degradation neutrality objective put forward after Rio+20 and in the Sustainable Development Goals (in particular target 15.3).

In a next step, analysis could focus on bridging between geo-spatial levels. For example, spot checks could evaluate how far the results using pan-European data coincide with the results of a similar analysis using regional and local data. Thus, the European data resulting from this study can be a starting point for more regional and local assessments, in particular where such data are lacking, and support the integration of land use aspects into coordinated decision-making across all governance levels as requested by PO1 of the 7th EAP.

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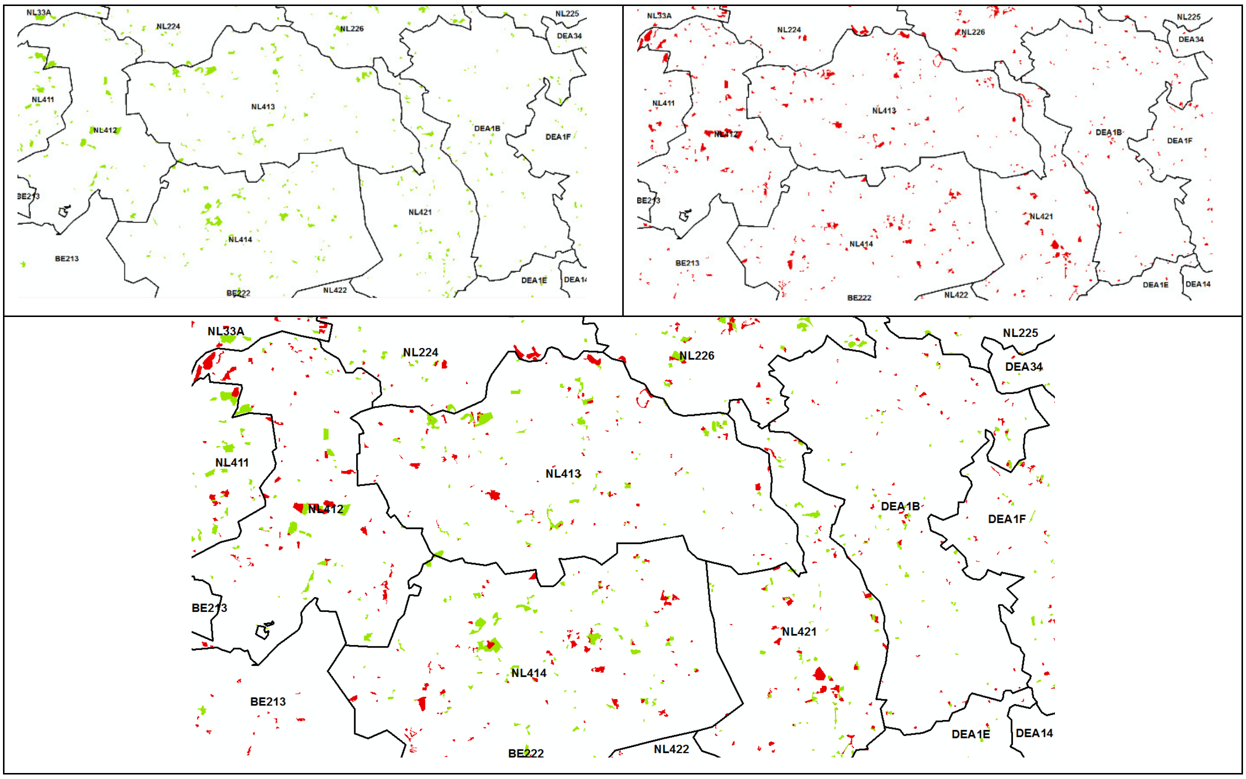
Annex A1: Production and grouping of land cover flows

The computation of the land cover flows (LCFs), which is usually done for the 6-year periods of Corine (i.e. 2000-2006 and 2006-2012), had to be adapted to the aim of working with one 12-year period from 2000-2012 to be able to capture more long-term trends.

Therefore, both single change layers (2000-2006 and 2006-2012) were merged into one layer.

Figure A1.1 Production of the merged change layers 2000-2006 and 2006-2012



The attribute table of this layer now contains all changes with their first Corine Land Cover (CLC) class, their second and, if available, their third (not all polygons have changes for the two periods).

Figure A1.2 Extract from the attribute table

union_id	CLC_ch_00-06	CLC_ch_06-12	CLC_00	CLC_06	CLC_12	FIRST_CLC	LAST_CLC	used_ch	comment
1	231-133	133-112	231	133	112	231	112	231-112	to changes in both change-layer on the same area
2	231-211		231	231		231	211	231-211	only changes between 00-06
3		211-212		211	212	211	212	211-212	only changes between 06-12
4	111-133	133-111	111	133	111	111	1111	111-111	overlapping but no change between 2000-2012
...									

The column "used_ch" always contains the combination of the first and last CLC class and assigns this change as the valid one for the respective polygon. Finally, these changes are the basis for the calculation of the LCFs according to the official method.

Table A1.1 Urban expansion

LCF	class_description	urban expansion
lcf21	Urban dense residential sprawl: Land uptake by continuous urban fabric (CLC 111) from non urban land	1
lcf22	Urban diffuse residential sprawl: Land uptake by discontinuous urban fabric (CLC 112) from non urban land.	1
lcf31	Sprawl of industrial & commercial sites: Non urban land uptake by new industrial and commercial sites	1
lcf32	Sprawl of transport networks: Non urban land uptake by new transport networks	1
lcf33	Sprawl of harbours: Development of harbours over non urban land and sea.	1
lcf34	Sprawl of airports: Development of airports over non urban land and sea.	1
lcf35	Sprawl of mines and quarrying areas: Non urban land uptake by mines and quarries.	1
lcf36	Sprawl of dumpsites: Non urban land uptake by waste dumpsites.	1
lcf37	Construction: Extension over non-urban land of areas under construction during the period (note: covers mainly construction of economic sites and infrastructures).	1
lcf38	Sprawl of sport and leisure facilities: Conversion from developed as well as non-urban land to sport and leisure facilities.	1

