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Demands on land: Mapping competing societal expectations for the functionality of agricultural soils in Europe

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ABSTRACT

The Common Agricultural Policy (CAP) of the European Union (EU) has been highly successful in securing the supply of food from Europe's agricultural land. However, new expectations have emerged from society on the functions that agricultural land should deliver, including the expectations that land should regulate and purify water, should sequester carbon to contribute to the mitigation of climate change, should provide a home for biodiversity and allow for the sustainable cycling of nutrients in animal and human waste streams. Through a series of reforms of the CAP, these expectations, or 'societal demands' have translated into a myriad of EU and national level policies aimed at safeguarding the sustainability and multifunctionality of European agriculture, resulting in a highly complex regulatory environment for land managers. The current reform of the CAP aims to simultaneously simplify and strengthen policy making on environmental protection and climate action, through the development of Strategic Plans at national level, which allow for more targeted and context-specific policy formation. In this paper, we contribute to the knowledge base underpinning the development of these Strategic Plans by mapping the variation in the societal demands for soil functions across EU Member States, based on an extensive review of the existing policy environment relating to sustainable and multifunctional land management. We show that the societal demands for primary production, water regulation and purification, carbon sequestration, biodiversity and nutrient cycling vary greatly between Member States, as determined by population, farming systems and livestock densities, geo-environmental conditions and landscape configuration. Moreover, the total societal demands for multifunctionality differs between Member States, with the lowest demands found in Member States that have designated the higher shares of EU CAP funding towards 'Pillar 2' expenditure, aimed at environmental protection and regional development. We review which lessons can be learnt from these observations, in the context of the proposals for the new CAP for the period 2021–2027, which include enhanced conditionality of direct income support for farmers and the instigation of eco-schemes in Pillar 1, in addition to Agri-Environmental and Climate Measures in Pillar 2. We conclude that the devolution of planning to Strategic Plans at national level provides an opportunity for more effective and targeted incentivisation of sustainable land management, provided that these plans take account for variations in the societal demand for soil functions, as well as the capacity of contrasting soils to deliver on this multifunctionality.

1. Introduction

1.1. Urgency

Agricultural land is the main interface between the global food system and the global environment, with land management impacting on, and being impacted by, the environment. Globally, agriculture contributes to the extraction of water (Hoekstra and Chapagain, 2008), deterioration of water quality, greenhouse gas emissions (Gerber et al., 2013) and regional depletion and accumulation of nutrients (Uwizeye et al., 2016). Dietary changes associated with rising affluence, growing populations and urbanisation are driving demand for livestock products

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with a global increase of 70% anticipated by 2050 (Gerber et al., 2013). Compared to the total agricultural sector, Leip et al. (2015) estimated that, in Europe, the livestock agricultural share accounts for 73% of water pollution including phosphorus and nitrogen losses and 81% of total greenhouse gas emissions. At the same time, agriculture is being affected by the very changes in the environment that it contributes to. Already between 2007–2016 land temperatures have increased by 1.6 °C since pre-industrial time with summer temperatures especially affecting southern Europe (European Commission (EC), 2018b). These changes are leading to changes in crop suitability in parts of Europe (Maracchi et al., 2005; Falloon and Betts, 2010; Kovats et al., 2014) with droughts and heat stress affecting plant production in Southern Europe, with a 30% yield decline possible by 2050 dependent upon the crop (Olesen and Bindi, 2002; Hart et al., 2017). Although longer crop growing seasons may occur in Northern Europe (e.g. Semenov, 2009), this region is likely to experience increased pest and disease pressures, increased nutrient leaching and a reduction in soil organic matter due to increased mineralisation associated with rising temperatures (Maracchi et al., 2005). Land use and land cover (LULC) in tandem with climate are driving patterns of biodiversity decline, which together are expected to continue to be a threat to agricultural biodiversity worldwide (Ostberg et al., 2015) including the decline of pollination insects such as the bumblebee (Marshall et al., 2018)

However, the effects of these environmental changes extend beyond agriculture and impact on society as a whole. At least 11% of the European population and 17% of its territory have been affected by water scarcity to date (SEC(2007) 993 & SEC(2007) 999). Climate change will almost certainly exacerbate these adverse impacts in the future, with more frequent and severe droughts expected across Europe. This incidence of floods has also increased, with over 213 major damaging floods between 1998 and 2009, causing the displacement of about half a million people and at least €52 billion in insured economic losses (Environment Agency (EEA, 2011). The coming decades are likely to see a higher flood risk in Europe and greater economic damage due to increased urbanization and climate change. Water quality remains at risk of eutrophication (European Commission (EC, 2017), resulting inter alia from losses of surplus nutrients from agricultural land to water (Grizzetti et al., 2011; European Commission (EC), 2018a).

Such are the changes in land management and the environment, that the structural integrity of Europe's ecosystems may be at risk: the EU assessment for the Habitats Directive for the period 2007–2012 showed that only 23% of animal and plant species assessments were considered to be in a favourable conservation status, with 60% of species assessed as facing unfavourable conditions. According to the latest data on European common birds, brought together by the Pan-European Common Bird Monitoring Scheme (PECBMS), farmland birds show a 55% decline since 1980 (European Bird Council Census (EBCC, 2018). Similarly, there has been a decline in grassland butterflies of almost 50% between 1990 and 2011, without any sign of recovery (Environment Agency (EEA, 2013a). Encouragingly, some populations of European bats (Environment Agency (EEA, 2013b) and large carnivores (European Commission (EC, 2012) appear to have recovered to some extent from past declines, reflecting the effectiveness of targeted conservation actions.

1.2. Policy context

During the first three decades of the EU Common Agricultural Policy (CAP), efforts were focussed on supporting the management of land for food production. Since the 1990s, EU policies have increasingly responded to the evolution of societal expectations that land management should also aim to maintain, restore and where necessary enhance the provision of ecosystem services such as flood mitigation and climate mitigation. This has led to the formulation of a multitude of Environmental Directives and successive reviews and reforms of the CAP, which we review in this paper. Many of these policies have been developed independently from each other, leading to the development of a myriad of policy instruments that apply to land management at farm scale and at national scale (Schulte et al., 2015). From the perspective of European land managers, this has resulted in one of the most complex agricultural policy environments in the world (O'Sullivan et al., 2019a; Schulte et al., 2017).

In preparation for the next CAP period of 2021–2027, the European Commission presented its proposals for modernising and simplifying the CAP in June 2018. Key elements of this proposal are: 1) Better targeting of funding towards small and medium sized farms; 2) guaranteeing a higher ambition on environmental and climate action; 3) putting agriculture at the heart of European society and 4) making greater use of knowledge and innovation (European Commission (EC), 2018c). Central to the delivery of these ambitions is the increased subsidiarity of the Commission to Member States (MS). This means that the current centralised top-down approach towards the formation of agricultural and agri-environmental policies and policy instruments will be replaced by more targeted and results-based approaches at MS level reflecting goals set at EU level. Individual MS will each be required to develop a Strategic Plan that will deliver on the overall objectives of the new CAP within the specific agri-environmental and societal context of that MS (European Commission (EC), 2018d).

1.3. Research context

In order for these Strategic Plans to deliver on the "higher ambition on environmental and climate action", national policy makers require knowledge and data to set appropriate agri-environmental targets and to devise land management strategies that can deliver on these targets. Put simply, knowledge is required on A) which ecosystem services are needed where; and B) which land management practices can be used to ensure that the these 'demands' for ecosystem services are met for contrasting soils, farm systems and environments.

