Grantham Research Institute on Climate Change and the Environment

Centre for Climate Change Economics and Policy

Distributional issues in natural capital accounting: An application to land ownership and ecosystem services in Scotland

Giles Atkinson and Paola Ovando

November 2020

Centre for Climate Change Economics and Policy Working Paper No. 382
ISSN 2515-5709 (Online)

Grantham Research Institute on Climate Change and the Environment Working Paper No. 354
ISSN 2515-5717 (Online)

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

The Grantham Foundation for the Protection of the Environment

University of Leeds

LSE The London School of Economics and Political Science

The Centre for Climate Change Economics and Policy (CCCEP) was established by the University of Leeds and the London School of Economics and Political Science in 2008 to advance public and private action on climate change through innovative, rigorous research. The Centre is funded by the UK Economic and Social Research Council. Its third phase started in October 2018 with seven projects:

1. Low-carbon, climate-resilient cities
2. Sustainable infrastructure finance
3. Low-carbon industrial strategies in challenging contexts
4. Integrating climate and development policies for 'climate compatible development'
5. Competitiveness in the low-carbon economy
6. Incentives for behaviour change
7. Climate information for adaptation

More information about CCCEP is available at www.cccep.ac.uk

The Grantham Research Institute on Climate Change and the Environment was established by the London School of Economics and Political Science in 2008 to bring together international expertise on economics, finance, geography, the environment, international development and political economy to create a world-leading centre for policy-relevant research and training. The Institute is funded by the Grantham Foundation for the Protection of the Environment and a number of other sources. It has 11 broad research areas:

1. Climate change adaptation and resilience
2. Climate change governance, legislation and litigation
3. Environmental behaviour
4. Environmental economic theory
5. Environmental policy evaluation
6. International climate politics
7. Science and impacts of climate change
8. Sustainable finance
9. Sustainable natural resources
10. Transition to zero emissions growth
11. UK national and local climate policies

More information about the Grantham Research Institute is available at www.lse.ac.uk/GranthamInstitute

Suggested citation:
Atkinson G and Ovando P (2020) *Distributional issues in natural capital accounting: An application to land ownership and ecosystem services in Scotland*. Centre for Climate Change Economics and Policy Working Paper 382/Grantham Research Institute on Climate Change and the Environment Working Paper 354. London: London School of Economics and Political Science

Distributional issues in natural capital accounting: An application to land ownership and ecosystem services in Scotland

Giles Atkinson(1)*, Paola Ovando(2),

(1) Department of Geography and Environment and Grantham Research Institute for Climate Change and Environment, London School of Economics and Political Science, UK
(2) Social, Economic and Geographical Sciences Group (SEGS), The James Hutton Institute, Scotland, UK.

November 2020

Abstract: Accounting for *ecosystems* is increasingly central to natural capital accounting. What is missing from this is an answer to questions about how natural capital is distributed. That is, who consumes ecosystem services and who owns the underlying asset(s). In this paper, we examine the significance of the ownership of natural capital – specifically, land which provides ecosystem services – in the context of natural capital accounting. We illustrate this in an empirical application to two ecosystem services, a range of ecosystem types and land ownership in Scotland, a context in which land reform debates are longstanding. Our findings indicate the relative importance of private land in ecosystem service supply, rather than land held by the public sector. We find relative concentration of ownership for land providing comparatively high amounts of carbon sequestration. For air pollution removal, however, the role of smaller to medium sized land holdings closer to urban settlements becomes more prominent. We discuss the implications of our findings for evolving debates about agricultural and environmental policy in the UK. More generally we argue the contributions in this paper represent important first steps in connecting natural capital accounting to broader concerns about disparities of income and wealth across and within countries.

Key words: distribution, ecosystem services, equity, natural capital accounts, landownership, Scotland.

JEL: Q56, Q57

Acknowledgements: Giles Atkinson acknowledges support from the Grantham Foundation for the Protection of the Environment and from the ESRC Centre for Climate Change Economics and Policy. Paola Ovando acknowledges the financial support of the Macaulay Development Trust though the Fellowship on Natural Capital. The authors thank Keith Matthews, Kirsty Blackstock, Annie McKee, and Michela Faccioli for their valuable comments and suggestions to the early version of this manuscript, and Gianna Gandossi for providing mapping support. Authors also thank the feedback from the participants of the Natural Capital Accounting session at the EAERE 2020 conference, and the participants of the DEFRA lunch Seminar 16.07.2020. This paper reflects only the authors views and not the views of the supporting institutions.

1. Introduction

Natural capital accounting (NCA) describes a body of statistical work that seeks to construct better metrics of nature for policy. While there is no hard and fast definition of what NCA is, at its core is an emphasis on measuring flows – i.e. typically called ‘ecosystem services as well as the underlying ‘natural capital stocks giving rise to these outputs. A connection to national accounting principles and practice is also a prominent theme (e.g. Obst and Vardon, 2014; Obst *et al*. 2016).

A core of this work has focused on *ecosystems*.[1] Barbier (2011) defines natural capital in this context as the physical area of a recognisable ecological landscape. For practical purposes this is typically interpreted as referring to broad (ecosystem) habitat types. A comprehensive framework for ecosystem accounting can be found in UN (2014). This sets out Experimental Ecosystem Accounts, as a component of the United Nations System of Environmental and Economic Accounts (i.e. the UN SEEA-EEA). A revised SEEA-EEA (UN, 2020) is to be published by the end of 2021, with an ultimate objective being its establishment as a statistical standard.

A growing number of countries have set these statistical processes for ecosystem accounting in motion (see, for a review and discussion, Heins *et al*., 2020). It is such efforts that we describe as NCA in this paper. The promise of these natural capital accounts is that they will provide important information about the value of natural capital and can be used to support public policy and land-use management decisions (see, for example, Helm, 2019). Increasingly NCA has considered the degree of spatial detail that is needed to make good on this promise (e.g. Bateman *et al*. 2011; Ovando *et al*. 2017; McVittie and Gleck, 2019; Faccioli *et al*. 2020). In the current paper we focus on a different spatial dimension that has so far been neglected in NCA: how natural capital is distributed amongst institutional actors (i.e. people and organizations).

Our contribution, in this paper, is two-fold. First, we show the relevance of distributional issues with regards to accounting for ecosystem assets and services. To the best of our knowledge, this is the first paper to make this connection to NCA. Secondly, we demonstrate the empirical significance of these concerns using an application to Scotland. Specifically, we account for the distribution of two ecosystem services (carbon sequestration and air pollution removal) across private and publicly held land on which natural capital is located. Our findings indicate the relative importance of private land in the supply of these ecosystem services. However, how natural capital value is distributed by relative size of private landholding depends on the particular ecosystem service examined.

Our starting point in arguing for the significance of distributional issues in NCA is that if natural capital is a critically valuable component of national wealth – as, for example, Helm (2019) compellingly argues – then knowing how that value is distributed is surely relevant as well. Typically, value is understood in terms of the *value to users*: that is, it is conceived as what ecosystem services are worth to the people who consume them. Of course, whether this

[1] Defined as a “… biological community together with the abiotic environment in which it is set.” (Begon *et al*. 2006, p499).

flow of value is sustained is contingent on management by institutions of the underlying factor – natural capital – that produces ecosystem services.

Distributional issues characterize this process of value creation at various points. Perhaps most obviously, where users of ecosystem services are households, questions might arise about how these flows are consumed across different socioeconomic groups (Mullin *et al*. 2018). Meya (2020) shows how the distribution of use of environmental goods (such as ecosystem services) by income group can affect the total value of that good. A further, but different, perspective is that land on which ecological production takes place – giving rise to ecosystem services – may have, in turn, an institutional owner: i.e. be these businesses, public bodies, charitable organizations and trusts or households.

For example, contributions by Cahill (2001), Wightman (1996) and most recently Shrubsole (2019) have sought to map land ownership – for the UK, Scotland, and England respectively. In doing so, these studies have highlighted a concentrated pattern of ownership amongst relatively large landholdings. Christophers (2018) examines the distribution of land across the UK in terms of recent historical trends in public vis-à-vis private ownership.[2] Benra and Nahuelhual (2019) look more specifically at natural capital in a study of two regions of Chile which explores the relationship between farm size (in terms of land area) and associated ownership of on-farm forest ecosystems.

Given that output of ecosystem services is typically unpriced, there is no corresponding income paid as compensation to an institutional holder of land for the provision of ecosystem service flows. In this respect, NCA can be viewed as part of the statistical architecture needed to construct policy responses given this distributional mismatch between users and owners of natural capital (HMG, 2018). But distributional issues within these groupings are also of considerable interest, not least for anticipating the distributional consequences of ensuing policy interventions.

One prominent policy example is payments for ecosystem services – a mainstay of economic contributions to debates about conservation policy (see, for example, Errize-de-Blas *et al*. 2016; Börner *et al*. 2017; Miteva, 2019). As an illustration, in the United Kingdom, a guiding principle of proposals for natural capital policy has been "public money for public goods", where public money refers to payments by government to private landholders and public good is defined to include the social value provided by ecosystem services and biodiversity protection (Bateman and Balmford, 2018).

Substantial attention has been devoted to assessing the effectiveness and efficiency of actual payment schemes (e.g. Börner *et al*. 2017) as well as distributional consequences (e.g. Pascual *et al*. 2014; Lansing, 2014). Concerns about distributional outcomes privileging larger landholders might not be unconnected to concerns about *procedural* justice. For example, institutional arrangements governing land management and ownership are likely to have implications for how distinct stakeholder groups are recognized or heard in decision-making

[2] Christophers (2018) critically assesses the trend from the 1980s of land privatization for which he estimates that about 50-60% of public land (that is, compared to holdings in the late 1970s) has been removed from the balance sheet of the public sector in England and Wales and about 20% in Scotland.

processes that shape the development of, and access to land (Wightman, 1996; Walker, 2012). There are parallels here with concerns articulated in the broader debate about wealth inequality and its measurement (e.g. Boushey *et al*. 2017; Piketty *et al*. 2018).

This rest of this paper is organized as follows. Section 2 sets out the accounting framework for looking at the distribution of natural capital. Section 3 describes our methods and data for our application. Section 4 outlines our findings and reflects on policy implications. Section 5 concludes.

2. Framework for natural capital accounting through a distributional lens

Our empirical focus is on the physical and monetary flow of ecosystem services disaggregated to look at distributional issues. For the most part, our emphasis is on landholders and ownership of land on which natural capital (ecosystem assets) is located. In this section we discuss frameworks for recording these flows in order to assess how natural capital is distributed.