Table A1.2 Agricultural intensification

LCF	class_description	Agricultural intensification
lcf421	Conversion from arable land to permanent irrigation perimeters: Extension of permanent irrigation (incl. rice fields) over arable land	1
lcf441	Conversion from permanent crops to permanent irrigation perimeters: Conversion from permanent crops (incl. when associated with arable land - CLC 241) to permanent (large) irrigation perimeters and rice fields	1
lcf442	Conversion from vineyards and orchards to non-irrigated arable land: Conversion from vineyards and orchards to non-irrigated arable land and from associations of annual and permanent crops to uniform arable land	1
lcf443	Conversion from olive groves to non-irrigated arable land: Conversion from olive groves to non-irrigated arable land, incl. conversions to associations of annual and permanent crops (CLC241) and of crops and pasture (CLC242).	1
lcf451	Conversion from arable land to vineyards and orchards: Plantation of vineyards, orchards on arable land.	1
lcf452	Conversion from arable land to olive groves: Plantation of olive groves on arable land.	1
lcf461	Conversion from pasture to permanent irrigation perimeters: Conversion of uniform pasture areas to permanent irrigation perimeters	1
lcf462	Intensive conversion from pasture to non-irrigated arable land and permanent crops: Conversion of uniform pasture areas to non-irrigated annual and permanent crops	1
lcf463	Diffuse conversion from pasture to arable and permanent crops: Conversion from complex cultivation patterns including pasture (CLC242) to uniform arable land and permanent crops as well as to associations of the last two (CLC241) and conversion of uniform pasture (CLC231) to complex cultivation patterns.	1

Table A1.3 Agricultural extensification

LCF	class_description	Agricultural extensification
lcf411	Uniform extension of set aside fallow land and pasture: Large parcels conversion from crop land to grassland.	1
lcf412	Diffuse extension of set aside fallow land and pasture: Conversion from crop land to complex cultivation patterns (with grassland) and from mixed agriculture to large pasture parcels.	1
lcf47	Extension of agro-forestry: Conversion of cultivated land and open pasture to agroforestry systems such as dehesas (note: conversion from 243, where natural vegetation is important, is recorded under lcf522)	1
lcf62	Withdrawal of farming without significant woodland creation: Farmland abandonment in favour of natural or semi-natural landscape (except forests and transitional woodland shrub), as long as they are a possible transition. Some odd cases are provisionally recorded as lcf99 Other changes and unknown.	1

Table A1.4 Agricultural expansion

LCF	class_description	Agricultural expansion
lcf511	Intensive conversion from forest to agriculture: Deforestation, including agricultural conversion of transitional woodland shrub, for cultivation of annual and permanent crops (incl. in association, CLC241).	1
lcf512	Diffuse conversion from forest to agriculture: Conversion from uniform forest to complex cultivation patterns, mosaic agricultural landscape and agro-forestry. Due to possible uncertainties in monitoring extension of pasture vs. recent fellings, conversion from forests to pasture land (CLC231) is recorded here.	1
lcf521	Intensive conversion from semi-natural land to agriculture: Conversion from dry semi-natural land (except CLC324, grouped with forests) to annual crops permanent crops and their association.	1
lcf522	Diffuse conversion from semi-natural land to agriculture: Conversion from dry semi-natural land (except CLC324, grouped with forests) to pasture and mixed agriculture with pasture.	1
lcf523	Conversions from agriculture-nature mosaics to continuous agriculture: Conversion from clc243, where natural areas are distinctive feature of the land systems to continuous agriculture. This is an over-estimation from an agriculture perspective but is justified in terms of analysis of ecological potentials of complex land systems	1
lcf53	Conversion from wetlands to agriculture: Conversion of wetlands to any type of farmland (CLC2)	1
lcf54	Conversion from developed areas to agriculture: Conversion of urban land to any type of farmland (CLC2)	1

Table A1.5 Forest expansion

LCF	class_description	Forest expansion
lcf61	Withdrawal of farming with woodland creation: Forest and woodland creation (incl. transitional woodland shrub) from all CLC agriculture types. Withdrawal of farming with woodland creation is a broader concept than farmland abandonment with woodland creation, which results more from decline of agriculture than afforestation programmes. Additional information is necessary to identify an abandonment process (type of agriculture, landscape type, socio-economic statistics…).	1
lcf71	Conversion from traditional woodland to forest: Conversion from transitional woodland to broadleaved, coniferous or mixed forest, taking place when shrubs can be detected as trees.	1
lcf72	Forest creation, afforestation: Forest creation and afforestation take place on all previously non agricultural landscapes where new forests can be identified. Extension of transitional woodland shrub over non-agricultural land is recorded as afforestation. Conversion from transitional woodland to broadleaved, coniferous or mixed forest are not a creation of forest territory and are therefore registered separately (lcf71).	1

Table A1.6 Forest fellings

LCF	class_description	Forest fellings
lcf74	Recent felling and transition: Conversion from broadleaved, coniferous and/or mixed forest to open semi-natural and natural dry land resulting more likely from felling. The main transition is towards CLC324 Transitional woodland shrub, although some other types can be detected. Due to uncertainties, all are provisionally considered as transitional states of forests.	1

Annex A2: Tables of share of land process impact (background tables for Map 3.1 and Map 3.2)

Table A2.1 Soil biomass production (arable crops): distribution of impact per land processes (% of total impact on good and average soils), highest impact value is highlighted