In preparation for these policy developments, the European Commission funded the LANDMARK (LAND Management: Assessment, Research, Knowledge base) project (www.landmark2020.eu) as part of the Horizon 2020 Research & Innovation Strategy. LANDMARK is a multi-actor consortium of 22 knowledge institutes, including universities, research institutes and extension services, from 14 EU countries and Switzerland, China and Brazil. It applies the framework of Functional Land Management (FLM) (Schulte et al., 2014) at European scale. FLM is an approach to optimising (rather than maximising) the delivery of land-based ecosystem services to meet societal expectations. FLM builds on, and simplifies, these land-based ecosystem services into five ubiquitous 'soil functions', i.e. 1) primary production of food, feed, fuel and fibre; 2) regulation and purification of water; 3) carbon storage, sequestration and climate regulation; 4) provision of habitats for biodiversity and 5) provision and cycling of nutrients.

Bringing together the knowledge, long-term datasets and models on this topic, LANDMARK has delivered a framework for quantifying the degree to which each of the soil functions can be 'supplied' by combinations of soil type, land use types, and land management practices, for the six main agri-environmental zones in Europe (Henriksen et al., 2018; Rutgers et al., 2018; Schröder et al., 2018; Vrebos et al., 2018; Wall et al., 2018; Wenng et al., 2018). In this paper, we complement this work with an assessment of the 'demand' for each of the five soil functions across Europe.

1.4. Quantifying the demands for soil functions

Different stakeholders with influence on how the land is managed, may have diverging expectations or demands for the extent to which land delivers each of the soil functions (e.g. LANDMARK, 2018; Bampa et al., 2019). For example, farmers may seek to increase carbon content of their soils up to levels deemed adequate to support soil structure, nutrient cycling and hence primary production at local scale (Eliasson

Table 1
Functional and societal objectives of EU and national policies relating to soil functions (adapted from Schulte et al., 2015).

Soil Function	Functional objective (farm scale)	Societal objective (EU / national scale)
Primary production	Provide farm income	Self-sufficiency
Water regulation & purification	Minimise water stress and provision of clean drinking water	Sufficient quantity of good quality water for human consumption and ecosystems
Carbon sequestration	Soil structure and functioning	Mitigation of climate change
Biodiversity	Supporting functional biodiversity	Supporting both functional and intrinsic biodiversity
Nutrient cycling	Valorisation of organic nutrients (Minimise expenditure on fertilizers)	Developing a circular bio-economy

et al., 2010; Jones et al., 2013). Contrastingly, environmental NGOs or governments may be interested to *further* increase carbon stocks with a view to mitigate climate change at national or global scale. Table 1 lists the functional and societal objectives for EU and national policies relating to each of the soil functions, based on the policy assessment by Schulte et al. (2015).

It is important to distinguish between these functional objectives and societal objectives as their realisation may require different approaches to incentivisation: functional objectives are of direct interest and relevance to land managers, and may be expected to provide a sustainable return on investment. Contrastingly, societal objectives may require additional land management practices for which the return on investment materialises at societal, rather than at farm level, which necessitates the formulation of financial or non-financial support instruments.

The degree of soil functioning that is required to meet the local functional objectives for a range of farm systems, soil types and environments has already been well studied and reported on (e.g. Schröder et al., 2016; Henriksen et al., 2018; Rutgers et al., 2018; Trajanov et al., 2018; Vrebos et al., 2018; Wall et al., 2018; Wenng et al., 2018). In this paper, we instead focus on the degree of additional soil functioning required to meet the societal objectives in the context of agriculture in the EU. We assume that national and European policies reflect (be it perfectly or imperfectly) the aggregate requirements and expectations of the various societal stakeholder groups. By mapping the spatial variation in these policy demands for each of the five soil functions, we explore differences in the societal expectations put on land managers across the MS. We relate this to the choices that individual MS have made during the current CAP in terms of funding instruments and amounts of funding targeted towards meeting agri-environmental objectives. From the lessons learnt from this evaluation, we assess opportunities for better alignment of agri-environmental instruments and expenditure to societal demands from land in the context of the negotiations on the new EU CAP for the period 2021–2027.

2. Theory and calculations

2.1. Generic approach

Our approach builds upon the outcomes of an EU level workshop, entitled "Are you getting what you want from your Land?" organized by the LANDMARK consortium at the COPA-COGECA offices in Brussels on 20 October 2016 (LANDMARK, 2018). At this workshop, a range of European stakeholders (Supplementary Material, Table S1) identified the main future environmental and socio-economic developments for European agriculture, along with the related demands on soil and land resources.

This was followed by an assessment of European policies that frame the societal demands for each of the five soil functions, building upon the work of Schulte et al. (2015) and Vrebos et al. (2017). This included the a) identification of relevant EU policies and b) EU policy objectives, as well as c) appropriate demand metrics that are a representation of the societal demand for each soil function, or at least a significant part thereof. Criteria used for the selection of demand metrics included the following:

- Demand metrics must be integrative of the various policy demands for each of the soil functions at MS scale;
- European datasets must be readily and publicly available for each of the demand metrics;
- Data are spatially available and can be mapped at least at NUTS1 level or higher;
- Demand metrics must be sensitive to both spatial and temporal variations, i.e. they can show differences between countries or regions and between years;
- Demand metrics for soil functions can be quantitatively linked to indicators for the supply of soil functions across Europe, as reported on by the LANDMARK consortium (Henriksen et al., 2018; Rutgers et al., 2018; Schröder et al., 2018; Wall et al., 2018; Wenng et al., 2018).

Below, we describe this process in detail for each of the soil functions.

Subsequently, we mapped the societal demands for soil functions using various publicly available datasets from e.g. Eurostat, EEA, JRC. Data were aggregated at NUTS levels and expressed as a demand per unit of Utilised Agricultural Area. Maps were produced using ArcGIS 10.2.

Finally, in order to compare the relative societal demands for all soil functions for individual MS, we converted the values for each of the soil functions to z-scores, similar to the approach used by Schulte et al. (2015).

2.2. Policy objectives and demand metrics for soil functions

2.2.1. Primary production

2.2.1.1. Policy context. As Europe emerged from its most recent period of food shortages in the 1940s, the EU Common Agricultural Policy (CAP) was introduced in 1962 as a "partnership between agriculture and society", with the overall objective to "provide affordable food for EU citizens and a fair standard of living for farmers". Such was its success in incentivising the productivity of European farms, that supply exceeded domestic demand by the end of the 1970s. During subsequent decades, the CAP has been reformed on a number of occasions and now includes objectives on rural development, job creation, tackling climate change and the sustainable use of natural resources. At the same time, food security remains the principal stated objective of the CAP today (European Commission (EC), 2018e).

Dietary demands for more exotic foods, and increased imports over time, mean that the demand for food in the EU is partially met by cultivation outside of the EU Concurrently, EU meat and dairy production is increasingly relying on imported protein crops and in particular soy-bean (Boerema et al., 2016). In 2013, the EU had net imports of around 27 million tons of soybeans and soybean products for oil production and animal feed, which has rendered the domestic cultivation of protein crops unprofitable. This geographic relocation of fodder crops to countries with less stringent environmental legislation has had far-reaching environmental impacts in regions outside of the focus of

Table 2
: EU policies including key targets and constraints related to bio-economy sector.