Bright *et al.* (2019) rehearses the framework that, for example, has informed UK statistical processes for NCA and which is consistent with the SEEA-EEA. This starts by identifying the physical stock of a natural capital asset. In the case of ecosystems this typically corresponds to a habitat type (e.g. woodland, semi-natural grassland, farmland and so on). The extent of the stock refers to its quantity (i.e. land area of a specific habitat type). However, assessing the stock might account also for quality via a separate account of the condition of the ecosystem asset.

The ecosystem service flow accounts record those outputs arising from the natural capital asset. These flows initially are recorded in terms of physical units: e.g. tonnes of carbon sequestered, pollutants absorbed (and perhaps associated number of adverse health outcomes averted) and so on. Monetary accounts may follow to record the value of these flows, assuming a suitable price exists to assign to an ecosystem service. If so, then the value of the stock, in monetary terms, can be calculated as the capitalized value of (annual) flows: i.e. the value of the outputs to users of ecosystem services (e.g. ONS, 2020a).

In the UK, as previously mentioned, an evolving body of work undertaken by the Office for National Statistics (ONS) has been based on this framework ONS (2018a). This includes highly aggregated accounts for total natural capital. It also includes a range of more detailed accounts covering: (a) specific habitats providing multiple ecosystem services (e.g. ONS, 2019b); and, (b) cross-cutting accounts for specific ecosystem services across all habitats (e.g. ONS, 2016).

Table 1 provides an example of ongoing work by the UK ONS to measure the aggregate value of natural capital in Scotland and the United Kingdom. Specifically, the data illustrated here refer to the value of flows of ecosystem services (produced by natural capital) in the year 2016 in current GBP (£) in total and in per capita terms. Scotland's share of total UK natural capital appears to be relatively large at least with respect to *provisioning* and *regulating* services. The table also identifies two of these regulating services – carbon sequestration and air pollution removal – that we explore later in this paper.[3]

Table 1: Aggregate Ecosystem Services in Scotland and the United Kingdom in 2016

	Total (£ millions)		Per capita (£)	
	Scotland	**UK**	**Scotland**	**UK**
Provisioning services	2,142	9,874	397	151
Regulating services	794	3,270	147	50
of which:				
-- Carbon sequestration	*721*	*1,760*	*134*	*27*
-- Air pollution removal	*72*	*1,241*	*13*	*19*
Cultural services	779	11,156	144	170
Total	3,715	24,300	688	370

Source: ONS (2019a, 2020a, 2020b). Prices deflated to 2016, from original ONS data.

Notes: Population used to calculate per capita estimates use mid-year estimates. Provisioning services includes: agricultural biomass, fish capture, timber, water abstraction, minerals, fossil fuels, and, renewable energy; Regulating services includes: carbon sequestration, air pollution removal, noise mitigation, and urban cooling; Cultural services includes recreation and amenity.

A natural development of ecosystem service flow accounts is based on a Supply and Use Table (SUT). In *national accounts*, this refers to the resources produced – economic goods and services – and their use by economic units (i.e. institutional units reflecting the various sectors of the economy) (see, UN 2009). In the case of NCA, the emphasis of a SUT is the flow of *ecosystem* services: from where these are supplied and how these are used.

This is illustrated in panel (a) of Figure 1, where ecosystem services might be described in physical or monetary terms. Ecosystem service *supply* is described by ecosystem types/ broad habitat categories (i.e. natural capital, as defined). Ecosystem service *use* indicates how ecosystem services are used by economic/ institutional units as intermediate inputs to businesses (e.g. soil fertility) and final use by households (e.g. air pollution removal and carbon sequestration) and so on.

This format provides the basis for developing important detail for decision-makers with regards to ecosystem service provision and which elements of the economic system are directly dependent on these flows, and to what extent (UN, 2020).[4] Nevertheless, this standard approach remains silent on distributional issues, although this silence can be viewed as preserving: "… a core set of ecosystem accounts to support a wide range of decision-making contexts" (UN, 2020, para. 11.48, p13).

[3] It is worth noting what these values mean. For air pollution removal, this corresponds to the estimated value of health benefits (estimated as avoided health costs) accruing (largely) to those living in Scotland or the UK. For carbon sequestration, it is the value of this service consistent with its contribution to the carbon emissions reduction target adopted by the UK in its carbon budgets.

[4] This, in turn, can be used to explore *indirect* dependencies given that the SUTs can be used as the basis for input-output tables.

(a) Conventional supply and use table for ecosystem services

	ECOSYSTEM SERVICES			ECONOMIC UNITS		TOT. USE
	Prov.	Reg.	Cult.	Intermediate	Final	
ECOSYSTEM SERVICES						
Provisioning						
Regulating,				USE		
Cultural						
ECOSYSTEM/ HABITAT TYPES						
Farmland						
Semi-natural grassland						
Woodland						
Mountain, moor, and hill		SUPPLY				
Freshwater						
Open water, wetland & floodplain						
Coastal margin						
Wildlife (non-urban) areas						
TOTAL OUTPUT						

(b) Extension to landholders

	ECOSYSTEM SERVICES			ECONOMIC UNITS		TOT. USE
	Prov.	Reg.	Cult.	Intermediate	Final	
ECOSYSTEM SERVICES						
Provisioning						
Regulating,				USE		
Cultural						
ECON. UNITS (LANDHOLDERS)						
Private		SUPPLY				
Public						
TOTAL OUTPUT						

Source: Adapted from Vallecillo *et al.* (2019); ONS (2020a)

Figure 1: Illustrative supply and use tables for ecosystem services

A familiar way of looking at distributional issues in relation to national accounts is a Social Accounting Matrix (or SAM) (Mainar-Causapé *et al.*, 2018, UN, 2009). A strength of that approach is that it permits a deep dive into distributional details across the full sequence of accounts in the SNA and provides an illustration, for example, of how income is distributed and redistributed within and between institutional units (such as households, government and so on). For present purposes, however, the most straightforward way of thinking about the distributional issues that we identify is via associated SUTs. This also has the advantage of being aligned with existing frameworks in NCA, thus illustrating how and where the distributional detail we consider in this paper extends this thinking.

Hence, what we propose essentially can be thought of as a cross-classification or an extension of more conventional SUTs that have typically been used in NCA. For example, the picture of ecosystem service use could develop detail on how air pollution removal services are consumed across different households perhaps distinguished by socioeconomic grouping (see section 4.2). Yet, as constructed, the supply portion of panel (a) in Figure 1 does not provide the basis for looking at possible distributional questions with regards to landholders. By assumption, the focus is on ecosystem type as the producing unit. To examine these issues what is needed is an extension or development of the standard SUT for ecosystem services.

This is described in panel (b) of Figure 1. What is changed is the lower portion of the panel, which now describes how ecosystem service supply can be attributed to natural capital on land which has an identifiable landholder such as a legal owner. We distinguish between two broad categories of landholder: those in the private and public sector discussed further in Section 3.

An interpretation of our approach therefore is that it augments the standard Supply Table in panel (a). That is, we cross-classify this standard way of presenting data on the supply of ecosystem services with information on who owns land on which ecosystem types are located. This aligns with the suggestion in UN (2020) and UN (2014, p30) that for policy analysis, ecosystem extent accounts may need to be extended. But whereas there, this is envisaged as contributing to the practical efficacy of policy interventions, we do so to explicate distributional issues with regards to ownership of land, within a NCA framework.

A more prescribed interpretation is that, in effect, we assume that landholders are the institutional owners of ecosystem assets, by token of their ownership of land on which these assets are located. An assessment of distributional issues amounts to a disaggregation of landholding groups within that institutional account. The basis for this is a designation of landholders as suppliers of ecosystem services given this ownership of the factor of production (ecosystem assets) that gives rise to these flows. In turn, flows of ecosystem services might be thought of as a type of secondary production by these institutional units (Vincent, 2015): i.e. in addition to its primary output whether that is, for example, in the agricultural or tourism sectors.[5]

3. Spatial distribution of landownership and ecosystem services in Scotland

The data used to construct land ownership distribution and natural capital accounts for the Scottish case study comprise the period 2015-2017, according to the latest period physical or monetary data are available. Monetary accounts are presented mainly for year 2016. Data used to estimate income distribution by zone covered the year 2014.

3.1 Land cover and use in Scotland

Scotland covers about 8 million hectares of land. Heather and heather grassland, enclosed farm, woodland, and semi- natural grassland are, in that order, the main broad habitats characterizing land *cover* in Scotland (Table 2). In terms of land *use*, agriculture is the

[5] UN (2020) proposes partitioning, for accounting purposes, an ecosystem asset into two parts and assigning each part to a different owner. The partition is based on whether the supply of ecosystem services from the asset SNA benefits are (privately consumed) or non-SNA benefits (publicly consumed). The former are assigned to landholders while the latter are assigned to general government as an "ecosystem trustee". Edens and Hein (2013), Van den Ven *et al*. (2019) and Campos *et al*. (2019) explore the rationale for this approach, and its alternatives.

predominant use in Scotland, accounting for around 70 percent of land, while forest cover is close to 19 percent of Scotland (most of which are coniferous plantations). Urban areas, including town and cities, transport network, infrastructure, industrial and retail sites, in turn account for about 2.5 percent of land use (Scotland's Environment, 2011).