Country	Agricultural expansion	Agricultural extensification	Water body expansion	Agricultural intensification	Urban expansion	Forest expansion	Forest fellings
AL	3.1	1.0	1.2	1.6	**51.3**	9.9	32.0
AT	2.7	0.3	0.3	0.1	24.1	7.1	**65.5**
BA	5.7	0.6	0.1	7.0	21.6	**38.2**	26.7
BE	1.0	1.0	1.6	0.2	22.0	20.1	**54.0**
BG	2.1	0.7	0.2	19.1	6.6	18.4	**52.8**
CH	2.6	0.3	0.0	1.0	**55.5**	29.7	10.8
CY	30.4	3.6	0.0	7.9	**55.1**	2.9	0.0
CZ	1.6	**49.1**	0.3	8.0	7.9	20.3	12.8
DE	3.2	10.0	3.1	24.9	**27.2**	15.4	16.1
DK	4.3	2.0	4.0	4.8	**40.1**	23.6	21.2
EE	0.1	10.0	0.0	14.5	2.5	32.1	**40.7**
EL	3.7	7.9	3.2	3.0	24.6	25.6	**32.1**
ES	5.0	4.3	1.3	23.4	**28.0**	17.4	20.5
FI	3.9	0.0	0.0	0.0	1.4	40.1	**54.6**
FR	1.1	0.5	0.5	2.5	18.8	23.6	**53.0**
HR	5.2	1.7	0.6	7.9	12.9	15.8	**56.0**
HU	0.8	6.8	0.7	15.7	4.7	**41.0**	30.3
IE	0.3	14.5	0.0	8.0	8.0	**42.6**	26.6
IS	10.9	0.0	30.2	1.0	26.3	**31.6**	0.0
IT	6.5	0.8	1.7	10.2	**31.1**	22.0	27.8
LI	0.0	0.0	0.0	0.0	**100.0**	0.0	0.0
LT	0.8	1.3	0.2	12.9	4.2	29.3	**51.3**
LU	1.2	3.0	0.0	6.4	13.8	**62.8**	13.0
LV	0.1	1.3	0.0	7.0	0.9	5.5	**85.3**
ME	2.2	0.0	0.0	9.5	25.1	25.4	**37.7**
MK	3.7	2.2	0.5	12.7	8.2	20.0	**52.7**
MT (17)							
NL	1.7	17.3	5.1	3.8	**64.2**	5.8	2.1
NO	0.5	0.0	0.0	0.0	4.6	17.4	**77.6**
PL	1.1	2.5	1.8	4.7	16.1	**42.3**	31.5
PT	1.6	0.4	1.0	2.1	6.1	31.1	**57.7**
RO	0.2	2.2	0.6	10.6	20.8	8.0	**57.6**
RS	5.4	4.8	3.1	13.4	12.3	29.8	**31.2**
SE	0.0	0.1	0.0	0.0	0.6	**55.2**	44.1
SI	2.1	0.3	2.0	0.0	**53.5**	10.4	31.7
SK	0.4	3.4	0.2	3.2	7.2	20.9	**64.6**
TR	10.5	6.8	9.5	13.5	**31.2**	15.0	13.4

(17) No data available for soil biomass production (arable crops) for Malta.

UK	1.0	0.3	0.4	0.4	11.1	28.8	**57.9**
XK	1.7	1.1	0.0	23.9	28.3	**32.7**	12.2

Table A2.2 Soil biomass production (grass): distribution of impact per land processes (% of total impact on 'good' and 'average' soils), highest impact value is highlighted

Country	Agricultural expansion	Agricultural extensification	Water body expansion	Agricultural intensification	Urban expansion	Forest expansion	Forest fellings
AL	1.6	1.5	1.3	1.4	**46.9**	11.6	35.6
AT	2.2	0.3	0.3	0.0	23.7	5.8	**67.8**
BA	5.9	0.9	0.1	7.7	19.2	**35.3**	30.9
BE	1.1	1.0	1.9	0.4	22.9	20.1	**52.7**
BG	2.1	0.6	0.3	19.1	8.7	17.8	**51.4**
CH	2.4	0.3	0.0	1.0	**53.1**	32.6	10.6
CY	22.3	2.7	0.1	5.8	**53.6**	15.3	0.2
CZ	1.5	**47.1**	0.3	7.7	7.5	22.2	13.6
DE	3.2	10.0	3.1	24.3	**27.8**	15.4	16.2
DK	4.3	1.8	3.8	4.6	**38.5**	22.6	24.4
EE	0.1	11.0	0.0	14.6	2.6	32.1	**39.6**
EL	3.5	7.2	6.9	2.7	24.1	24.5	**31.1**
ES	7.2	3.4	1.3	20.8	**23.3**	20.9	23.2
FI	3.8	0.0	0.0	0.0	1.6	40.2	**54.4**
FR	1.1	0.5	0.5	2.5	18.9	23.8	**52.7**
HR	5.2	3.7	0.5	8.6	11.9	14.2	**55.9**
HU	0.8	6.8	0.7	16.3	5.2	**40.5**	29.8
IE	0.3	14.3	0.0	8.0	7.9	**42.7**	26.8
IS	13.2	0.0	28.9	1.1	26.4	**30.4**	0.0
IT	6.4	0.8	1.6	11.6	**31.5**	21.2	27.1
LI	0.0	0.0	0.0	0.0	**100.0**	0.0	0.0
LT	0.8	2.7	0.2	14.6	4.1	30.5	**47.0**
LU	1.2	2.8	0.0	6.6	14.5	**63.2**	11.7
LV	0.1	1.3	0.0	9.1	0.8	4.8	**83.8**
ME	2.8	0.0	0.0	5.8	22.7	29.2	**39.5**
MK	3.2	1.9	1.2	11.1	7.6	21.5	**53.4**
MT ([18])							
NL	1.6	18.3	3.9	3.2	**64.6**	5.6	2.8
NO	0.4	0.0	0.0	0.0	5.1	15.4	**79.2**
PL	1.2	2.3	1.5	4.1	15.4	**41.0**	34.6
PT	1.8	0.7	2.1	13.4	4.4	24.1	**53.4**
RO	0.2	1.7	0.4	8.1	16.2	6.5	**66.9**
RS	5.5	5.0	3.4	14.5	11.5	29.9	**30.1**
SE	0.0	0.1	0.0	0.0	0.6	**54.4**	44.9
SI	1.8	0.2	1.9	0.0	**45.2**	10.4	40.5
SK	0.5	3.1	0.2	3.5	6.6	20.8	**65.3**

([18]) No data available for soil biomass production (grass) for Malta.