Main policy	Key targets and constraints
2009 Renewable Energy Directive (RED I)	• 20% energy mix from renewable fuels – with 7% cap of biofuels in energy sector; • Biofuel efficiency ≥ 35%, compared to fossil fuel; • Must not be grown on land that is currently used for food production; • Must not be grown on forests, wetlands and high biodiversity grassland; • Biofuels should not occupy > 7% of agricultural land.
The ILUC (Indirect Land Use Change) Directive (EU) 2015/2013	• EU executive proposed reducing the contribution of conventional biofuels in transport from a maximum of 7% in 2021 to 3.8% in 2030; • Set an obligation to raise the share of other "low emissions fuels" such as renewable electricity and advanced biofuels in transport to 6.8%.
Revised RED (RED II) November 30, 2016	• Cap of food crop-based biofuels from 7% in 2021 to 3.8% in 2030; • A minimum share of energy from advanced biofuels from 1.5% in 2021 to 6.8% by 2030. EC lists of acceptable feedstock for the production of advanced biofuels in Annex IX Part A & B; • A sub-target from 0.5 % in 2021 to 3.6% by 2030 for advanced biofuels produced with feedstocks listed in part A, Annex IX; • Advanced alternative fuels used for aviation and maritime can be counted 1.2 times toward the 6.8% renewable energy mandate.

the CAP, thus effectively constituting an export of externalities (Meyfroid et al., 2013; Uwizeye et al., 2016 under review; O'Sullivan et al., 2019b). A circular economy would comprise of a scenario in which the EU is producing sufficient fodder and recycle nutrients locally or at least within the EU-territory.

Since the 2000's, the EU has witnessed the emergence of a new demand, namely the production of agrichemicals and biofuels. Launched and adopted on 13 February 2012, the EU's Bioeconomy Strategy addresses the production of renewable resources and their conversion into products and bio-energy. A low-emission economy that includes novel crops for oils and fibre for the biochemistry industry, will add a significant claim on land resources within and outside the EU (Weinzettel et al., 2013). Over time, concerns that the 10% target for conventional biofuels would compete with food crops has prompted the shift from first generation to second generation biofuels (i.e. fuel from waste and by-products) (Mohr and Raman, 2013; Boutesteijn et al., 2017). Table 2 indicates the key policies, the associated targets and related constraints to the sector.

The EU demand for biofuel extends beyond production within Europe with some 53% of EU biodiesel derived from imported feedstock, of which 33% is made from imported palm oil. Europe's imports of vegetable oils amounted to 10.1 million tons in 2016, of which 6.6 million tons of palm oil (Bentivoglio et al., 2018). As EU production rules for biofuels are not applicable outside the EU, the sustainability of these imports is unknown and may therefore not contribute to the global challenge of climate mitigation (Widengard et al., 2018) or sustainable development. As of 2018, the European Parliament voted to limit the support to biofuels made from food crops to 2017 consumption levels and never higher than 7% of all transport fuels (European Parliament, 2018). Other changes included the removal of palm oil biodiesel as a contributing source towards the 2021 renewable target, along with an overall transport target of 12% containing a 10% blending mandate for 'advanced' fuels, which includes renewable electricity, waste-based biofuels and "recycled carbon fuels". Palm oil based biodiesel production will continue to receive subsidies until 2030.

Thus, the key policy challenge is to manage the competing demands for food, feed, fuel and fibre in such a way that they all can co-exist in a sustainable way.

2.2.1.2. Metrics for the societal demand for the production of food, feed, fuel and fibre. Food: The average European consumes about 2.5 kg of food per day, of which 40% are dairy products, eggs and meat products. Based on earlier work by Meier and Christen (2013) we assume a 2000 m^2 requirement of land per person per year. Wiegmann et al. (2005) calculated that the production of this food requires approximately 2400 m^2 per capita, of which approximately 700 m^2 (29%) for grassland (dairy), 600 m^2 (25%) for animal feed (meat), 900 m^2 (40%) for grains and 200 m^2 (8%) for vegetables and fruits. Because we will calculate feed for animals as a separate demand factor, we excluded these from the calculations for food production. As a result, the demand for land to produce food equates to approximately 0.2 ha (incl. meat, eggs and dairy) or 0.1 ha (excl. meat, eggs and dairy) per capita, translating into *c.* 50,000,000 ha of farmland to produce the grains, vegetables and fruits needed for self-sufficiency at EU scale.

Feed: The EU-28 is home to about 89 million cows, 147 million pigs, 86 million sheep, 12.5 million goats and 13 billion chickens (https://ec.europa.eu/eurostat/cache/metadata/en/apro_anip_esms.htm). The total feed demand, as calculated by using generic dietary needs based on the following assumptions listed in Supplementary Table S2, sums up to roughly 600 million tonnes. Assuming a dry matter yield of feed crops of 10 tons ha^{-1}, this equates to a demand for 60,000,000 hectares of farmland. Data on the number of animals is available at NUTS 2 level (tgs00045) and was mapped accordingly.

Fibre: We estimated the current demand for bio-based industrial production from the import of non-wood based products listed in the EUROSTAT trade database (https://ec.europa.eu/eurostat/web/international-trade-in-goods/data). Net imports of agriculture-based non-edible products amounted to roughly 1 billion tonnes per year for the EU-28 territory (for period 2012–2017). Future additional demand will include novel crops suitable for the production of synthetic products that can be used in the chemical industry and allow for the manufacturing of a much higher diversity of end-products.

Fuel: for the quantification of demand for fuel, we used the "Shares" dataset from Eurostat (http://ec.europa.eu/eurostat/web/energy/data/shares). The total amount of fuel used in transport in 2016 amounted to 309,774 ktoe (kilo tons of oil equivalent). We adopted the 10% target for biofuel feedstock production as the metric for the demand. For crop biodiesel specifically, only 47% of the feedstocks were grown in the EU in 2015, a decline from 60% (5977 ktoe) in 2010 (Gerasimchuk, 2013; Ecofys, 2014).

Biodiesel is produced by pressing and refining of, among others rapeseed, linseed, sunflower, castor. If we assume an average yield of 3 tons of rapeseed per hectare and an extractable oil fraction of 40%, one hectare can produce 1.2 tons of biodiesel, or about 14,000 l. Bioethanol is produced from wheat, maize, sugar beet, and other crops, through microbial fermentation of sugars (starch). One ton of wheat yields about 340 l of bioethanol. With a yield of 8 ton wheat per hectare (Brisson et al., 2010; Palosuo et al., 2011), this sums up to 2720 l ha^{-1}.

2.2.2. Water regulation and purification

2.2.2.1. Policy context. The main overall objective of EU water policy is to ensure access to good quality water in sufficient quantity for all citizens, and to ensure the good status of all water bodies. This relates to

both the regulation of water quantities, and the safeguarding of water quality of all waterbodies, including surface waters, groundwater and estuarine waters.

There are various directives, communications and other policy documents that relate to the regulation and purification of water by agricultural land, of which the most important are:

- EC Communication - Water scarcity and droughts in the European Union (COM/2007/0414)
- Water Scarcity & Droughts – 2012 Policy Review – Building blocks Non-Paper
- EC Communication - Blueprint to Safeguard Europe's Water Resources (COM(2012) 673)
- EU Water Framework Directive (2000/60/EC)
- The Nitrates Directive (2000/60/EC)

Drought in Europe is a hazard with a wide range of transboundary, environmental and socio-economic impacts on various sectors including agriculture, energy production, public water supply and water quality (Blauhut et al., 2015). Agriculture is the main pressure on renewable water resources in the EU, accounting for 66% of total water usage in spring 2014, with 80% of total water abstraction for agriculture taking place in the Mediterranean region: whilst the total irrigated area in southern Europe increased by 12% between 2002 and 2014, the total harvested agricultural production decreased by 36% in the same period in this region (EEA, 2017). Building on the Water Scarcity and Droughts Communication, the Blueprint to Safeguard Europe's Water Resources outlines actions that concentrate on better implementation of current water legislation and integration of water policy objectives into other policies. It addresses the need for more quantitative water management, including the identification and implementation of the concept of ecological flow, as well as a legal framework for addressing illegal abstraction of water.