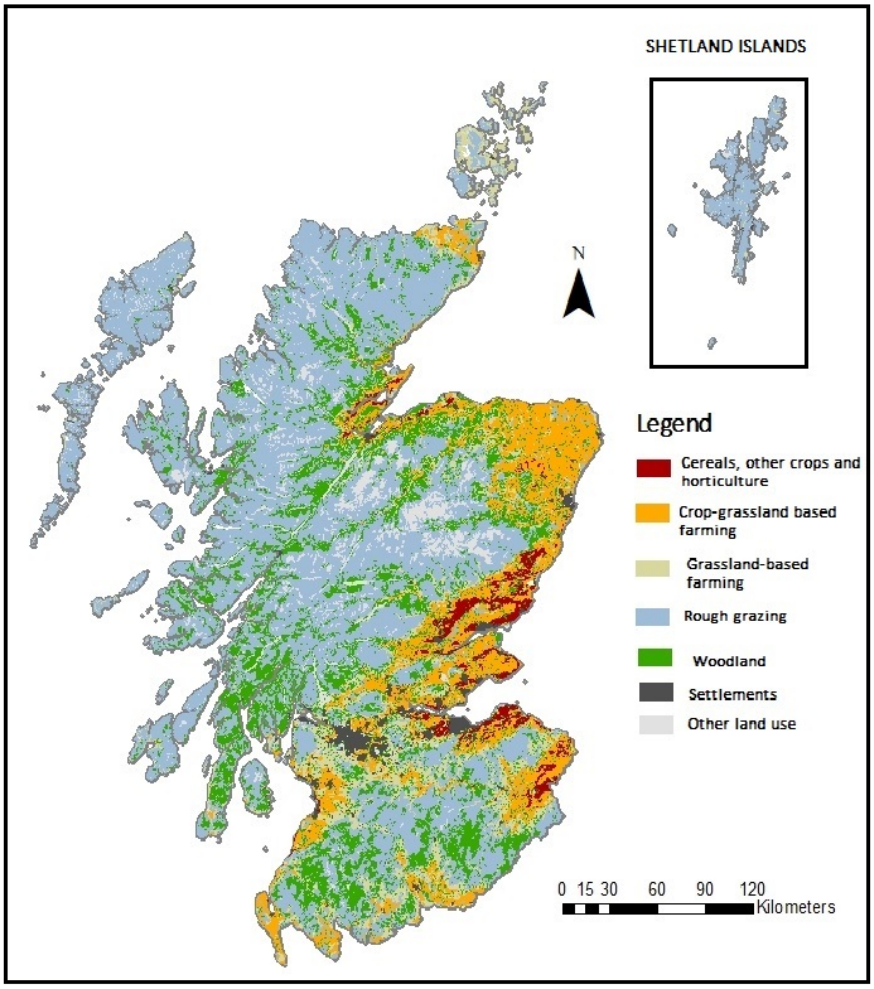
Table 2: Land cover by broad habitat in Scotland

Broad habitat	Closing stock 2015	
	(000 ha)	%
Woodland	1,340	17.0
Enclosed farm	2,043	25.9
Semi-natural grassland	1,213	15.4
Dwarf shrub heath (heather and heather grassland)	2,080	26.3
Bogs	647	8.2
Inland rock	150	1.9
Freshwater and wetland	158	2.0
Coastal margins	87	1.1
Others	174	2.2

Source: *Own elaboration* based on LCM 2015 aggregated data (CEH, 2017).

Figure 2 shows the distribution of agricultural land, woodland, and settlement areas in Scotland. Land more suitable for agricultural cultivation is concentrated in lowland areas of the East coast, and through the central belt and Ayrshire in the South West. Much of the remainder of Scotland is more constrained in terms of agricultural potential (e.g. grassland and rough grazing), as it is at higher altitudes.

Relevant differences in landownership are observed regarding agricultural and forest land cover. About 35 percent of woodland areas in Scotland belongs to National Forest Estate holdings (Forestry Commission, 2018), while most agricultural land is in private hands. Historically, agriculture was carried out on land leased from landowners by tenants. However, tenancy has declined throughout the 20th century, with the latest available Scottish Agricultural Census results indicating that about 1.28 million of the 6.2 million hectares used for agriculture was rented by June 2018 (Scottish Government, 2019a).



Source: *Own elaboration* based on (1) The Land Capability for agriculture copy right and data base © The James Hutton Institute (2018). Used with permission of the James Hutton Institute. All rights reserved; and (2) Scotland's National Forestry Inventory data (2018) (Forestry Commission, 2019). © Crown copyright and data right (2018). Ordnance survey (100021242); and Settlement areas under OS Open data (April 2019). Reproduced with permission under the Open Government Licence v 2.0. Created 28.01.2020.

Notes: (1) Agricultural land use (crop, grassland, and rough pasture areas) in Scotland shows a high correspondence with capability of land for agriculture, as shown in McVittie *et al*. (2019). Figure 1 makes use of a map of land capability for agriculture to estimate the location of broad agricultural land use categories.

Figure 2: Land use distribution in Scotland(1)

3.2 Partial landownership distribution in Scotland

The question of who owns the land and the issues arising from the scale of landownership concentration in Scotland is long-standing and has proved politically contentious.[6] Indeed,

[6] Scotland, historically, has a highly concentrated system of land ownership that is feudal in origin. This feudal system of land tenure formally was brought to an end on 28 November 2004 when The Abolition of Feudal Tenure (Scotland) Act 2000 came into force. This was replaced in law with a system of outright ownership of land.

the persistence of what is viewed by many as a highly concentrated land ownership pattern has contributed to making demands for land reform focal in Scotland. For example, the pioneering 2003 Land Reform (Scotland) Act established statutory public rights of access to land and ensured provisions under which bodies – representing rural and crofting[7] communities – could purchase land (see Combe *et al*., 2020)

More recently, the Land Reform (Scotland) Act 2016 highlights a continued appetite for land reform aimed at a more diverse pattern of landownership and tenure along with financial support for implementation (Combe *et al*. 2020). However, despite these legislative developments, landownership remains highly concentrated in Scotland and continues to be dominated by a small number of private owners. We provide the substance for this claim by presenting next a comprehensive, but partial, picture of land ownership distribution in Scotland.

Table 3: Estimated total and public rural land in Scotland

Class		**Land area**		**Source**
		ha	**%**	
Total land		7,923,165	100.0	Ordnance Survey (2019)
Urban areas	Settlements' boundaries	175,004.8	2.2	NRS (2016)
	Transport network, industry, retail, infrastructure sites	23,000	0.3	Estimated
	Estimated total	198,004.8	2.5	Estimated
Estimated rural land	Estimated total	7,725,161	97.5	Estimated as residual value
Owner	**Property**	**Land area**		**Source**
Total public land	Estimated total	895,294	11.3	
Crown	*Crown Estate*	*35,500*	*0.4*	Elliot et al. (2014:52)
Scottish Government	*National Forest Estate*	*633,859*	*8.0*	Scottish Government (2019b)
	Crofting Estates	*95,200*	*1.2*	Elliot et al. (2014:52)
	Scottish Natural Heritage	*34,435*	*0.4*	SNH (2018)
	Scottish Water	*24,300*	*0.3*	Based on Elliot et al. (2014:52)
	Highlands & Islands Enterprise	*4,000*	*0.1*	
	Estimated Other	*10,000*	*0.1*	
Local Government	*Estimated Total*	*33,000*	*0.4*	
UK Government	*Ministry of Defence*	*25,000*	*0.3*	
Total community land	Community Ownership	209,810	2.6	Scottish Government (2019b)
Rest of land (assumed private)	Estimated total	6,620,057	83.6	Estimated as residual value

Source: *Own elaboration* based on the above referred maps and data sources.

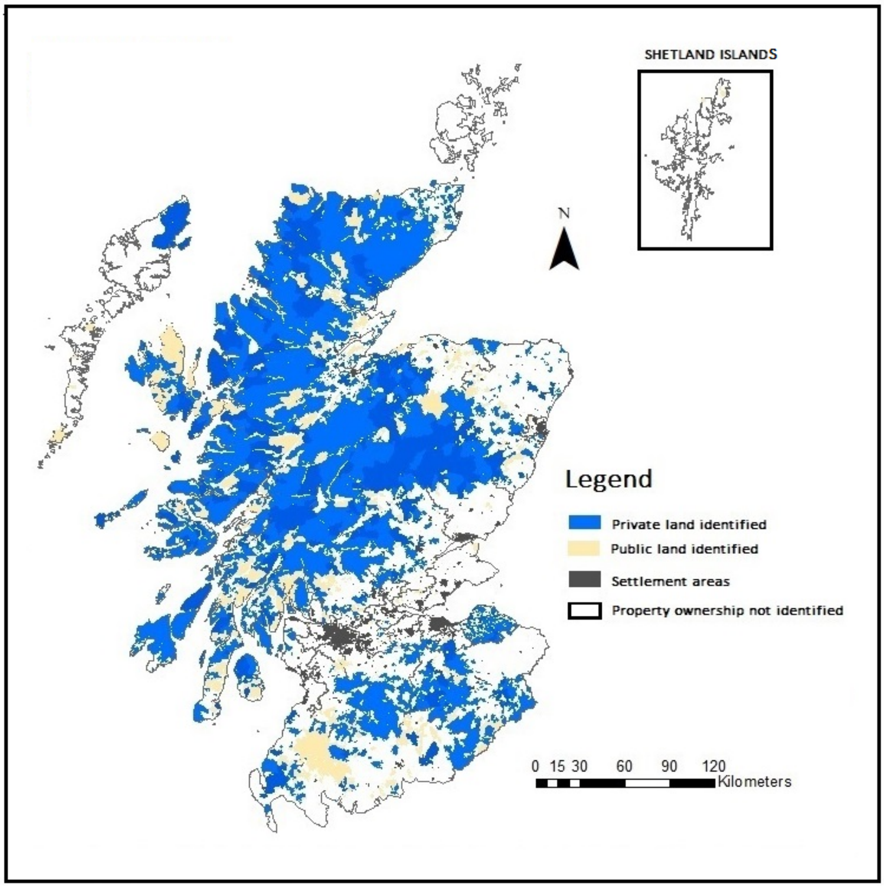
Our landownership distribution picture is partial because important gaps in public records on landownership make it very difficult to be precise about who owns each parcel of rural land in Scotland. This data gap makes even a superficially simple question – e.g. what is the share of rural land that is in private hands? – difficult to answer. What is known, however, is that most land property in Scotland is privately held. Just over 11 percent of land in Scotland is publicity owned: this is mainly held by the Scottish government and to a lesser extent by

[7] Crofting is a traditional social system of landholding characterized by its community network. A croft is a relatively small unit of land ranging from less than 0.5 to more than 50 hectares. (Crofting Commission, 2019).

local government and the Crown Estate (Elliot *et al*., 2014). Community landownership accounts for only 2.6 percent. This suggests a residual value of 83.6 percent of rural land likely being privately owned (Table 3).

We use Andy Wightman's *Who owns Scotland* (2015) database to analyze spatial aspects of landownership distribution in Scotland. This map was developed using a range of methods and information sources, including the raw title deeds held in the National Archives of Scotland, and recordings by the Registers of Scotland in the Register of Sasines[8] and Land Register.

The *Who owns Scotland*'s map covers about 3.9 million hectares of land, representing nearly half of the total land mass in the country. This also accounts for about 60 percent of privately-owned land (an area estimated as a residual value between total land area and public land in Table 3). The share of land covered in the *Who owns Scotland* map varies spatially (see Annex to the current paper section A.1).



Source: *Own elaboration* based on *Who owns Scotland* property map (2015), and National Forest estates map (Scottish Government (2019a), and Settlement areas under OS Open data (April 2019). Reproduced with permission under the Open Government Licence v 2.0. The James Hutton Institute. Created 21.01.2020.