TR	10.3	6.6	9.4	13.1	**31.2**	15.4	14.0
UK	1.0	0.3	0.4	0.4	10.8	28.9	**58.2**
XK	1.6	1.0	0.0	22.3	27.3	**35.7**	12.2

Table A2.3 Soil biomass production (forest): distribution of impact per land processes (% of total impact on good and average soils), highest impact value is highlighted

Country	Agricultural expansion	Agricultural extensification	Water body expansion	Agricultural intensification	Urban expansion	Forest expansion	Forest fellings
AT	2.2	0.3	0.2	0.0	22.5	6.0	**68.9**
BE	1.0	0.8	1.8	0.4	20.9	20.2	**54.8**
BG	2.1	0.6	0.4	19.2	7.8	18.3	**51.6**
CZ	1.7	**45.6**	0.1	7.3	3.6	23.1	18.7
DE	2.3	9.5	2.1	23.9	**26.7**	15.1	20.4
DK	4.2	1.4	3.7	4.8	**39.0**	22.7	24.2
EE	0.2	16.2	0.0	16.5	6.8	**30.7**	29.6
EL	3.2	4.0	4.3	1.4	19.1	27.0	**40.8**
ES	10.5	3.8	1.9	**25.7**	19.1	19.4	19.7
FI	1.0	0.1	0.0	0.0	14.4	34.1	**50.4**
FR	1.1	0.5	0.4	3.0	18.1	24.8	**52.1**
HU	0.7	7.4	0.8	16.3	5.1	**39.8**	30.0
IE	0.2	12.7	0.0	7.3	7.3	**46.6**	25.8
IT	6.2	1.0	1.4	12.6	**31.2**	21.0	26.6
LT	0.3	2.0	0.9	11.6	7.0	26.6	**51.6**
LU	2.2	2.1	0.0	6.5	22.7	**56.6**	9.9
LV	0.1	0.5	0.1	3.0	1.6	5.7	**89.1**
NL	1.7	17.1	3.5	3.3	**65.7**	5.8	3.0
PL	0.7	2.0	0.7	2.2	9.3	40.7	**44.5**
PT	3.3	0.8	2.2	7.9	4.1	30.5	**51.2**
RO	0.2	2.2	0.8	13.4	23.5	7.2	**52.7**
SE	0.2	0.5	0.0	0.2	4.3	34.5	**60.2**
SI	1.2	0.1	0.7	0.0	39.3	8.7	**49.9**
SK	0.2	4.9	0.3	6.2	9.9	24.4	**54.1**
UK	1.1	0.3	0.3	0.4	11.2	29.7	**57.0**

Table A2.4 Soil carbon pool: distribution of impact per land processes (% of total impact on good and average soils), highest impact value is highlighted

Country	Agricultural expansion	Agricultural extensification	Water body expansion	Agricultural intensification	Urban expansion	Forest expansion	Forest fellings
AL	1.1	1.2	1.6	0.9	14.6	20.5	**60.1**
AT	0.7	0.1	0.1	0.0	14.4	5.0	**79.7**
BA	3.8	0.9	0.0	8.9	10.5	34.0	**41.8**
BE	1.0	2.8	7.1	3.0	**57.2**	6.9	22.0
BG	0.9	0.0	0.5	1.1	3.8	23.2	**70.4**

CY	15.9	0.1	0.3	0.2	21.0	**57.4**	5.1
CZ	0.5	30.3	0.1	2.4	3.1	**38.8**	24.7
DE	1.9	6.6	4.3	18.9	18.2	20.0	**30.1**
DK	1.8	1.5	3.1	2.9	6.5	19.4	**64.9**
EE	0.0	5.5	0.0	7.0	2.4	37.6	**47.4**
EL	3.1	0.3	1.0	0.1	9.7	33.6	**52.1**
ES	15.0	0.5	1.3	2.5	9.7	33.4	**37.6**
FI	3.8	0.1	0.0	0.0	5.9	34.6	**55.7**
FR	1.1	0.3	0.3	2.3	8.9	24.7	**62.3**
HR	6.2	2.8	0.3	6.7	14.3	14.5	**55.3**
HU	0.5	2.3	0.3	4.6	1.5	35.6	**55.1**
IE	0.1	15.1	0.0	8.7	8.2	**39.5**	28.4
IT	6.4	0.3	1.3	0.5	7.2	34.2	**50.1**
LI	0.0	0.0	0.0	0.0	**100.0**	0.0	0.0
LT	0.1	0.5	0.1	3.6	0.8	30.6	**64.3**
LU	1.5	5.0	0.0	20.8	**59.1**	9.3	4.4
LV	0.1	0.7	0.0	6.6	0.6	4.6	**87.5**
ME	2.2	1.0	0.0	4.7	19.3	26.4	**46.4**
MK	0.9	0.4	2.8	0.7	2.5	26.8	**66.0**
NL	1.8	21.0	4.6	3.7	**63.6**	5.2	0.1
NO	0.9	0.0	0.0	0.0	11.3	16.1	**71.6**
PL	0.3	1.0	0.9	1.4	6.7	44.1	**45.7**
PT	3.4	0.1	1.4	0.2	3.4	28.8	**62.7**
RO	0.0	0.4	0.2	2.6	6.4	6.9	**83.5**
RS	5.3	0.5	1.0	3.2	3.6	38.7	**47.6**
SE	0.2	0.1	0.0	0.1	3.2	**48.9**	47.5
SI	1.0	0.1	1.0	0.0	34.1	10.5	**53.3**
SK	0.3	0.6	0.1	0.5	2.2	20.9	**75.4**
UK	0.8	0.5	0.3	0.5	11.7	29.0	**57.2**
XK	1.1	0.7	0.0	7.7	8.9	**60.6**	21.0

Table A2.5 Soil biodiversity pool: distribution of impact per land processes (% of total impact on good and average soils), highest impact value is highlighted