Notwithstanding the complexity of causal relationships associated with deteriorating water quality (Grizzetti et al., 2017), high N inputs to agricultural systems in many regions of the EU has resulted, inter alia, in the leaching of nitrogen to groundwater and surface waters (Velthof et al., 2009), setting off a cascade of environmental and human health problems (Erisman et al., 2008; Galloway et al., 2008) at a high societal cost (Van Grinsven et al., 2012, 2014). The Nitrates Directive (91/676/EEC) (European Union (EU, 2000) aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices. Surface freshwater and groundwater should be considered affected by nitrate pollution when their nitrate contents exceed 50 mg l^{-1}, necessitating the designation of nitrate vulnerable zones (NVZ). The Water Framework Directive (WFD), (Directive 2000/60/EC) requires MS to draw up River Basin Management Plans to safeguard the 110 river basins across the EU. Under the WFD, all surface waters are required to achieve good ecological and chemical status, while high status waters must be maintained in this condition.

2.2.2.2. Metrics for the societal demand for water regulation and purification. Flood mitigation: under the Flood Directive, MS are required to make Flood Risk Management Plans every 5 years; they are free to set targets to reduce flooding in the various categories (various severity classes / return frequencies). But these targets are only partially and weakly related to soil management in agricultural areas, which makes it difficult to derive meaningful and spatially explicit metrics for the for societal demand for flood mitigation. Therefore, no demand metric was produced.

Droughts: we considered three demand metrics for the societal demand for drought mitigation:

- Drought frequency, severity and duration statistics, based on Spinoni et al. (2016) and Jonathan et al. (2018);
- The qualitative likelihood of impact occurrence by Blauhut et al. (2016);
- The crop water deficit, i.e. the difference between the crop-specific water requirement and the water available through precipitation.

Of these metrics, only the crop water deficit allows for the spatially explicit mapping of the agricultural demand for water as computed by the EU Joint Research Centre using WOFOST crop simulation model (Peltonen-Sainio et al., 2016; De Wit et al., 2018) at a 25 km resolution (see e.g. https://www.eea.europa.eu/data-and-maps/indicators/water-requirement-2/assessment). Because this crop water deficit simulation does not take irrigation into account, it is an appropriate proxy for the total irrigation demand.

Water purification: EU MS have established Nutrient Management Plans (NMPs) to meet requirements under the Water Framework Directive and Nitrates Directive with a view to minimising surpluses of agricultural N and phosphorus (P). We modified the "Gross nutrient balance on agricultural land" (t2020_rn310) as the overarching metric for Water Quality regulation. The metric is part of the Resource Efficiency Scoreboard and is used to monitor progress towards a resource efficient Europe (i.e. the implementation of the Europe 2020 Resource Efficient Flagship initiative) on the key thematic objective of 'Land and soils' (see e.g. http://ec.europa.eu/eurostat/cache/metadata/en/t2020_rn310_esmsip2.htm and http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aei_pr_gnb&lang=en). The metric measures the potential threat to the environment of N and P surpluses or deficits in agricultural soils. Land types included are arable land, permanent crops and permanent grassland. These nutrient balance calculations are available for NUTS1 through the Eurostat databases (Şaban Özbek et al., 2015).

Because certain losses of nitrogen to the environment are unavoidable in agricultural systems (Uwizeye et al., 2016, we define the demand for water purification as the amount of the nitrogen surplus that must be mitigated to ensure that the net nitrate concentrations of the receiving waterbodies stays below the maximum allowable concentration of 50 mg l^{-1} of nitrate (corresponding to 11.3 mg l^{-1} of nitrate-N). This demand can be calculated as: $\Delta N - 0.113 * Er$, where ΔN represents the nitrogen surplus and E_r represents effective rainfall calculated as precipitation less evapotranspiration 2005–2015 derived from the MARS Agriforecast Toolbox provided by the European Commission (http://agri4cast.jrc.ec.europa.eu/).

2.2.3. Carbon sequestration and regulation

2.2.3.1. Policy objectives. Climate change is a global challenge, where causes and impacts are spatially connected at planetary level. Therefore, the societal demand for carbon sequestration is framed in the first instance by the United Nations Convention on Climate Change (UNFCCC), supported by the Intergovernmental Panel on Climate Change (IPCC). The most recent policy objectives are framed in the Paris Agreement (2015), and include a target to limit global temperature rise to 2 degrees C, with an aspiration to a limit of 1.5 degrees C. Countries commit to Independent Nationally Determined Contributions (INDCs), which are expected to expand in ambition over time, as new technologies and practices become available. The EU participates in the UNFCCC negotiations as a single bloc.

EU policies are framed by the EU Roadmap for a 2050 low-carbon economy (European Commission (EC, 2011), which is consistent with the Paris Agreement and sets out the overall goals and ambition for the EU as follows:

- by 2050, the EU should cut greenhouse gas emissions to 80% below 1990 levels
- Milestones to achieve this are 40% emissions cuts by 2030 and 60% by 2040
- All sectors need to contribute

For agriculture, the EU Roadmap states:

"As global food demand grows, the share of agriculture in the EU's total emissions will rise to about a third by 2050, but reductions are possible. Agriculture will need to cut emissions from fertilisers, manure and livestock and can contribute to the storage of CO_2 in soils and forests. Changes towards a more healthy diet with more vegetables and less meat can also reduce emission."

In practice, this means that agricultural emissions are projected to be reduced by approximately 50% by 2050, compared to 1990.

In the medium term, the recent EU Climate and Energy Framework for 2030 (for the period 2021–2030) sets targets of a 43% reduction in greenhouse gas (GHG) emissions for the Emission Trading Sectors (ETS) and -30% for the Non-Emission Trading Sectors (non-ETS), which includes the agricultural sector and the Land Use, Land Use Change and Forestry (LULUCF) sector. This overall EU target is differentiated by MS, and translates into specific targets for the Non-ETS sectors of individual MS (Supplementary Material, Table S3).

Agricultural emissions relate to a basket of gases, mainly methane, nitrous oxides and carbon dioxide. As a result, the mitigation of agricultural emissions requires a concerted approach to animal management, crop management and soil management that is context specific for individual countries (Eory et al., 2018). For soil management, the policy discourse has recently focussed on the preservation and potential for further storage of soil carbon through a reduction in the emissions that result from drained wetlands, as specified in the IPCC wetlands supplement (IPCC, 2014) and land degradation, or the augmentation of carbon sequestration (see e.g. Schulte et al., 2016; Rumpel et al., 2018).

In contrast to the EU Climate and Energy Package for 2020, the new 2030 Framework allows for the preservation and sequestration to be (partially) accounted in the form of LULUCF credits in meeting Non-ETS targets, subject to strict conditions. This is known as the "flexibility" mechanism. Each MS has been allocated a maximum amount of credits that can be included from the land use sector to the Effort Sharing Regulation (Supplementary Material Table S3). This country-specific amount specifies the maximum amount of soil carbon sequestration that can be used by each MS as a valid climate mitigation strategy for the 2021–2030 period in Europe.