Figure 3: Landownership distribution in Scotland (partial cover)

[8] The Sasine Register is the older type of register in Scotland involving a chronological list of land deeds based on written descriptions of properties (unlike the modern Land Register, which is map-based).

Figure 3 shows the spatial distribution of the private properties recorded in Wightman's map, along with publicly owned land. The latter includes National Forest Estate holdings as well as (albeit only partially) Crown Estate Scotland and Scottish Natural Heritage properties. This figure offers a partial cover of rural landownership, with relatively large parts of the Scottish Islands, the Grampian (North East), Central and South regions of Scotland unmapped.

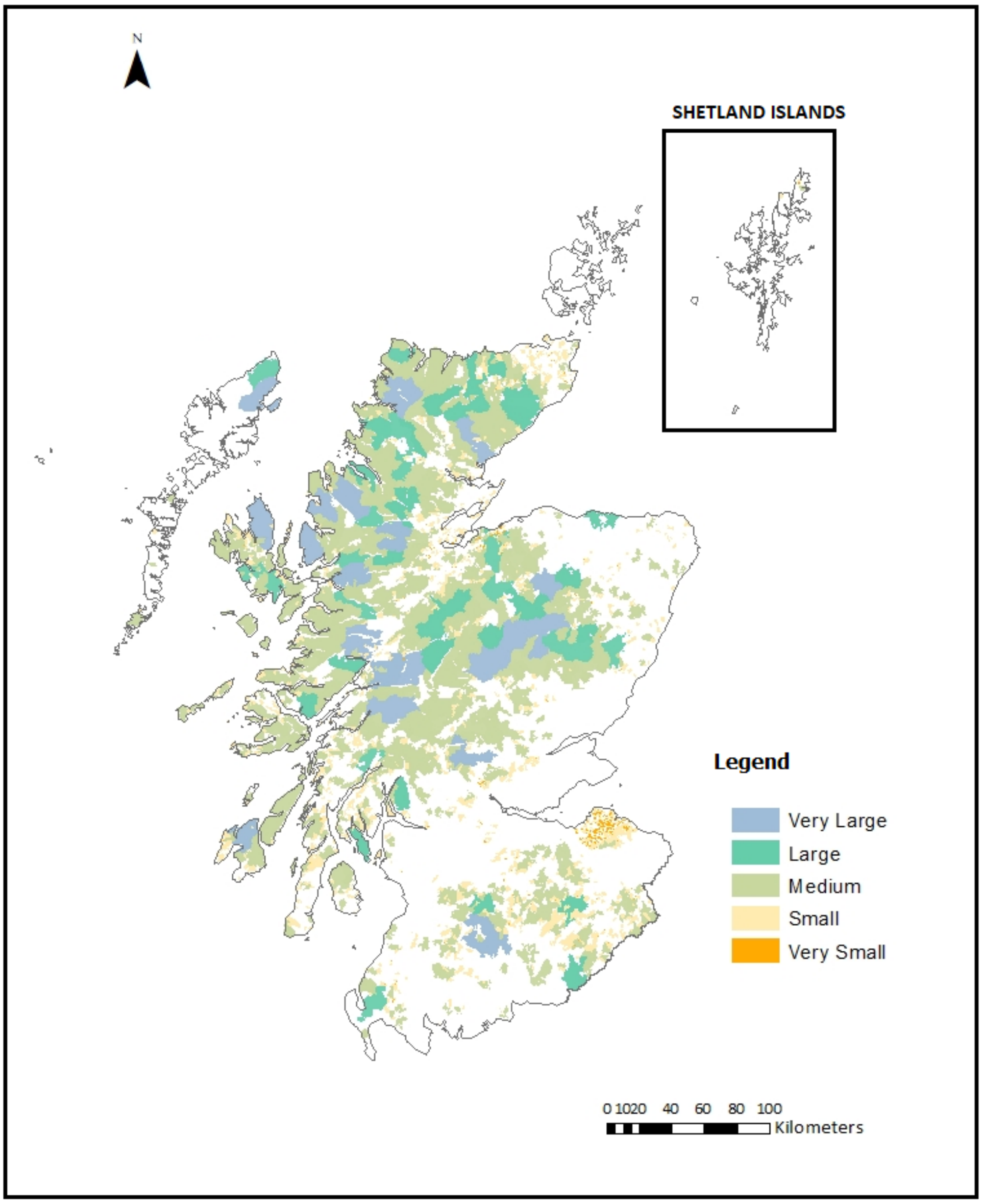
The map in Figure 3 records 2,575 private properties belonging to about 1,735 different private individuals or organizations. About one third of privately-owned land that is mapped belongs to individual landowners with another third belonging to private companies. The remaining land is mainly owned through private Trusts[9] and to a lesser extent by Charities.

The size of rural properties mapped in Figure 3 is relatively heterogeneous, with an average area of 1,513 (±3,518) hectares. About half of the properties have sizes lower than one thousand hectares, although these only cover a combined 12 percent of the private land mapped in the *Who owns Scotland* database. Concentration of landownership in Scotland is further evidenced by the fact that 240 individual owners and 307 companies own 44 percent of total rural land in Scotland.

This latter share of land accounts for medium to very large properties which are distributed across Scotland (Figure 4). Private companies and land owned through Trusts account for most of rural land (80 percent) covered by large to very large properties. In contrast, very small to small properties are mainly owned by individual landowners (Table 4). We also observe that where there are data about landownership in North-East Scotland (mainly the Grampian region) properties tend to be small to medium size in areas dominated by agricultural land uses, while in areas less suitable for agricultural activity, properties are of a medium to very large size class (Figures 2 and 4).

As discussed in Section 2, we now turn to focus on landholders as suppliers of ecosystem services: air pollution removal and carbon sequestration. By necessity, however, our focus is further narrowed on legal ownership whereas a more general approach would look also at all land managers (including tenants as well as landowners making use of their own land). This is a caveat given that the supply of ecosystem services may be more directly connected with land management practices and decisions, not necessarily taken by landowners but by whomever is the land manager.

[9] A Trust is a legal entity created by a party (the trustor) through which a second party (the trustee) holds the right to manage the trustee's assets or property for the benefit of a third party (the beneficiary).



Source: *Own elaboration* based on Who owns Scotland property map (2015), and Settlement areas under OS Open data (April 2019). Reproduced with permission under the Open Government Licence v 2.0. The James Hutton Institute. Created 21.01.2020.

Figure 4: Distribution of private property size in Scotland (partial cover)

Table 4 property size classes do not represent land holding in areas suited for crops (Figure 2). Those areas are dominated by agricultural holdings of less than 100 hectares. It is estimated that 52 percent of holdings account for 1.6 per cent of the total land, comprising 26,830 holdings of less than ten hectares in size (Scottish Government, 2018). These holdings are not included in the analysis. More research is needed in order to complete the landownership and usership database in Scotland. A database such as the Integrated Administration and Control System (IACS), used to support rural payments in the frame of the Common Agricultural Policy (CAP) in Scotland could help in both regards, although it does not cover agricultural holdings of less than 3 hectares, which are more frequent in peri-urban areas.

Table 4: Private land distribution by property size class (partial data for Scotland)

Property size class	Size criteria (ha) [1]	Number of properties		Size of property (ha) [2]		Number of different owners[3]	Total private land area considered	
		Nº	(%)	Mean	SD		Hectares	%
Very Small	<100	611	23.7	36.7	(29.7)	248	22,449	0.6
Small	<1,000	1,238	48.1	392.5	(227.0)	1,063	485,855	12.5
Medium	<10,000	661	25.7	3,285.2	(2,279.0)	592	2,171,528	55.7
Large	<20,000	47	1.8	14,468.8	(2,759.9)	47	680,033	17.4
Very Large	≥20,000	18	0.7	29,853.0	(6,484.1)	18	537,354	13.8
Total		**2,575**	**100.0**	**1,513.5**	**(3,518.5)**	**1,735**	**3,897,219**	**100.0**

Notes: [1] Size criteria proposed by Hindle et al. (2014: 30). [2] Average size per category, standard deviation (SD) in parenthesis. [3] Different landowners considered in Who owns Scotland map. Some landowners own different properties of different size; hence the total number of landowners does to correspond to the sum of the number of landowners by property size class.

Source: *Own elaboration* based on Who owns Scotland map (2015).

3.3 Spatial distribution of air pollution removal and carbon sequestration services

The distributional issues we assess relate primarily to two ecosystem services. One – air pollution removal services – is localized in terms of its impacts on users. The other – i.e. carbon sequestration – is global in terms of the (net) impact on climate stability. While we cannot claim the generality by looking at the distribution of a fuller suite of ecosystem services, this focus on a local service and a global service captures key aspects of the problem. Both of these services are examples of what UN (2014) refers to as *non-SNA benefits*: that is, benefits consumed by individuals which are not obviously the outcome of an economic production process currently defined within the SNA boundaries. These are also public ecosystem services as flows which are (largely) consumed by institutional units other than landholders.

Our empirical focus looks additionally at the production factor – ecosystem assets or ecosystem type – at the heart of the supply of these service flows as well as the way in which these assets effectively are owned by economic institutions who own land which, in turn, can be characterized by ecosystem type.

We turn now to a summary of the data we use for our assessment of the spatial distribution of air pollution removal and carbon sequestration services. Further details can be found in the Annex (see section A.2). A common link here is vegetation in providing both an air quality and a global climate regulating service. The former refers to capturing airborne pollutants and removing them from the atmosphere through internal absorption of pollutants via stomatal uptake as well as the deposition of pollutants on external surfaces such as leaves and bark (Jones *et al*. 2017). The latter refers to uptake of carbon dioxide from the atmosphere and the fixing of this gas as carbon into vegetation structures.

Air pollution removed by broad habitats is estimated by the ONS (2018b) for six pollutants ($PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2 and O_3) across the UK by broad habitat types. The location of vegetation is an important determinant of the quantity and value of air quality regulation it delivers. This is because the amount of service provided depends upon the amount of vegetation, air quality, population, and transport of pollutants. As expected, air quality regulation services are higher in more populated areas, with lower vegetation cover. Figure 5 shows the spatial distribution of air pollutants removal services in Scotland. Where woodlands are present in Scotland, such as in South and South-west of the country (Figure 2), these have the largest impact on air pollutants deposition (especially, for particulates and ozone).

On the other hand, we use the recent report by the Centre for Ecology and Hydrology (Clilverd *et al.* 2019) to estimate net carbon sequestration by forestlands in Scotland. This CEH report provides estimates of both carbon dioxide emissions and removals to and from the atmosphere by local authority in Scotland. Those estimates include (net) carbon removal by forestland and emissions from soils due to land use change *from* and *to* cropland, grassland, and settlements. In that case, our analysis considered average net carbon sequestration values by forest hectare of forest and local authority.