Country	Agricultural expansion	Agricultural extensification	Water body expansion	Agricultural intensification	Urban expansion	Forest expansion	Forest fellings
AT	0.9	0.1	0.1	0.0	12.1	5.1	**81.9**
BE	0.2	0.6	0.5	0.3	5.8	24.2	**68.3**
BG	1.4	0.2	0.5	6.3	5.0	20.5	**66.1**
CZ	0.8	31.5	0.1	4.4	3.1	**36.4**	23.7
DE	2.2	4.5	4.2	18.6	11.3	24.9	**34.3**
DK	2.9	0.9	2.5	3.0	8.7	30.6	**51.4**
EE	0.1	6.9	0.0	11.5	2.1	36.1	**43.3**
EL	2.9	0.6	1.6	0.2	10.7	32.5	**51.6**
ES	14.0	0.9	1.6	4.0	8.8	31.4	**39.4**
FI	4.4	0.0	0.0	0.0	2.0	40.3	**53.2**
FR	0.9	0.3	0.2	1.8	5.6	29.0	**62.2**
HU	0.5	4.6	0.4	9.3	1.5	36.7	**47.0**
IE	0.2	10.2	0.0	9.6	7.2	**46.0**	26.7

IT	5.2	0.8	1.4	0.8	6.8	33.4	**51.5**
LT	0.3	1.2	0.1	10.6	1.4	33.5	**52.8**
LU	0.8	2.0	0.0	2.8	14.9	**68.4**	11.1
LV	0.1	0.8	0.0	7.0	0.7	5.0	**86.4**
NL	0.5	22.8	3.4	5.1	**56.0**	4.8	7.3
PL	0.4	1.0	0.8	1.0	5.5	42.9	**48.5**
PT	3.2	0.3	1.3	0.6	3.1	29.0	**62.5**
RO	0.1	0.5	0.3	2.7	3.7	6.3	**86.4**
SE	0.0	0.0	0.0	0.0	0.4	**54.3**	45.2
SI	1.3	0.0	1.1	0.0	27.0	11.1	**59.4**
SK	0.4	0.7	0.0	0.9	1.2	23.0	**73.7**
UK	0.5	0.2	0.1	0.2	6.3	30.9	**61.7**

Annex A3: Tables of impact distribution per country (background tables for Figure 3.2 and Figure 3.3)

Table A3.1 Soil biomass production (arable land): area and shares of average and good soils, and total and relative impact per country

Country	All soils (ha)	Average and good soils (ha)	Good soils (ha)	Percentage of average and good soils	Percentage of good soils	Share of good soils in average and good soils	Total impact on average and good soils (ha)	Total impact on good soils (ha)	Percentage of average and good soils affected by impact	Percentage of good soils affected by impact
AL	2 875 504	1 827 060	409 546	63.5	14.2	22.4	47 381	16 992	2.6	4.1
AT	8 394 788	4 447 766	1 288 872	53.0	15.4	29.0	38 030	8 483	0.9	0.7
BA	5 123 495	3 449 447	170 106	67.3	3.3	4.9	40 359	2 305	1.2	1.4
BE	3 066 419	2 685 938	2 629 660	87.6	85.8	97.9	29 365	28 812	1.1	1.1
BG	11 098 858	8 553 925	502 371	77.1	4.5	5.9	80 491	5 650	0.9	1.1
CH	4 128 698	1 774 676	509 845	43.0	12.3	28.7	2 724	1 454	0.2	0.3
CY	924 920	104 791	0	11.3	n/a	n/a	1 181	0	1.1	n/a
CZ	7 886 978	7 576 911	5 804 336	96.1	73.6	76.6	311 132	224 148	4.1	3.9
DE	35 773 820	31 451 703	16 841 072	87.9	47.1	53.5	345 785	181 897	1.1	1.1
DK	4 317 446	3 626 032	2 953 528	84.0	68.4	81.5	45 740	37 543	1.3	1.3
EE	4 533 569	3 255 442	1 088 314	71.8	24.0	33.4	205 151	69 766	6.3	6.4
EL	13 173 561	3 541 666	423 914	26.9	3.2	12.0	53 839	8 200	1.5	1.9
ES	50 597 999	11 636 459	3 564 327	23.0	7.0	30.6	321 814	82 850	2.8	2.3
FI	33 761 660	29 536 542	701 245	87.5	2.1	2.4	1 279 808	26 031	4.3	3.7
FR	54 908 244	40 033 745	28 445 517	72.9	51.8	71.1	737 226	616 113	1.8	2.2
HR	5 659 933	2 817 823	126 571	49.8	2.2	4.5	43 222	1 791	1.5	1.4
HU	9 301 316	7 417 717	835 262	79.7	9.0	11.3	432 788	25 399	5.8	3.0
IE	6 995 786	5 471 470	4 082 335	78.2	58.4	74.6	229 158	156 793	4.2	3.8
IS	10 270 008	7 263 948	4 402 287	70.7	42.9	60.6	18 212	13 408	0.3	0.3
IT	30 060 097	17 727 180	4 351 267	59.0	14.5	24.5	193 603	39 773	1.1	0.9
LI	15 964	15 573	7 940	97.6	49.7	51.0	15	15	0.1	0.2