Similar to Kyoto commitments, each MS must ensure that the LULUCF sector in its territory has no net emissions. The proposed regulation on LULUCF contains specific rules for afforestation and deforestation, managed cropland, managed grassland, managed wetland and managed forest land.

2.2.3.2. Metrics for societal demand for carbon sequestration. We selected the maximum amount of C-sequestration that can be accounted for at MS scale as the metric for the societal demand on agricultural land management to contribute to climate change mitigation. The percentages in the right-hand column of Appendix 1 refer to the percentage of total national non-ETS emissions. Therefore, the maximum demand for carbon sequestration (DCS) can be computed for each MS as follows:

$$DCS = \text{Flexibility\%} \times E_{non\text{-}ETS}$$

Where $E_{non\text{-}ETS}$ is the total amount of national non-ETS emissions (Supplementary Material, Table S3).

2.2.4. Biodiversity

2.2.4.1. Policy objectives. The main EU policy frameworks for the preservation and restoration of biodiversity in agricultural areas are the Birds Directive, the Habitat Directive, the Biodiversity Strategy and the CAP.

The Birds Directive (79/409/EEC), adopted in 1979 and amended in 2009 (2009/147/EC), was one of the first environmental legislations of the EU. It focussed on the protection of habitats for endangered and migratory bird species and required MS to designate Special Protection Areas (SPAs). In 1994, these SPAs were incorporated into the Natura 2000 ecological network, established under the Habitats Directive (92/43/EEC), which was aimed at protecting rare and endangered flora and fauna in general.

In May 2011, the European Union adopted a new Biodiversity Strategy in line with the Conference of the Parties to the Convention on Biological Diversity in Nagoya, Japan, in 2010. This EU strategy aims to halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020. However, the 2015 State and Outlook report of the European Environment Agency suggests that these objectives are unlikely to be met since loss of biodiversity and the degradation of ecosystem services have continued since the 2010 baseline. Specifically, the continuing decline in the status of species and habitats associated with agriculture indicates that additional measures may be required.

The CAP addresses the preservation of habitats and biodiversity through two mechanisms:

1 The co-financing of national agri-environmental schemes (under CAP Pillar 2) that facilitate specific measures for the preservation of habitats and biodiversity. Under these voluntary schemes, farmers may adopt environmentally-friendly farming techniques, over and above legal obligations, for a minimum period of at least five years, in return for payments that provide compensation for additional costs and income foregone. Examples of commitments covered by national/regional agri-environmental schemes include low-intensity pasture systems, integrated farm management, organic agriculture, the preservation of landscape and historical features such as hedgerows, ditches and woods and the conservation of high-value habitats and their associated biodiversity.
2 The inclusion of 'greening measures' within the scope of cross-compliance: this innovation, brought in under the 2013 CAP reform makes 30% of the direct income support payments to farmers (under CAP Pillar 1) conditional on compliance with practices that are beneficial to the environment and the climate. These include:
3 crop diversification: this requires at least two crops to be grown on arable farms larger than 10 ha and three crops on arable farms larger 30 ha;
4 maintenance of permanent grasslands in at least 5% of their farmland;
5 the designation of 'ecologically beneficial elements' or 'Ecological Focus Areas', (EFAs) to 5% of the land area (applicable only to farms with over 15 ha of arable land). EFAs may cover a broad spectre of features, including fallow land, field margins, hedges and trees, buffer strips or catch crops or nitrogen-fixing crops.

The effectiveness of these greening measures has been questioned (Pe'er et al., 2014, 2017). Because EFAs apply only to farms with more than 15 ha of arable land, and MS can reduce their required spatial extent to 2.5% or lower in some regions, more than 88% of EU farms are exempted from the regulation, accounting for over 48% of farmed area. Furthermore, EFAs are not required on farms with permanent crops, grasslands, or pastures. The European Court of Auditors (2017) found that greening measure added significant complexity to the CAP as a result of overlaps with other environmental instruments of the CAP, including standards on good agricultural and environmental condition of land (GAECs).

2.2.4.2. Metrics for the societal demand for the preservation of biodiversity. Soil biodiversity (both below- and aboveground) plays a key role in regulating processes that underpin the delivery of a wide variety of ecosystem services. Nevertheless, the lack of a European-wide standardised set of indicators of soil biodiversity and of reference values (Van Leeuwen et al., 2017), as well as an insufficient understanding of the relationships between the various components of soil biodiversity, the different agricultural practices and the delivery of ecosystem

services, renders the mapping of the demand for farmland biodiversity based on soil bio-indicators currently implausible.

Therefore, we used the agri-environmental metric 'population trends of farmland birds'. This is the sole biodiversity-related indicator out of the 28 agri-environmental indicators (AEI) selected by the European Commission (COM/2006/0508fin.l) to monitor the integration of environmental concerns into the CAP.

Birds are recognised as an ecological indicator taxon and are considered to be good proxies for measuring the diversity and integrity of ecosystems as they tend to be at the top of the food chain, present large ranges and the ability to move elsewhere when their environment becomes unsuitable; they are therefore responsive to changes in their habitat.

More specifically we used the 'Common farmland birds' (39 species), which have a high dependence on agricultural habitats in the nesting season and for feeding. The indices are based on data from 26 EU MSs, derived from annually operated surveys of national breeding birds collated by the Pan-European Common Bird Monitoring Scheme (PECBMS). For each MS, we computed the compound annual rate of change of common farmland species at national level. This compound annual rate of change makes it possible to compare the average annual rates of change in countries with different starting and end years of their time series.

2.2.5. Nutrient cycling

2.2.5.1. Policy context. The EU Circular Economy Action Plan, and the linked Directive on Critical Raw Materials (CRM), highlights the need for an integrated approach to raw materials that are deemed essential for the production of a broad range of goods used in everyday life and are crucial for a strong industrial base (Mathieux et al., 2017).

Of the critical raw materials, P is the only one that relates directly to agriculture: it is an essential nutrient for plants, animals and humans and is therefore crucial for all life on the planet - in this context it underpins the bio-economy. The historically abundant availability of P fertilizers has contributed to the decoupling of crop production and livestock production (Uwizeye et al., 2016). This specialisation has resulted in manure (and thus P) applications in excess of agronomic requirements in some regions, and full dependency on mineral fertilizer P in others. This disruption to the cycling of P is compensated for by imports into the EU in the form of animal feed and (feedstocks for) fertilizers. In its natural form, P only exists as phosphate rocks, a finite resource, mainly used for the production of fertilisers (86%), but also for the production of detergents and animal feedstock. The EU is dependent on mined P from concentrated production from three external countries, which represents a significant supply risk.

Building on previous policies concerned with both the environmental impact and future geopolitical consequences of the non-cyclic use of P (Table 3), the Circular Economy Action Plan encourages practices that replace nutrients from primary raw materials with recycled nutrients from waste streams.

2.2.5.2. Metrics for the demand for nutrient cycling. The demand for the soil function 'nutrient cycling' is quantified by estimating the amount of agricultural land needed in the EU as a whole and per individual nuts region, to accommodate the recycling of P present in livestock manures, whilst minimizing accumulation or depletion of P in soils.

Livestock manures: the amount of P can be derived from the sum product of livestock numbers and livestock-specific P excretions. Information on livestock numbers was derived from the Eurostat database: http://ec.europa.eu/eurostat/data/database. Total farm livestock populations were estimated at 147 million pigs, 88 million cattle (~25% dairy cattle), 1.3 billion poultry (mostly broilers and laying hens), 83 million sheep and 10 million goats. Total P excretion by livestock was estimated at 1.8 Mt a^{-1} P and has not changed substantially over the last fifteen years (Sutton and Reis, 2011; Leip et al., 2015; Velthof, 2015; Hou et al., 2016; Van Dijk et al., 2016; Hou et al., 2017). More information on livestock-specific P excretions can be found in Sebek et al. (2014) and Anonymous (2011).