4. Results and Discussion

4.1 Delivery of ecosystem services

Aggregated natural capital accounts for carbon sequestration, indicate that about 71 percent of the physical and monetary value associated with this ecosystem service flow was mainly provided by woodland in 2016. Woodland contributes to 28 percent of air pollution removal services, while enclosed farm, mountainous and moorland areas 23 percent each and semi-natural grassland 17 percent. Considering that most of farmland and more than 50 percent of woodland areas is in private hands, it is expected that a relevant part of ecosystem services is delivered by privately owned land in Scotland.

In what follows in the remainder of this section, we analyze the spatial distribution and the contribution of private and public lands to the provision of air pollution removal by broad habitats and global climate mitigation services (through net carbon sequestration by forest).

Air quality regulation services

Figure 5 shows the spatial distribution of the estimated air pollution removal by pollutant in 2015 in Scotland. This figure shows that absorption and deposition of SO_2, NO_2 and NH_3 is greater is areas which are more densely populated (see settlement areas in Figure 3). The overall air pollution removal value would depend on the pollutant concentration, which is lower in more remote areas (e.g. the Highlands in the North West). Hence, it would be expected that the monetary values (for flow and asset) associated with air pollution removal would be lower when air quality is higher (and vice versa), other things being equal.

The air pollution removal model for vegetation also permits monetary natural capital accounts (Jones *et al*., 2017). It does so by considering health benefits in terms of changes in pollutants exposure and avoided health outcomes at the local authority level (e.g., hospital admissions, losses in life years and deaths). Figure 6a shows the estimated spatial distribution of the monetary value associated with air pollution removal by vegetation. Monetary value is defined in terms of avoided health costs (2015 data updated to 2016 prices) by person and local authority or district in Scotland. The per hectare values in Figure 6(a) consider mid-year population by local authority or district, and spatial distribution of total air pollution removal (weighted by the quantity of pollutant instead of by its toxicity).

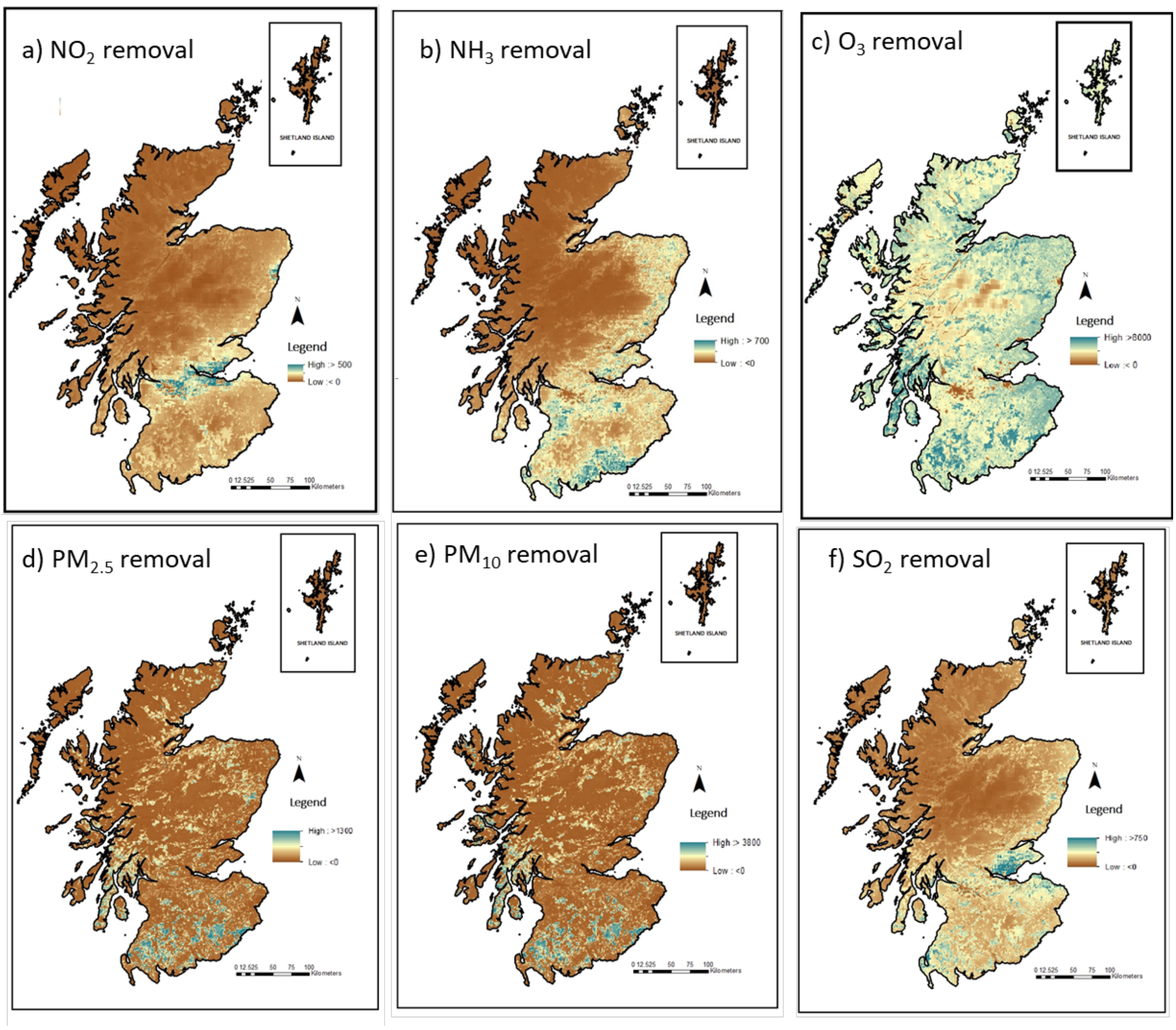
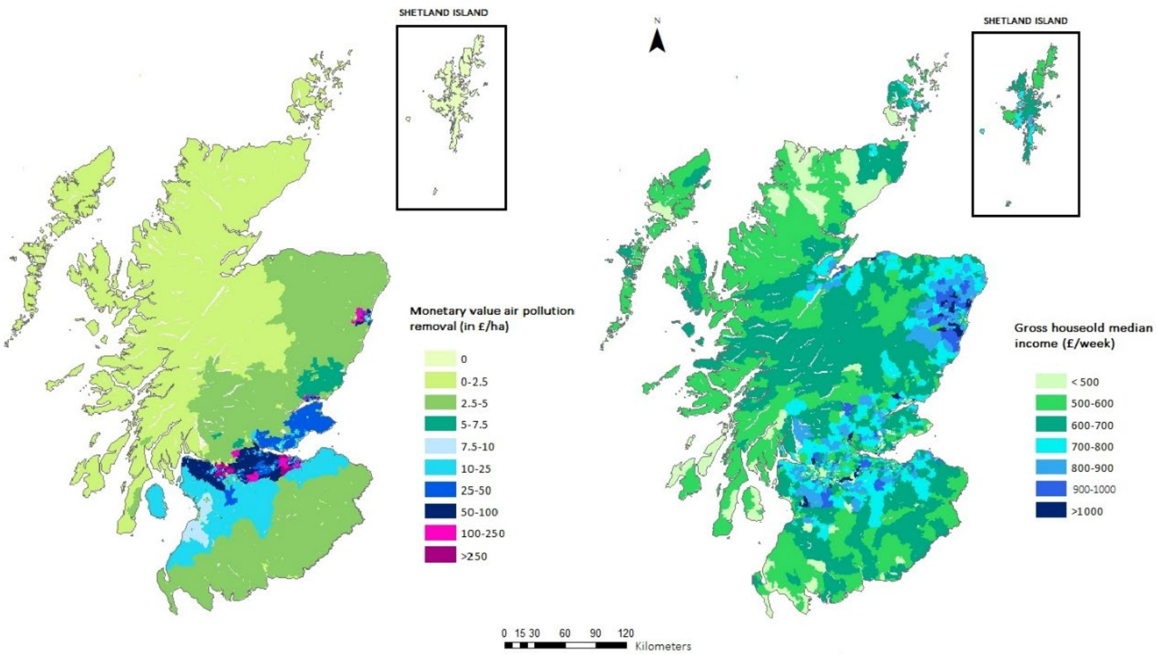


Figure 5: Net air pollution removal by vegetation and pollutant in Scotland
(2015 data per pollutant in kg per 1 km grid square, source ONS (2018b)

This figure shows that air pollution removal amounts less than £10 per hectare of land across much of Scottish territory, with and average value of £12/ha. Nevertheless, there are substantially higher values in a few areas: notably, those areas in the central belt. Needless to say, it is not a coincidence that these are also some of the most populated areas. It is this primary factor in combination with the proximity of vegetation and ambient pollution levels that is driving these higher values. Drawing a link to our earlier discussion of distributional detail within a SUT for ecosystem services, how these values are distributed across people – as users of air pollution removal services – is also of interest. Figure 6 (b) shows how (gross) median income is distributed across Scotland based on 2014 data from the Scottish Government (2017).

a) Monetary value air pollution removal b) Gross median household income distribution



Source: *Own elaboration* based on (a) ONS (2018b) air pollution removal data set, and monetary data on Avoided health damage costs (£ per person, updated to year 2016), and mid-year total population by district and local authority in Scotland; and (b) Weekly local level income estimated 2014 (Scottish Government, 2017). Gross median income values updated to 2016 prices. Reproduced with the permission under the Open Government Licence v 2.0.

Figure 6: Avoided health damage costs (partial cover) (in £ per hectare, year 2016) **compared to gross household income distribution (**in £ per week, updated to year 2016)

This, and other related data, are described in more detail in the Annex to the current paper. In terms of percentage distribution of air pollution removal values our data across local authority areas indicates that typically in excess of 60% of total value is consumed by those households in the two lowest income ranges (Table A.6 in the Annex). Nonetheless, the value of this ecosystem service in relation to income is relatively low, at least according to our data. It may also be, as a practical matter, that the degree of spatial resolution in official data for NCA does not necessarily lend itself to the detail needed for robust interpretations in terms of environmental justice (e.g. Walker, 2012).