LT	6 490 075	3 567 643	13 079	55.0	0.2	0.4	92 511	53	2.6	0.4
LU	259 513	192 233	101 280	74.1	39.0	52.7	3 111	1 163	1.6	1.1
LV	6 459 629	3 919 341	315 233	60.7	4.9	8.0	216 421	11 775	5.5	3.7
ME	1 387 896	377 160	95 674	27.2	6.9	25.4	2 314	670	0.6	0.7
MK	2 543 623	1 593 283	418 260	62.6	16.4	26.3	35 280	11 711	2.2	2.8
MT	31 617	0	0	n/a 0	n/a	n/a	0	0	n/a	n/a
NL	3 737 428	2 173 775	2 068 274	58.2	55.3	95.1	58 433	52 662	2.7	2.5
NO	32 302 659	8 653 841	3 761 180	26.8	11.6	43.5	182 512	67 786	2.1	1.8
PL	31 194 131	24 051 996	6 822 427	77.1	21.9	28.4	341 597	68 410	1.4	1.0
PT	9 196 949	3 139 798	143 808	34.1	1.6	4.6	326 909	8 685	10.4	6.0
RO	23 836 492	20 865 283	6 151 170	87.5	25.8	29.5	94 184	17 595	0.5	0.3
RS	7 731 376	5 928 274	1 806 298	76.7	23.4	30.5	50 818	17 203	0.9	1.0
SE	44 956 121	35 859 522	7 504 395	79.8	16.7	20.9	4 393 716	748 789	12.3	10.0
SI	2 027 351	1 064 440	82 155	52.5	4.1	7.7	1 898	73	0.2	0.1
SK	4 902 729	3 421 274	134 155	69.8	2.7	3.9	114 488	2 251	3.3	1.7
TR	78 029 089	28 884 201	23 552 679	37.0	30.2	81.5	170 456	103 836	0.6	0.4
UK	24 461 775	19 489 786	11 302 151	79.7	46.2	58.0	337 124	143 215	1.7	1.3
XK	1 100 462	861 819	796	78.3	0.1	0.1	12 309	15	1.4	1.9
Total (EEA-39)	**583 517 978**	**358 259 481**	**143 411 329**	**61.4**	**24.6**	**40.0**	**10 891 103**	**2 803 314**	**3.0**	**2.0**

Table A3.2 Soil biomass production (grassland): area and shares of average and good soils, and total and relative impact per country

Country	All soils (ha)	Average and good soils (ha)	Good soils (ha)	Percentage of average and good soils	Percentage of good soils	Percentage of good soils in average and good soils	Total impact on average and good soils (ha)	Total impact on good soils (ha)	Percentage of average and good soils affected by impact	Percentage of good soils affected by impact
AL	2 875 504	2 224 115	892 290	77.3	31.0	40.1	53 738	32 635	2.4	3.7
AT	8 394 788	5 585 342	2 822 758	66.5	33.6	50.5	49 833	21 779	0.9	0.8
BA	5 123 495	4 204 163	1 418 471	82.1	27.7	33.7	49 207	18 806	1.2	1.3
BE	3 066 419	2 976 792	2 680 117	97.1	87.4	90.0	31 135	29 288	1.0	1.1
BG	11 098 858	9 876 430	3 421 996	89.0	30.8	34.6	89 722	30 574	0.9	0.9
CH	4 128 698	2 497 117	1 105 367	60.5	26.8	44.3	3 222	2 466	0.1	0.2
CY	924 920	130 346	0	14.1	n/a	n/a	1 607	0	1.2	n/a
CZ	7 886 978	7 801 494	7 409 889	98.9	94.0	95.0	325 587	306 736	4.2	4.1
DE	35 773 820	33 313 011	22 651 209	93.1	63.3	68.0	362 020	247 961	1.1	1.1
DK	4 317 446	4 170 586	3 762 317	96.6	87.1	90.2	51 720	47 485	1.2	1.3
EE	4 533 569	4 008 477	1 781 207	88.4	39.3	44.4	244 508	130 429	6.1	7.3
EL	13 173 561	4 600 844	929 877	34.9	7.1	20.2	64 582	11 770	1.4	1.3
ES	50 597 999	17 426 676	4 825 420	34.4	9.5	27.7	450 604	103 797	2.6	2.2
FI	33 761 660	30 632 694	23 179 408	90.7	68.7	75.7	1 309 320	1 066 743	4.3	4.6
FR	54 908 244	43 221 338	33 650 186	78.7	61.3	77.9	759 554	679 267	1.8	2.0
HR	5 659 933	3 853 821	222 479	68.1	3.9	5.8	64 186	4 968	1.7	2.2
HU	9 301 316	8 046 801	3 576 735	86.5	38.5	44.4	453 057	139 810	5.6	3.9
IE	6 995 786	5 550 809	4 593 490	79.3	65.7	82.8	232 001	190 402	4.2	4.1
IS	10 270 008	7 419 047	6 869 919	72.2	66.9	92.6	19 139	17 311	0.3	0.3
IT	30 060 097	21 497 705	7 293 535	71.5	24.3	33.9	223 015	69 829	1.0	1.0
LI	15 964	15 688	14 685	98.3	92.0	93.6	15	15	0.1	0.1
LT	6 490 075	4 849 837	13 079	74.7	0.2	0.3	122 284	53	2.5	0.4
LU	259 513	215 846	156 799	83.2	60.4	72.6	3 453	2 034	1.6	1.3

LV	6 459 629	5 555 196	460 835	86.0	7.1	8.3	314 506	18 958	5.7	4.1
ME	1 387 896	718 982	131 078	51.8	9.4	18.2	3 837	719	0.5	0.5
MK	2 543 623	1 805 715	752 083	71.0	29.6	41.7	40 534	18 629	2.2	2.5
MT	31 617	0	0	n/a	n/a	n/a	0	0	n/a	n/a
NL	3 737 428	3 362 194	2 068 289	90.0	55.3	61.5	83 528	52 662	2.5	2.5
NO	32 302 659	10 698 178	3 844 239	33.1	11.9	35.9	245 802	99 903	2.3	2.6
PL	31 194 131	29 927 550	14 085 258	95.9	45.2	47.1	441 475	151 822	1.5	1.1
PT	9 196 949	2 340 982	101 270	25.5	1.1	4.3	270 876	3 039	11.6	3.0
RO	23 836 492	22 580 335	8 257 889	94.7	34.6	36.6	125 129	28 007	0.6	0.3
RS	7 731 376	6 594 066	2 341 375	85.3	30.3	35.5	55 582	19 229	0.8	0.8
SE	44 956 121	37 093 052	5 022 584	82.5	11.2	13.5	4 530 775	484 151	12.2	9.6
SI	2 027 351	1 304 796	202 223	64.4	10.0	15.5	2 663	163	0.2	0.1
SK	4 902 729	4 331 811	1 582 225	88.4	32.3	36.5	146 678	60 148	3.4	3.8
TR	78 029 089	29 873 924	25 701 376	38.3	32.9	86.0	175 897	110 257	0.6	0.4
UK	24 461 775	20 386 356	17 049 209	83.3	69.7	83.6	354 574	275 218	1.7	1.6
XK	1 100 462	957 109	3 585	87.0	0.3	0.4	13 245	94	1.4	2.6
Total (EEA-39)	**583 517 978**	**401 649 227**	**214 874 745**	**68.8**	**36.8**	**53.5**	**11 768 610**	**4 477 157**	**2.9**	**2.1**