3. Results

Fig. 1 shows the spatial variation in the societal demands for the functionality of agricultural land, specifically for the five soil functions. It shows that for each of these functions, the societal demands vary greatly across the EU. The demand for primary production is loosely related to the regional variation in population density (see e.g. https://ec.europa.eu/eurostat/statistics-explained/images/c/c6/GEOSTAT_population_grid_2011.png). Contrastingly, the demands for water purification and nutrient cycling are loosely related to regional patterns in farming intensity (see e.g. https://ec.europa.eu/agriculture/cap-indicators/context/2017/c33_en.jpg). Spatial patterns for the demands for carbon sequestration and biodiversity are more ambiguous, with the highest demands for the restoration of biodiversity in South-Eastern and Northern MS.

The correlation matrix in Fig. 2 illustrates that the demands for food, fibre and feed are correlated ($p < 0.001$), as are the demands for carbon sequestration, feed and nutrient cycling, all these latter demands relating to the presence of livestock farming. Of equal interest is the lack of correlation between the demands for some of the functions, specifically between the demands for biodiversity and water regulation when compared with the demands for other functions. These latter demands are defined by neither population nor livestock densities, and are instead determined by landscape configurations and the combination of cropping systems and geoclimatic conditions, respectively.

Table 3
European policies related to the environmental impact of the non-cyclic use of phosphorus.

Year	Name	Reference
1986	EU Directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:31986L0278
1991	Nitrates Directive (Council Directive of 12 December 1991 Concerning the Protection of Waters Against Pollution Caused by Nitrates from Agricultural Sources) (91/676/EEC)	http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31991LO676. Accessed: 06/06/2017
1991	Waste Water Directive	http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31991L0271
2000	Water Framework Directive	http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060
2008	Waste Directive	http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0098
2015	Closing the loop: an EU action plan for the circular economy.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614
2017	Report on the implementation status and programmes for implementation of Council directive concerning urban waste water treatment.	http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2017:749:FIN
2017	Review of waste policy and legislation.	http://ec.europa.eu/environment/waste/target_review.htm
2018	Report on critical raw materials and the circular economy	http://ec.europa.eu/docsroom/documents/27348

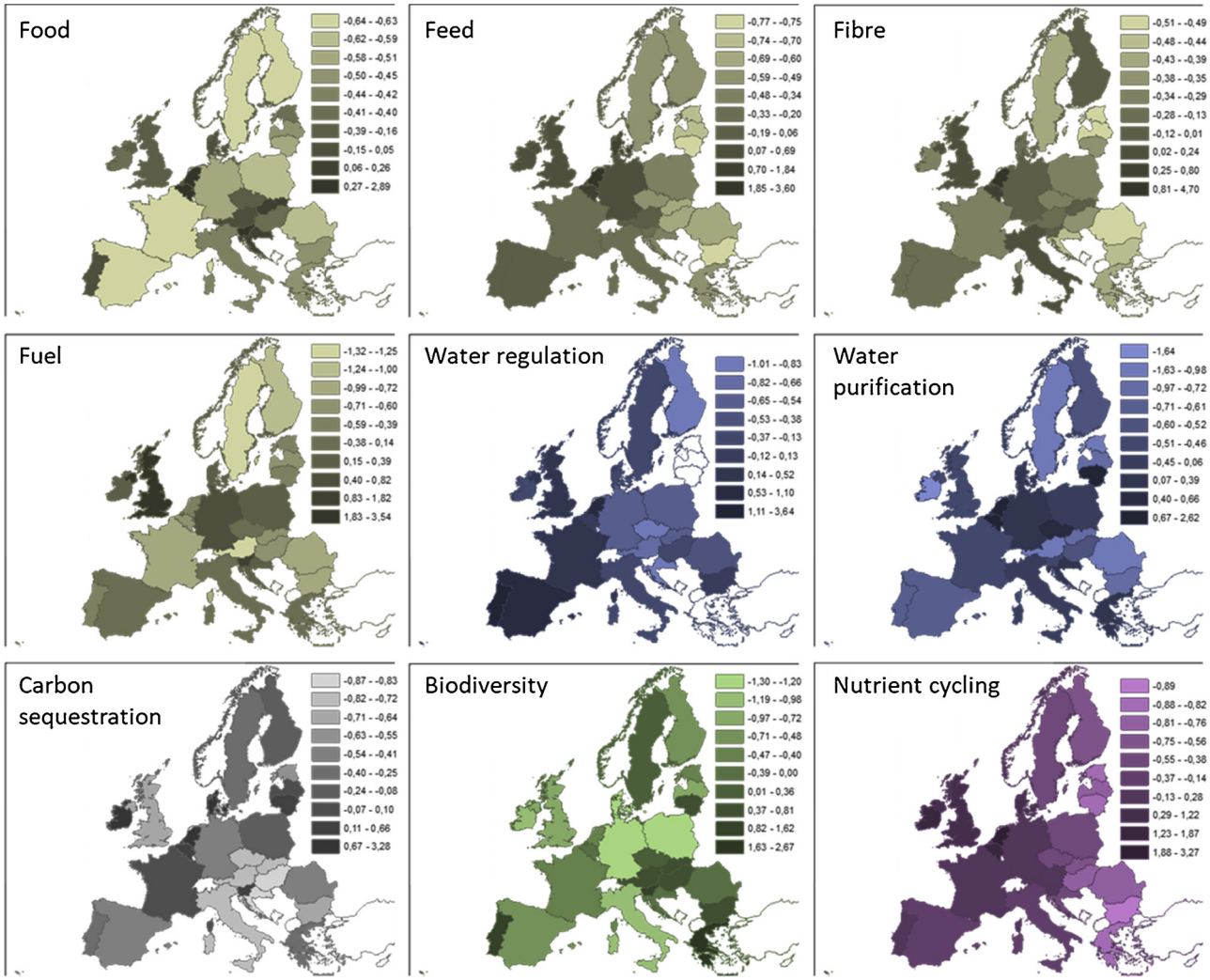

Fig. 1. Distribution (z-scores) of societal demands for the five soil functions: primary production (composed of the societal demands for food, feed, fuel and fibre), water regulation and purification, carbon sequestration, biodiversity and nutrient cycling. Darker shades areas indicate a higher-than-average demand, while paler shades indicate a lower-than-average demand. White areas indicate no data available.

4. Discussion

4.1. Constraints

In this assessment, we simplified each societal demand to one or two metrics per soil functions or EU policy. In practice, policies, as well as the associated demand metrics, are intertwined. For example, the WFD aims to achieve "good quality status" for all waterbodies across Europe. "Good quality" is benchmarked against both chemical and biological criteria, which in turn are composed of multiple indicators. Chemical indicators include both the nitrate and the phosphorus content (and their temporal dynamics) of waterbodies, which are, inter alia, a function of nutrient balances on land. These same nutrient balances are also pivotal in determining the demand for nutrient cycling (the fifth soil function). Similar linkages exist between the demands for nutrient cycling and primary production, with the former being a precursor to the latter (Schröder et al., 2016). In order to avoid double accounting in the computation of z-scores, we disentangled the societal demands for nutrient cycling by pragmatically attributing the nitrogen balance to computations for the demand for water purification, and the phosphorus balance to the assessment of the demand for nutrient cycling.