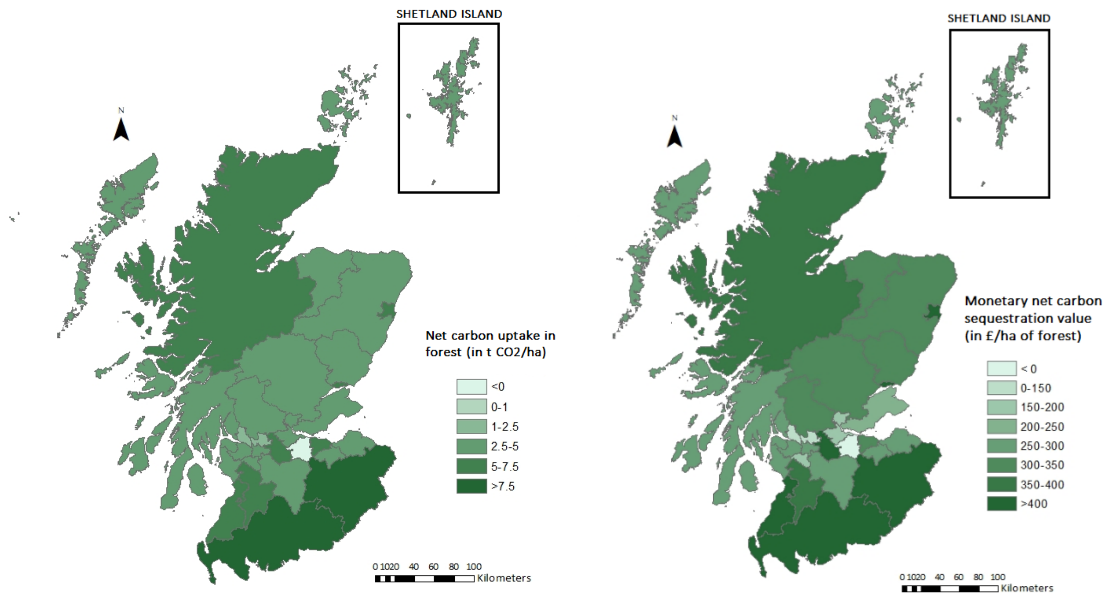
Global climate regulation through net carbon sequestration by vegetation

Figure 7 describes estimated average net carbon uptake per hectare of forestland[10] by local authority. This figure shows relatively highly aggregated data that does not allow for a detailed spatial analysis in the provision of carbon sequestration services. On average, in 2017

[10] That is, once emissions from estimated deforestation in settlements and grasslands as well as forest fires are considered.

each hectare of forest in Scotland sequestered about 5.2 CO_2 tonnes. This translates into a monetary value close to £331 per hectare of forest, when 2016 central non-traded carbon values are considered (BEIS, 2012).[11]

a) Physical values (2017) b) Monetary values (2016)



Source: *Own estimations* based on 2017 carbon emission and removals in the Land Use, Land Use Change and Forestry Sector (LULUCF) (Clilverd *et al*. 2019), National Forest inventory data (2018), and non-traded carbon sequestration values (year 2016). Reproduced with the permission under the Open Government Licence v 2.0.

Figure 7: Estimated net carbon uptake and value by forestland by local authority in Scotland

The value of net carbon sequestration varies within a range from negative values (i.e. net GHG emissions instead of net sequestration) to more than 7.5 tons of CO_2 per hectare per year of woodland being removed from the atmosphere. It should be noted that this value only accounts for net forestland carbon sequestration. When changes in soil carbon stock from other land uses, namely grassland, and cropland, and associated land use changes, net carbon sequestration drops to 0.55 CO_2 tonnes per hectare of land in Scotland.

4.2 Landownership and provision of ecosystem services in Scotland

Table 5 gives a partial view of the relative contribution of private and public land in the provision of our two ecosystem services in Scotland. These are preliminary estimations based on available information on public and private forest and rural land distribution.

The relevance of public and private land for carbon sequestration is estimated considering both the net carbon uptake (Figure 7a) and the partial distribution of private land by property size and public land by local authority. These partial results indicate that 64 percent of net

[11] Data available in Table 3 of the data tables supporting the Green Book toolkit and guidance (BEIS, 2012).

carbon sequestration by forestland would occur in private forest areas. A large portion of this carbon sequestration (56%) apparently occurs in medium to very large properties.

Table 5: Physical distribution of selected ecosystem services by broad habitat in Scotland (2016)

Broad habitat	**Distribution of ecosystem services[1] by habitat (%)**	
	Carbon sequestration	**Air pollution removal**
Farmland	29.3	23.2
Cropland		
Grassland	*29.3*	
Semi-natural grassland		17.3
Woodland	70.7	27.9
Mountain, moor, and hill		22.8
Freshwater		
Open water, wetland & floodplain		8.7
Costal margin		0.1
Wildlife areas		
Other (non-urban) areas		
Built up areas and gardens		
Total	100.0	100.0

Source: ONS (2020a).
Notes: [1] Distribution based on physical flows and monetary flows (when available) for year 2016.

Table 6: Distribution by Type of Landholder of Two Ecosystem Services in Scotland

(a) Percentage contribution to the delivery of ecosystem services (partial cover)

Ecosystem service	**Percentage of ES delivered by type of ownership (%)**					
	Private land (according to the property size)					**Public land (total)**
	Very small to Small (<1,000 ha)	**Medium** (<10,000 ha)	**Large** (<20,000 ha)	**Very Large** (>20,000 ha)	**Total**	
Net CO_2e sequestration by forests[1]	8	36	11	9	64	36
Air pollution removal [2] physical	32	46	2	1	81	19
Air pollution removal [2] value	35	40	1	0	77	23

(b) Distributional supply table (GBP, £, millions, 2016 prices)

Landholders		**Net CO_2e sequestration[2]**	**Air pollution removal[2]**	**TOTAL**
Public		223	9	232
Private		396	30	426
– of which:	*Very large*	*56*	*~0*	*56*
	Large	*68*	*~0*	*68*
	Medium	*223*	*16*	*239*
	Small to very small	*50*	*14*	*64*
	TOTAL	619	39	638

Notes: [1] Forest carbon sequestration based upon distribution of public and private forest by local authority. [2] Total air pollution removal estimations only consider private and public land mapped in Figure 2.

On aggregated terms air pollution removal had a monetary value of £39 million for the areas covered in this study (2016 prices). Carbon sequestration monetary value over the same period and study area amounts to £619 million. These values represent 55% and 85%, respectively, of the total air pollution and carbon sequestration services monetary flows for the period 2016 (ONS, 2020), also expressed in 2016 prices for comparison purposes. Table 6b illustrates the distribution of these values in monetary terms.

Helm (2019) argues what is important is the balance sheet. By this he means not necessarily the present value of the flow of ecosystem, but the extent of the underlying asset. Table 7 provides a physical statement on these lines by describing the 9 broad habitat types in the natural capital account for Scotland published by the ONS. Specifically, the Table refers to the extent of ecosystem assets on the private land that we have mapped (using the Wightman database) and classified according to the 5 categories of size of holdings of landowners.

Table 7: Land cover by broad habitat and size of the farm (in hectares)

Broad habitat/ ecosystem type	Very Small	Small	Medium	Large	Very Large	Total
Woodland	2,223	98,290	352,206	106,156	83,376	**642,251**
Enclosed farm	1,458	63,112	194,978	56,865	44,476	**360,887**
Semi-natural grassland	1,369	100,274	524,301	165,899	128,810	**920,653**
Dwarf shrub heath	677	121,432	731,634	226,880	189,788	**1,270,411**
Bogs	24	13,882	91,505	30,331	20,778	**156,521**
Inland rock	399	7,658	72,521	18,304	27,425	**126,307**
Freshwater and wetland	148	10,397	86,373	45,464	35,530	**177,912**
Coastal margins	12	3,727	13,484	3,410	4,834	**25,466**
Urban and sub-urban	320	10,685	21,779	11,130	9,259	**53,173**
Total	**6,631**	**429,456**	**2,088,782**	**664,438**	**544,274**	**3,733,580**

Source: *Own elaboration* based on Who owns Scotland maps (2015) and CEH Land Cover Maps (LCM 2007) (Morton *et al*. 2011)

Notes: Totals may not correspond to row or column sums due to rounding.

Given the data in Table 7 describes *total* hectares in each ecosystem type across our five categories of size of landholdings, the influence of the concentration of landownership in Scotland is again apparent. That is, by definition, while a given property in the first two columns of the Table will not be large in terms of hectares the fact that there are relatively few of these properties in this category means that these account for a small proportion of total land area covered by any of the 9 ecosystem types.

This is a matter of degree. When compared against the *individual* categories of large or very large landholdings, ecosystem extent is broadly comparable or greater for some ecosystem types, notably woodland and enclosed farm but also, to a lesser extent, coastal margins and urban and sub-urban. There is a clear preponderance of ecosystem extent being in medium-sized landholdings, apart from in two cases (freshwater and wetland/ urban and sub-urban). Table 7 also indicates ecosystem extent *within* each size category of landholding. Although relatively minor in absolute terms, the proportion of woodland and semi-natural grassland within smaller sized landholdings is notable.

4.3 Discussion

Our empirical application throws light on the way in which the supply of ecosystem service, and the underlying ecosystem asset, is distributed across landowners characterized by size of landholding. Notwithstanding some important caveats (see Sections 3 and 4), our findings are relevant to contemporary debates about natural capital policy. As an illustration, Natural Capital Committee (NCC, 2020) asserts that: "… public funding for agriculture should be focused on delivery of environmental public goods" (p12), with payments reflecting, in some way, the value of public goods provided. Bateman and Balmford (2018) explore the implications of this and, in doing so, produce a candidate list of what the public good refers to in terms of the social value provided by ecosystem services and biodiversity protection. This includes both the ecosystem services we examine in this paper.

Operationalizing this payment principle is envisaged as a way of reversing natural capital degradation and, in the UK context, a framework for environmental and agricultural policy following UK exit from the European Union (EU) and its institutions, notably the Common Agricultural Policy (Helm, 2019). An effective scheme, in practice, will require information about who are the recipients and what it is that they supply. In this sense, our empirical analysis is simply based on the sorts of data that might be required on landholders and landownership, *regardless* of whether policymakers are concerned about distributional issues (see Maes *et al*. 2018 for a discussion of informational demands).

Returning to the central theme of our paper, where natural capital policy involves such payments, this explicit incentivization of natural capital maintenance and improvement – to use the terminology of Naidu (2017) – endows these landholders with financialized claims on the stream of ecosystem services they provide. In the case of landowners specifically such claims are realized on the land that they manage or perhaps capitalized in the land that they lease to tenants. Of course, such interventions – and financialized claims – will also have distributional consequences that are important to monitor and evaluate. Our key findings in Section 4.2 can be viewed in this context. Most clearly, the primacy of private land ownership in Scotland makes clear that these actors are central to the supply of the ecosystem services that we examine.