Table A3.3 Soil biomass production (forest): area and shares of average and good soils, and total and relative impact per country

Country	All soils (ha)	Average and good soils (ha)	Good soils (ha)	Percentage of average and good soils	Percentage of good soils	Percentage of good soils in average and good soils	Total impact on average and good soils (ha)	Total impact on good soils (ha)	Percentage of average and good soils affected by impact	Percentage of good soils affected by impact
AT	8 394 788	5 916 433	285 996	70.5	3.4	4.8	48 000	2 770	0.8	1.0
BE	3 066 419	2 948 564	718 230	96.2	23.4	24.4	30 302	16 477	1.0	2.3
BG	11 098 858	10 547 985	199 838	95.0	1.8	1.9	94 450	836	0.9	0.4
CZ	7 886 978	2 781 399	9 394	35.3	0.1	0.3	134 727	1 777	4.8	18.9
DE	35 773 820	32 852 608	1 219 723	91.8	3.4	3.7	357 561	24 124	1.1	2.0
DK	4 317 446	3 289 297	77 012	76.2	1.8	2.3	39 766	585	1.2	0.8
EE	4 533 569	193 771	0	4.3	n/a	n/a	12 917	0	6.7	n/a
EL	13 173 561	11 480 298	8 746 889	87.1	66.4	76.2	144 329	113 909	1.3	1.3
ES	50 597 999	44 990 245	19 418 779	88.9	38.4	43.2	1 095 463	636 100	2.4	3.3
FI	33 761 660	206 397	0	0.6	n/a	n/a	7 040	0	3.4	n/a
FR	54 908 244	50 543 397	16 872 220	92.1	30.7	33.4	851 924	537 538	1.7	3.2
HU	9 301 316	7 427 688	0	79.9	n/a	n/a	410 014	0	5.5	n/a
IE	6 995 786	6 248 583	5 064 491	89.3	72.4	81.1	261 985	215 791	4.2	4.3
IT	30 060 097	26 224 804	19 022 668	87.2	63.3	72.5	249 063	198 388	0.9	1.0
LT	6 490 075	1 358 322	0	20.9	n/a	n/a	26 924	0	2.0	n/a
LU	259 513	254 209	15 861	98.0	6.1	6.2	4 061	145	1.6	0.9
LV	6 459 629	1 346 889	0	20.9	n/a	n/a	87 765	0	6.5	n/a
NL	3 737 428	3 113 768	114 721	83.3	3.1	3.7	75 806	2 727	2.4	2.4
PL	31 194 131	7 146 093	0	22.9	n/a	n/a	133 848	0	1.9	n/a
PT	9 196 949	8 420 518	8 342 879	91.6	90.7	99.1	858 319	855 274	10.2	10.3
RO	23 836 492	14 748 521	0	61.9	n/a	n/a	50 231	0	0.3	n/a
SE	44 956 121	3 289 842	11 900	7.3	0.0	0.4	178 546	805	5.4	6.8
SI	2 027 351	1 752 406	182 321	86.4	9.0	10.4	3 695	864	0.2	0.5

SK	4 902 729	2 642 418	100	53.9	0.0	0.0	65 091	23	2.5	23.0
UK	24 461 775	20 942 645	8 242 816	85.6	33.7	39.4	356 652	210 232	1.7	2.6
Total	**431 392 734**	**270 667 098**	**88 545 838**	**62.7**	**20.5**	**32.7**	**5 578 483**	**2 818 364**	**2.1**	**3.2**

Table A3.4 Soil carbon pool: area and shares of average and good soils, and total and relative impact per country

Country	All soils (ha)	Average and good soils (ha)	Good soils (ha)	Percentage of average and good soils	Percentage of good soils	% of good soils in average and good soils	Total impact on average and good soils (ha)	Total impact on good soils (ha)	Percentage of average and good soils affected by impact	Percentage of good soils affected by impact
AL	2 875 504	2 132 530	2 038 906	74.2	70.9	95.6	35 737	34 294	1.7	1.7
AT	8 394 788	6 604 952	5 632 211	78.7	67.1	85.3	60 244	57 396	0.9	1.0
BA	5 123 495	3 919 848	3 093 913	76.5	60.4	78.9	43 166	32 791	1.1	1.1
BE	3 066 419	955 001	0	31.1	n/a	n/a	3 799	0	0.4	n/a
BG	11 098 858	4 996 744	4 718 510	45.0	42.5	94.4	67 923	66 975	1.4	1.4
CY	924 920	408 829	408 829	44.2	44.2	100.0	18 426	18 426	4.5	4.5
CZ	7 886 978	3 528 044	2 786 396	44.7	35.3	79.0	171 124	120 958	4.9	4.3
DE	35 773 820	17 920 668	9 827 716	50.1	27.5	54.8	224 605	139 698	1.3	1.4
DK	4 317 446	507 516	351 712	11.8	8.1	69.3	14 837	13 353	2.9	3.8
EE	4 533 569	2 938 363	2 626 163	64.8	57.9	89.4	202 952	183 618	6.9	7.0
EL	13 173 561	7 387 062	7 304 665	56.1	55.4	98.9	113 572	112 555	1.5	1.5
ES	50 597 999	25 312 002	23 532 094	50.0	46.5	93.0	603 829	586 304	2.4	2.5
FI	33 761 660	3 489 982	2 530 749	10.3	7.5	72.5	123 954	115 587	3.6	4.6
FR	54 908 244	28 587 735	15 082 795	52.1	27.5	52.8	630 007	559 513	2.2	3.7
HR	5 659 933	4 110 197	2 933 192	72.6	51.8	71.4	76 967	63 333	1.9	2.2
HU	9 301 316	1 985 472	1 638 416	21.3	17.6	82.5	187 594	171 111	9.4	10.4
IE	6 995 786	5 424 737	4 677 754	77.5	66.9	86.2	231 315	200 591	4.3	4.3
IT	30 060 097	13 240 945	12 657 823	44.0	42.1	95.6	125 811	121 746	1.0	1.0
LI	15 964	12 881	9 594	80.7	60.1	74.5	7	0	0.1	n/a
LT	6 490 075	1 540 708	1 326 944	23.7	20.4	86.1	71 391	68 452	4.6	5.2
LU	259 513	122 569	0	47.2	n/a	n/a	976	0	0.8	n/a
LV	6 459 629	4 832 604	3 311 563	74.8	51.3	68.5	352 699	315 288	7.3	9.5
ME	1 387 896	1 257 999	1 114 361	90.6	80.3	88.6	5 242	4 708	0.4	0.4
MK	2 543 623	1 631 859	1 518 541	64.2	59.7	93.1	43 804	42 563	2.7	2.8
NL	3 737 428	1 362 021	1 161	36.4	0.0	0.1	44 224	34	3.2	2.9
NO	32 302 659	3 994 182	3 054 234	12.4	9.5	76.5	35 195	29 725	0.9	1.0