Secondly, our assessment was limited to societal demands for soil functions that are mediated by soil and land management. While land management is a pivotal interface between agriculture and the environment. Agri-environmental management comprises more than land management alone. For example, reductions in emissions of ammonia or greenhouse gases other than CO_2 typically require changes to farm management practices unrelated to soils (e.g. Eory et al., 2018). The societal demand for soil functions presented in this paper is therefore part of, but not synonymous with, the societal demand for ecosystem services in general.

Finally, we applied our assessment at MS scale, which may hide regional variation and 'pressure points', for example for the demand for the function nutrient cycling, as well as regional variation in the environmental conditions, such as the rainfall surplus used for the computation of the water purification function. The project "Regionalisation of Gross Nitrogen Balances with the CAPRI model" (RegNiBal) provides methodological information on the gross nutrient balance for HSMU (Homogeneous Soil Mapping Units). The objective of the pilot project was to evaluate differences between national Eurostat/OECD GNB figures and the GNB figures calculated using CAPRI, and to assess the feasibility of using the CAPRI model to (operationally) provide regional GNB data to complement the national GNBs. The report indicates that Regional GNB estimations produce more accurate results than the national estimations, especially for countries that experience different climates or have regionally differing agricultural production systems (Şaban Özbek et al., 2015; Leip et al., 2015).

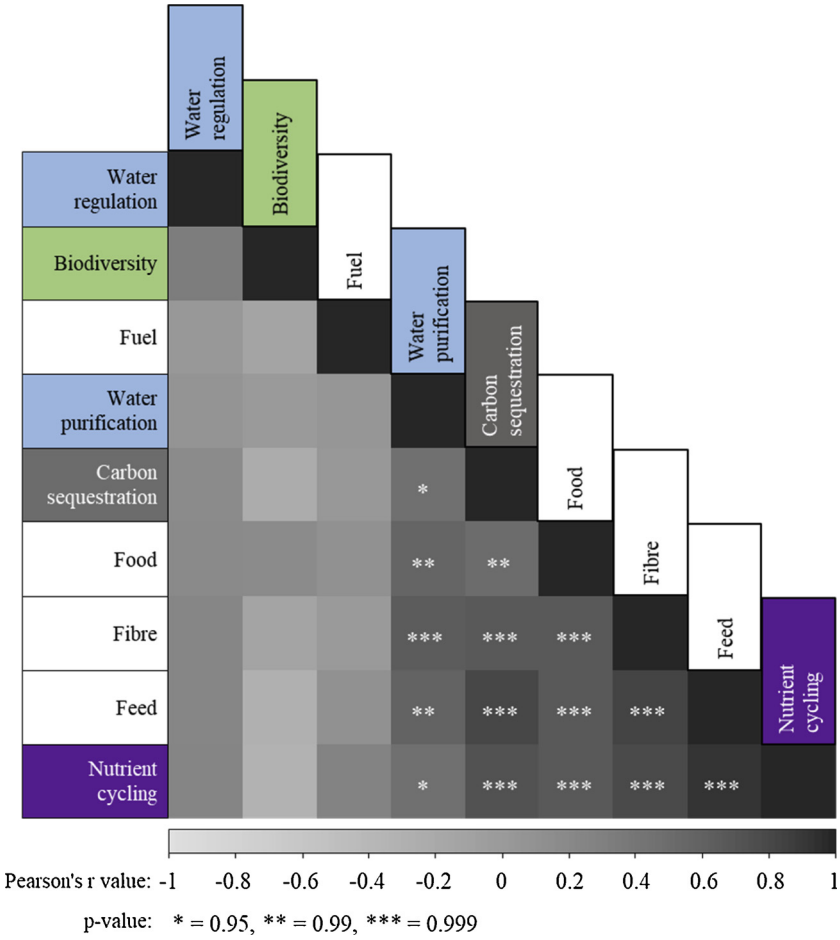

Fig. 2. correlation matrix of the societal demand for the five soil functions.

4.2. Implications for the new CAP and Strategic Plans

The purpose of this exercise, therefore, is not to pinpoint specific geographical areas that fall short of meeting EU policy objectives; rather, our aim is to guide policy making and elucidate relative priorities for land management for individual MS. This approach is consistent with the objectives of the European Commission in the development of a framework for 'Land as a Resource', in particular in addressing the gap between demand and availability of land and by setting synergies and trade-offs between land uses and functions (Deloitte, 2014).

Fig. 3 illustrates this point by showing the heterogeneity in the relative demand for each of the soil functions across Europe. For example, the challenges of meeting societal demands in Portugal, Ireland, Greece and the UK are of markedly different natures, and suggest prioritisation of the land functions water regulation, carbon sequestration, biodiversity and primary production (specifically biofuel), respectively. Also, differences in the overall challenge of meeting all societal demands become clear, with very large demands placed on farmers in the Netherlands, and to a lesser extent Belgium. By and large, the challenge of meeting multiple policy demands is lower in newer MS, with the exception of Slovenia.

The same figure shows the relative spending on the second pillar of the CAP for each MS over the period 2014–2018, as a fraction of total expenditure (Pillars 1 and 2, including national co-financing contributions), based on figures compiled by ECORYS (2016) and the European Commission (https://ec.europa.eu/agriculture/sites/agriculture/files/cap-funding/budget/mff-2014-2020/mff-figures-and-cap_en.pdf), and excluding small MS such as Malta and Luxembourg with CAP expenditure < 1bn. This second pillar is "designed to support rural areas of the Union and meet the wide range of economic, environmental and societal challenges of the 21st century." A higher degree of flexibility (in comparison with the first pillar) enables regional, national and local authorities to formulate their individual seven-year rural development programmes based on a European 'menu of measures' (http://www.europarl.europa.eu/factsheets/en/sheet/110/second-pillar-of-the-cap-rural-development-policy). This flexibility suggests that these national programmes can be considered harbingers of the national Strategic Plans to be developed as part of the new CAP 2021–2027. In this context, it is striking that MS in which the societal demands, equating to the challenges associated with meeting EU policy objectives, are below average for at least four of the five functions, have consistently (with the exception of Spain) dedicated more than 25% of their CAP expenditure to Pillar 2 payments. Conversely, the lowest expenditure on Pillar 2 can be observed in MS in which farmers are faced with multiple above-average demands, with the Netherlands, Denmark and the UK notably devoting less than 25% to the rural development programmes under the current CAP.

Whilst no causality can be implied from these correlations (for example, new MS may have allocated a larger amount of Pillar 2 funding for the purposes of regional economic development, rather than for the purpose of incentivising environmentally sustainable land management (Matthews, 2018a), valuable lessons may be drawn for the design and implementation of the Strategic Plans under the next CAP. In the draft Strategic Plans regulation proposed by the Commission, the "higher environmental and climate action ambition" is proposed to be secured through a three-pronged approach (Matthews, 2018b):