Whether this matters is arguable.[12] Perspectives on land reform amongst stakeholder groups in Scotland, for example, differ on this (Valluri-Nitsch *et al*. 2018). For stakeholders concerned about how land is *managed* what matters more is how policy interventions better align the behaviour of those who own or manage land with the public good. On this view, who owns natural capital might be a secondary concern so long as the policy regime provides sufficient flows of ecosystem services to users, and perhaps further ensures that these flows are reasonably equitably distributed amongst these users. However, the concern of those concerned about how the land is *owned* relates to a point made in broader wealth inequality

[12] The relationship between efficacy of natural capital management and structure of landownership is not likely to be straightforward (Teytelboym, 2019). For example, a regulatory objective may be the protection of contiguous land areas so as to better facilitate a coherent nature policy (e.g. Lawton *et al*. 2010). If the strategic complexities of this increase in the number of landowners, fragmented land ownership may complicate this goal being reached.

debates. In the words of DeLong *et al*. (2017) ownership of substantial wealth provides: "…a megaphone with which to amplify the voices of the wealthy both in the corridors of power and in the public sphere" (p3).

Such arguments in this broader literature relate to inequality in total private wealth rather than private land ownership per se. Nor do our results provide a commentary on *wealth in-the-round*: that is, we are not able to comment on the extent to which large landowners in Scotland are wealthy in other respects (although see Christophers, 2018). Nevertheless, our findings permit reflections on the concentration of land ownership in the context of the supply of ecosystem service flows. This strikes us as highly suggestive that private institutional actors are central and will be proactive in any future shaping of natural capital policy. This is all the more so given the critique in NCC (2020) that the values of aggregate natural capital in, for example, ONS (2020a) – and that we draw upon in the current paper – are highly conservative (i.e. too low). In other words, landowners in our case study might have an even greater whip-hand in shaping natural capital policy than our results suggest, given this implicit claim by the NCC that the ecosystem services that they supply are far greater in value.[13]

These concerns about wealth distribution relate to natural capital policy *processes*. The argument, for example, might be that larger landowners can use their power and status to influence the terms of policy in their favour. Not all agree that the outcomes are inevitably thus. In the context of the UK, Helm (2019) asserts that the beneficiaries that natural capital payments would create would be more marginal farmers: "… small family mixed farms of lowlands and hill farmers" (p103). However, no empirical evidence in support of this arguably appealing claim is provided, although see e.g. Guiomar *et al*. (2018) for a review of evidence. Our findings for Scotland appear to be somewhat equivocal on this issue, at least in the context of the totality of ecosystem services supplied across landholdings. In Section 4.2, we find that more concentrated land holdings appear to be relatively important for (net) carbon sequestration services whereas there is a greater tendency for smaller and medium sized holdings to be significant in the supply of air pollution removal services.

That said, drawing on evidence from natural capital accounts presents only a snapshot of the ownership of ecosystem assets and distribution of supply of ecosystem services – in the current period (e.g. an accounting year). Actual natural capital payment initiatives are often envisaged as applying to *additional* provision of some ecosystem asset or service provision (relative perhaps to current provision or some other baseline or reference point). This point itself may be important for framing debates about fairness of, and public support for, natural capital policy. Social justice concerns differ with regards to perceived fairness of different sources of income (Atkinson, 2009). That is, the *source* of income is relevant to concepts of justice and fairness. As an illustration, payments based on current or status quo provision of ecosystem service values might be perceived as "unearned income", perhaps analogous to

[13] Specifically, the NCC states that: "The latest UK natural capital accounts estimated that in 2016 the partial value of UK natural capital to be around £951 billion … This is a disappointingly low estimate when compared to the UK housing stock which has been estimated at around £7.3 trillion in 2019." (2020, p28).

rentiers defined by e.g. Mazzacuto (2017), a situation where capital owners passively collect a return on their wealth.

Ultimately, of course, distributional consequences will be determined by the detail of actual policy interventions. Moreover, agricultural and environmental policies are devolved responsibilities in the UK[14] meaning that it is in the domain of each of the devolved parliaments or assemblies within the Union to determine what this replacement for the CAP might look like (HMG, 2018; Coe and Finlay, 2020; Brand and Atherton, 2020). Uncertainties remain such as notably the degree to which food security concerns will weigh on future policy as a result of lessons learned from the ongoing Covid-19 emergency. Yet if the direction of travel in natural capital policy within the UK, and its devolved administrations, is the replacement of direct farm payments with natural capital payments to landholders then our findings are a starting point for exploring the distributional implications of these interventions.

To reiterate, our empirical finding for Scotland is that wealth distribution outcomes can differ depending on which ecosystem service – and so which aspect of natural value – is being considered. It follows therefore that the distributional impact of a new policy, given this current pattern of natural capital location, might depend on how payments are weighted towards particular ecosystem services. Bateman and Balmford (2018), in this respect, advocate payments rules that recognize trade-offs and co-benefits between ecosystem services. Lastly, any distributional impact is a *net* effect. There is a long-standing debate about the extent to which wealthier farmers already benefit disproportionately from CAP subsidies (e,g, NAO 2019, Hendricks *et al*., 2013). It follows that any distributional consequences of novel policy institutions should be evaluated also in the light of this.

Scotland represents a case where existing land inequality lends itself naturally to posing distributional questions of NCA. Our emphasis, however, on distributional issues in the ownership of ecosystem assets and the supply of ecosystem services are relevant beyond this context. For example, Shrubsole (2019) provides an assessment of land ownership in England. This indicates a slightly lower proportion of land that is publicly owned, although a non-trivial amount of private land is owned by privatized utilities especially those companies in the water sector. Just under a third of land remains in the ownership of aristocratic estates. How much natural capital is located on such land strikes us as an interesting further question, although beyond the scope of the current paper. Kay *et al*. (2015) look more broadly across Europe at the distribution of farmland and, in doing so, chart an increasing trend towards concentration of ownership in larger farms. Benra and Nahuelhual (2019) and Faguet *et al*. (2020) explore land ownership in Chile and Colombia respectively with the latter study finding a nuanced picture of land inequality in the context of transfers of public land to the private sector, but with evidence in some regions of elite capture either as a result of historical or contemporary policy processes.

[14] As opposed to reserved responsibilities including foreign policy and defence which are the domain of the UK Parliament.

5. Conclusions

Natural capital accounting provides a powerful framework for organizing otherwise voluminous information on ecosystem assets – and natural capital more generally – as well as the flow of services that these assets produce. This, in turn, provides a systematic basis for addressing a correspondingly large number of economic and policy questions.

How natural capital is distributed also matters. Indeed, this is acknowledged by the growing attention given to spatially explicit NCA. This increasingly emphasizes the locality and location of natural capital, as the basis for more effective and economically efficient policy formulation. The contribution in our paper is to utilize what is known about natural capital location to forge connections to debates about how this wealth is distributed among institutional actors, especially landholders.

Natural capital policy additionally will have distributional consequences. Understanding who might benefit from regulatory interventions that seek to maintain and enhance natural capital could reveal, in turn, how wealth distribution changes as a result of otherwise desirable and innovative policies. Given the emerging centrality of NCA to decision-making it becomes ever more important that this work is aligned to providing answers to such distributional questions. This especially might be the case if novel payments translate de facto natural capital ownership into income and wealth for larger landholders.

In this paper, we have sought to make links in particular regarding land ownership to natural capital accounting. As we discuss the empirical challenge is not inconsiderable, not least given what is publicly known and available about landownership and the spatial disaggregation of existing NCA for application to Scotland. We have focused on two categories of ecosystem service: air pollution removal and carbon sequestration services. These two distinct flows provide a useful contrast given that, in the latter, the location of the ecosystem 'does not matter at least, relative to where people live – in terms of the value of the service provided, and in the former it does. That is, in the case of air pollution removal what is important is ownership of land that it is in relative proximity to urban population centres.

A hierarchy of extensions to our research suggest themselves. Expanding the ecosystem services considered would reveal whether this reinforces our findings, and the contrasts between the carbon sequestration and air pollution removal cases. More generally, our emphasis on distributional issues in NCA should be of considerable interest beyond the Scottish and UK settings. They deserve to be more at the heart of NCA especially as this measurement tool becomes ever more present and integrated within the balance sheets of nations.

References

Atkinson, A.B. (2009) "Factor Shares: The Principal Problem of Political Economy?", *Oxford Review of Economic Policy*, 25(1): 3-16.

Barbier, E.B. (2011) *Capitalizing on Nature: Ecosystems as Natural Assets*, Cambridge University Press, Cambridge.

Bateman, I. J., Balmford, B. (2018) Public funding for public goods: A post-Brexit perspective on principles for agricultural policy, *Land Use Policy*, 79: 293-300,

Bateman, I.J., Mace, G.,M., Fezzi, C., Atkinson, G., Turner, K. (2011) Economic Analysis for Ecosystem Service Assessments, *Environmental and Resource Economics* 48, 177–218.

Begon M. Townsend, C.R. and Harper, J.L. (2006) *Ecology: From Individuals to Ecosystems*, 4th Edition, John Wiley & Sons.

BEIS (2012), *Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal*, Department for Business, Energy and Industrial Strategy. Available online: https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal [last accessed 04.06.2020}

Benra, F. and Nahuelhual, L. (2019) A Trilogy of Inequalities: Land Ownership, Forest Cover and Ecosystem Services Distribution, *Land Use Policy*, 82: 247-257.

Börner, J. Baylis, K. Corbera, E. Ezzine-De-Blas, D. Honey-Rosés, J. Persson, U.M. and Wunder, S. (2017), The Effectiveness of Payments for Environmental Services, *World Development*, 96: 359–374.

Boushey, H. DeLong, J.D. and Steinbaum, M. (eds.) *After Piketty: The Agenda for Economics and Inequality*, Harvard University Press, Cambridge, Mass.

Brand, A. and Atherton, S. (2020) *Revised UK Agriculture Bill 2020*, SPICe Briefing 20-28, Scottish Parliament, Edinburgh.

Bright, G., Connors, E., Grice, J. (2019) Measuring Natural Capital: Towards Accounts for the UK and a Basis for Improved Decision-making, *Oxford Review of Economic Policy*, 35(1): 188-108.

Cahill, K. (2001) *Who Owns Britain?*, Canongate, Edinburgh.