PL	31 194 131	6 057 740	3 600 220	19.4	11.5	59.4	155 711	138 676	2.6	3.9
PT	9 196 949	4 606 733	4 270 064	50.1	46.4	92.7	685 643	676 444	14.9	15.8
RO	23 836 492	8 741 845	6 188 061	36.7	26.0	70.8	69 508	61 451	0.8	1.0
RS	7 731 376	3 152 347	2 962 548	40.8	38.3	94.0	36 469	36 162	1.2	1.2
SE	44 956 121	2 069 247	1 783 912	4.6	4.0	86.2	143 396	139 423	6.9	7.8
SI	2 027 351	1 765 546	1 277 404	87.1	63.0	72.4	4 031	3 564	0.2	0.3
SK	4 902 729	1 801 266	1 413 996	36.7	28.8	78.5	94 846	87 463	5.3	6.2
UK	24 461 775	11 190 955	5 098 218	45.7	20.8	45.6	169 233	137 490	1.5	2.7
XK	1 100 462	676 618	627 432	61.5	57.0	92.7	7 823	7 436	1.2	1.2
Total (EEA39)	**491 058 566**	**188 267 748**	**139 400 095**	**38.3**	**28.4**	**74.0**	**4 856 062**	**4 347 128**	**2.6**	**3.1**

Table A3.5 Soil biodiversity pool: area and shares of average and good soils, and total and relative impact per country

Country	All soils (ha)	Average and good soils (ha)	Good soils (ha)	Percentage of average and good soils	Percentage of good soils	% of good soils in average and good soils	Total impact on average and good soils (ha)	Total impact on good soils (ha)	Percentage of average and good soils affected by impact	Percentage of good soils affected by impact
AT	8 394 788	5 776 634	5 231 951	68.8	62.3	90.6	57 518	54 916	1.0	1.0
BE	3 066 419	1 079 691	944 859	35.2	30.8	87.5	22 701	21 730	2.1	2.3
BG	11 098 858	5 892 742	5 679 840	53.1	51.2	96.4	66 705	65 078	1.1	1.1
CZ	7 886 978	3 655 068	3 362 471	46.3	42.6	92.0	162 985	148 553	4.5	4.4
DE	35 773 820	14 746 236	13 972 550	41.2	39.1	94.8	194 883	179 314	1.3	1.3
DK	4 317 446	764 433	446 314	17.7	10.3	58.4	19 447	11 964	2.5	2.7
EE	4 533 569	2 756 255	2 731 156	60.8	60.2	99.1	192 855	183 438	7.0	6.7
EL	13 173 561	8 175 626	5 073 118	62.1	38.5	62.1	114 785	81 479	1.4	1.6
ES	50 597 999	26 348 416	17 763 263	52.1	35.1	67.4	545 070	339 128	2.1	1.9
FI	33 761 660	11 468 638	1 198 822	34.0	3.6	10.5	476 398	53 112	4.2	4.4
FR	54 908 244	27 724 680	24 461 034	50.5	44.5	88.2	685 031	611 022	2.5	2.5
HU	9 301 316	2 760 563	2 639 322	29.7	28.4	95.6	252 350	237 158	9.1	9.0
IE	6 995 786	4 478 158	4 426 020	64.0	63.3	98.8	169 335	165 276	3.8	3.7
IT	30 060 097	14 218 155	11 579 402	47.3	38.5	81.4	112 222	98 538	0.8	0.9
LT	6 490 075	2 899 607	2 602 980	44.7	40.1	89.8	120 348	107 320	4.2	4.1
LU	259 513	153 891	149 493	59.3	57.6	97.1	3 071	2 963	2.0	2.0
LV	6 459 629	4 553 228	4 258 798	70.5	65.9	93.5	337 324	320 843	7.4	7.5
NL	3 737 428	1 502 358	1 319 538	40.2	35.3	87.8	29 849	26 914	2.0	2.0
PL	31 194 131	12 859 290	11 438 347	41.2	36.7	89.0	305 997	251 207	2.4	2.2
PT	9 196 949	5 118 631	3 110 915	55.7	33.8	60.8	660 883	458 197	12.9	14.7
RO	23 836 492	11 543 115	10 447 212	48.4	43.8	90.5	106 585	97 751	0.9	0.9

SE	44 956 121	34 512 252	24 095 440	76.8	53.6	69.8	4 360 161	2 641 933	12.6	11.0
SI	2 027 351	1 551 521	1 512 541	76.5	74.6	97.5	3 603	3 518	0.2	0.2
SK	4 902 729	2 810 579	2 713 671	57.3	55.4	96.6	135 930	121 360	4.8	4.5
UK	24 461 775	13 846 959	12 483 038	56.6	51.0	90.2	337 977	319 846	2.4	2.6
Total	431 392 734	221 196 727	173 642 095	51.3	40.3	78.5	9 474 014	6 602 558	4.3	3.8

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