1 Enhanced conditionality: enhancing the effectiveness of the cross-

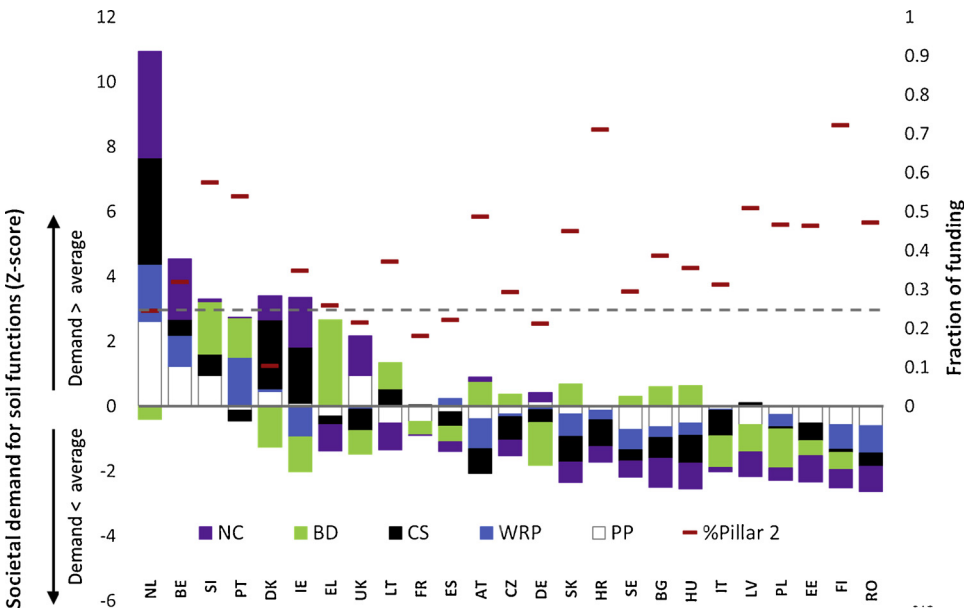

Fig. 3. Relative demand for soil functions from agricultural land among EU MS (left axis), and relative expenditure on Pillar 2 schemes by each MS (dashed line = 25%). NC = Nutrient Cycling, BD = Biodiversity, CS = Carbon Sequestration, WRP = Water Regulation and Purification, PP = Primary Production. P1 = Pillar 1; P2 = Pillar 2. NL = Netherlands, BE = Belgium, SI = Slovenia, PT = Portugal, DK = Denmark, IE = Ireland, EL = Greece, UK = United Kingdom, LT = Lithuania, FR = France, ES = Spain, AT = Austria, CZ = Czech Republic, DE = Germany, SK = Slovakia, HR = Croatia, SE = Sweden, BG = Bulgaria, HU = Hungary, IT = Italy, LV = Latvia, PL = Poland, EE = Estonia, FI = Finland, RO = Romania.

compliance regulations for the single farm payment by modification of measures (e.g. replacing crop diversity with crop rotation), the introduction of new measures (e.g. the protection of carbon-rich soils) and the removal of current exemptions to the greening requirements;

2 The continuation of agri-environmental and climate measures (AECM) schemes under Pillar 2; these schemes will be mandatory for MS to offer to land managers as voluntary measures. Funding is limited to compensating for 'costs-incurred' and must be co-financed by MS;

3 The introduction of a new 'eco-scheme' in Pillar 1 which, similar to the AECMs, must be offered by MSs as voluntary measures to farmers. In contrast to the AECM scheme, funding under this eco-scheme can be offered as income support, limiting eligibility to those meeting the 'active farmers' definition, defined by MS.

The rationale behind having both an AECM scheme under Pillar 2 and an eco-scheme under Pillar 1 is as of yet unclear (pers. comm. Allan Matthews), other than that it permits larger expenditure on environmental and climate initiatives without necessitating large budgetary transfers between Pillar 1 and Pillar 2. Of particular relevance here is the planned 15% reduction in co-financing on Pillar 2, as opposed to single digit reductions for Pillar 1, (Matthews, 2018), with the expectation of increased national contributions to the AECMs.

This allows MS two pathways to facilitate farmers in meeting the societal demands for soil functions: 1) by formulating attractive eco-schemes and 2) by increasing national contributions to AECMs. The success of these schemes in delivering on the "higher ambition for environmental and climate action" will depend on their design and implementation of the Strategic Plans. The design of these plans may be augmented if they are cognisant of the relative priorities in the demand for soil functions in each of the MS, and when they selectively incentivise land management practices that promote the synergistic delivery of those soil functions for which demand is highest.

However, while many synergies exist between management practices for augmenting soil functions, e.g. between nutrient cycling and primary production, nutrient cycling and water purification and biodiversity and soil carbon sequestration, trade-offs between management practices also occur, which makes it difficult to augment *all* functions on *all* soils for *all* farm systems. Neither may this be necessary: while all policy objectives must be delivered at MS level, this may be achieved by a composite of actions at farm scale or regional scale that are aimed at meeting individual policy demands. The scale of management is typically defined within the policy demand and is reflective of the extent to which competing demand can be off-set. For example, within the Nitrates Directive, all farmers in Nitrate Vulnerable Zones are expected to manage nutrients with a view to maintaining nitrate concentrations below 50 mg l^{-1}. In contrast, national carbon sequestration targets must be met at larger scales and so incentivisation schemes to respond to this challenge can be managed at the regional or national scale. The proposed formulation of Strategic Plans at national level provides an opportunity to target incentives towards soil/land use combinations that are best placed to deliver on the local or national societal expectations.

To aid the process of optimising the utilisation of land as a resource, the LANDMARK project has developed models that quantify the potential supply of each of the soil functions as dependent on farm type, soil type, environment and management, based on a meta-analyses of European datasets (Henriksen et al., 2018; Rutgers et al., 2018; Schröder et al., 2018; Vrebos et al., 2018; Wall et al., 2018; Wenng et al., 2018). These models are operationalised by the Soil Navigator: a Decision Support Tool (DST) that guides farmers, land managers and extension agents in selecting the most relevant and effective management practices to optimise synergies and minimise trade-offs. It provides straight-forward advice on land management, based on the capacity of the local soil to deliver on the five soil functions, as well as the societal demands for each of these functions, as specified by the user. It thus allows for evidence-based yet low-complexity decision making on sustainable land management.

The subsequent implementation of the Strategic Plans may be aided by the provision of such targeted DSTs in order to meet both the functional and societal demands for soil functions on individual farms. Indeed, as part of the drive to make greater use of knowledge and innovation, national rollout of such DSTs is a mandatory requirement for MSs under the new proposed enhanced conditionality measures. The delivery of such tools that synthesise and translate the complexities of the interactions between soils, environment, policy requirements and land management into advice to practitioners is currently subject to further studies by the LANDMARK consortium (O'Sullivan et al., 2019b).

5. Conclusions

We conclude that land managers in the EU are operating in a

complex policy and regulatory environment, that manifests itself in a myriad of EU and national regulations and voluntary schemes relating to the sustainable management of land. The current review of the EU agricultural policy seeks to simultaneously simplify this regulatory environment and raise the ambition for safeguarding environmental sustainability and climate action, through the development of targeted Strategic Plans at national level, which allows for a more targeted and context-specific approach to incentivising sustainable land management practices.

In this paper, we have demonstrated that:

- The societal demands for the five functions that our land provides vary between MSs, allowing for a degree of targeting in the Strategic Plans (put simply: different countries may prioritise different functions from the land);
- The aggregated societal demand for all soil functions differs between MSs, with lowest demands found in countries that currently designate the highest percentages of EU CAP funding to Pillar 2 expenditure, which is associated with higher (relative) rates of national exchequer co-funding; this may provide valuable lessons for countries with higher societal demands for soil functions.

The CAP proposals for the period 2021–2027 provide an opportunity for MSs to design schemes that can specifically target those challenges that represent key areas for concern and are likely to cost national exchequers in fines should they not meet their prescribed targets. The challenge thus is for MS to make these schemes sufficiently attractive to stimulate farmer uptake. The new design allows schemes to be tailored to better fit their context, which provides an opportunity to engage experts in priority areas for their design at MS level.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2019.06.011.

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