Campos, P., Caparrós, A., Oviedo, J.L., Ovando, P., Álvarez-Farizo, B., Díaz-Balteiro, L., Carranza, J., Beguería, S., Díaz, M., Herruzo, A.C., Martínez-Peña, F., Soliño, M., Álvarez, A., Martínez-Jauregui, M., Pasalodos-Tato, M., de Frutos, P., Aldea, J., Almazán, E., Concepción, E.D., Mesa, B., Romero, C., Serrano-Notivoli, R., Fernández, C., Torres-Porras, J., Montero, G. (2019) Bridging the Gap Between National and Ecosystem Accounting Application in Andalusian Forests, Spain, *Ecological Economics*, 157: 218-236.

CEH (2017). Land Cover Maps 2015 (LCM 2015) Statistics. Centre for Ecology and Hydrology. Available online: https://www.ceh.ac.uk/land-cover-map-2015-statistics [las accessed 19/05/2020].

Christophers, B. (2018) *The New Enclosure: The Appropriation of Public Land in Neoliberal Britain*, Verso, London.

Clilverd, H., Buys, G., Thomson, A., Malcom, H., Henshall, P., Matthews, R., (2019). M*apping Carbon Emissions & Removals for the Land Use , Land Use Change & Forestry Sector. Report based on the 1990-2017 Inventory*. Centre for Ecology and Hydrology.

Coe, S. and Finlay, A. (2020) *The Agriculture Bill 2019-21*, Briefing Paper Number CBP 8702, House of Commons Library, London.

Combe, M.M., Glass, J., Tindley, A. (2020) Introduction. In: Combe, M.M., Glass, J., Tindley (eds). *Land Reform in Scotland. History, Law and Policy*. Edinburgh University Press, Edinburgh, pp. 1-20.

Crofting Commission (2020). Crofting Fact & Figures. Webpage of the Crofting Commission. Online resources: https://www.crofting.scotland.gov.uk/crofting [last accessed 06.11.2020].

DeLong, J.D. Boushey, H. and Steinbaum, M. (2017) "*Capital in the Twentieth Century*, Three Years Later", in Boushey, H. DeLong, J.D. and Steinbaum, M. (eds.) *After Piketty: The Agenda for Economics and Inequality*, Harvard University Press, Cambridge, Mass.

Edens, B. and Hein, L. (2013) Towards a Consistent Approach for Ecosystem Accounting, *Ecological Economics*, 90: 41-52.

Elliot, A., Watt, J., Cooke, I., Tabor, P. (2014). *The Land of Scotland and the Common Good*. Report of the Land Reform Review Group. Scottish Goverment.

Ezzine-de-Blas D. Wunder S. Ruiz-Pérez, M and Moreno-Sanchez RdP (2016) Global Patterns in the Implementation of Payments for Environmental Services, *PLoS ONE*, 11(3): e0149847. doi:10.1371/journal.pone.0149847

Faccioli, M. Zonnevel, S., Tyler, C., Day, B. (2019) *Local Natural Capital Accounting: does it deliver useful management information? A case study of Dartmoor and Exmoor National Parks*, LEEP, University of Exeter, Exeter.

Forestry Commission (2019) *National Forest Inventory Woodland Scotland 2018*. Available online at http://data-forestry.opendata.arcgis.com/ (last accesses 22.01.2020), Forestry Commission.

Forestry Commission (2018). Forestry Statistics 2018 - *A compendium of statistics about woodland, forestry and primary wood processing in the United Kingdom*, Forestry Commission.

Heins, L. Bagstad, K.,J., Obst, C., Edens, B., Schenau, S., Castillo, G., Souland, F., Brown, C., Driver, A., Bordt, M., Steurer, A., Harris, R., Caparrós, A. (2020), Global Progress in the Compilation of Natural Capital Accounts for Ecosystems, *Science*, 367(6477): 514-515.

Helm, D. (2019) *Green and Prosperous Land: A Blueprint for Rescuing the British Countryside*, William Collins.

Hendricks, N.P., Janzen, J.P., Dhuyvetter, K.C. (2013) Subsidy Incidence and Inertia in Farmland Rental Markets: Estimates from a Dynamic Panel, *Journal of Agricultural and Resource Economics* 37(3): 361-378.

Hindle, R., Thomson, S., Skerratt, S., McMorran, R., Onea, P. (2014). *Economic Contribution of Estates in Scotland: An Economic Assessment for Scottish Land & Estates*. Scottish Government.

HMG (HM Government) (2018) *A Green Future: Our 25 Year Plan to Improve the Environment*, OGL, London.

Jones, L., Vieno, M., Morton, D., Cryle, P., Holland, M., Carnell, E., Nemitz, E., Hall, J., Beck, R., Reis, S., Pritchard, N., Hayes, F., Mills, G., Koshy, A., Dickie, I., (2017). *Developing Estimates for the Valuation of Air Pollution Removal in Ecosystem Accounts*. Final report UK Office of National Statistics.

Lansing., D.M. (2014). Unequal Access to Payments for Ecosystem Services: The Case of Costa Rica. *Development and Change* 45(6), 1310-1331.

Lawton, J.H. Brotherton, P.N.M. Brown, V.K. Elphick, C. Fitter, A.H. Forshaw, J. Haddow, R.W. Hilborne, S. Leafe, R.N. Mace, G.M. Southgate, M.P. Sutherland, W.A. Tew, T.E. Varley, J. and Wynne, G.R. (2010) *Making Space for Nature: a review of England's wildlife* *sites and ecological network*, Department for Environment, Food and Rural Affairs (Defra), London.

Maes J, Teller A, Erhard M, Grizzetti B, Barredo JI, Paracchini ML, Condé S, Somma F, Orgiazzi A, Jones A, Zulian A, Vallecilo S, Petersen JE, Marquardt D, Kovacevic V, Abdul Malak D, Marin AI, Czúcz B, Mauri A, Loffler P, Bastrup- Birk A, Biala K, Christiansen T, Werner B (2018). *Mapping and Assessment of Ecosystems and their Services. An analytical framework for mapping and assessment of ecosystem condition in EU*. Discussion paper – Final January 2018. European Union.

Mainar-Causapé, A. J.,Ferrari, E., McDonald, S. (2018). *Social Accounting Matrices: basic aspects and main steps for estimation*. EUR 29297 EN, JRC Technical Reports. Publications Office of the European Union, Luxembourg, 2018, doi:10.2760/010600.

Mazzacuto, M. (2018) *The Value of Everything: Making and Taking in the Global Economy*, Allan Lane, London.

McVittie, A. and Gleck, K. (2019) *Natural Capital Accounts for Scotland: Forest Sector Accounts*, Scottish Government.

McVittie, A., Roberts, M., Hopkins, J., Glenk, K. (2019). *Natural Capital Accounts for Scotland: Agriculture Sector Accounts*, Scottish Government.

Meya, J.N. (2020) Environmental Inequality and Economic Valuation. *Environmental and Resource Economics* 76, 235-270.

Mitchell, G. and Dorling, D. (2003) An environmental justice analysis of British air quality, *Environment and Planning A*, 35: 909-929.

Miteva, D. (2019) The Integration of Natural Capital into Development Policies, *Oxford Review of Economic Policy*, 35(1): 162-181.

Morton, D., Rowland, C., Wood, C., Meek, L., Marston, C., Smith, G., Simpson, I.C. (2011) Final report for LCM2007 - the new UK land cover map. CS Technical report No. 11/07 NERC/Centre for Ecology and Hydrology 112pp.

Mullin, K. Mitchell, G., Rizwan Nawaz, N., Waters, R.D. (2018) Natural Capital and the Poor in England: Towards an Environmental Justice Analysis of Ecosystem Services in a High-Income Country, *Landscape and Urban Planning*, 176: 10-21.

Naidu, S. (2017) "A Political Economy Take on W/Y", in Boushey, H. DeLong, J.D. and Steinbaum, M. (eds.) *After Piketty: The Agenda for Economics and Inequality*, Harvard University Press, Cambridge, Mass.

NAO (National Audit Office) (2019) *Early Review of the New Farming Programme*, NAO, London.

NCC (Natural Capital Committee) (2020) *State of Natural Capital: Annual Report 2020*, NCC, London.

NRS (National Records of Scotland), 2016. Scottish Settlement boundaries version (released March 2018)

Obst, C., Hein, L., Edens, B. (2016). National Accounting and the Valuation of Ecosystem Assets and Their Services. *Environmental and Resource Economics* 64(1),1-23.

Obst, C., Vardon, M. (2014). Recording environmental assets in the national accounts. *Oxford Review of Economic Policy*, 30, 126–144.

ONS (2020a) *Scottish Natural Capital Accounts: 2020,* ONS, London.

ONS (2020b) *Population Estimates for the UK, England and Wales, Scotland and Northern Ireland: mid-2018,* ONS, London.

ONS (2019a) *UK Natural Capital Accounts: 2019*, ONS, London.

ONS (2019b) UK Natural Capital: Mountains, Moorland and Heath Accounts, ONS, London.

ONS (2018a) UK Natural Capital: Interim Review and Revised 2020 Roadmap, ONS, London.
ONS (2018b) UK air pollution removal: how much pollution does vegetation remove in your area? Office for National Statistics Available online: https://www.ons.gov.uk/ (last accessed 23/01/18).
ONS (2016) UK Natural Capital: Experimental Carbon Stock Accounts, Preliminary Estimates, ONS, London.
Ovando, P., Caparrós, A., Diaz-Balteiro, L., Pasalodos, M., Beguería, S., Oviedo, J.L., Montero, G., Campos, P. (2017). Spatial Valuation of Forests Environmental Assets: An Application to Andalusian Silvopastoral Farms. *Land Economics* 93 (1): 87-108.
Pascual, U. Phelps, J. Garmendia, E. Brown, K. Corbera, E. Martin, A. Gomez-Baggethun, E. and Muradian, R. (2014) Social Equity Matters in Payments for Ecosystem Services, *BioScience*, 64(11): 1027-1036.
Piketty, T. Saez, E. and Zucman, G. (2018) "Distributional National Accounts: Methods and Estimates for the United States", *Quarterly Journal of Economics*, 133(2): 553-609.
Riley C.B. and Gardiner M.M. (2020) Examining the distributional equity of urban tree canopy cover and ecosystem services across United States cities, *PLoS ONE*, 15(2): e0228499. https://doi.org/10.1371/journal.pone.0228499
Saez, E. (2017) "The Research Agenda after *Capital in the Twentieth Century*", in Boushey, H. DeLong, J.D. and Steinbaum, M. (eds.) *After Piketty: The Agenda for Economics and Inequality*, Harvard University Press, Cambridge, Mass.
Scotland's Environment (2011). *Land Use and Management*. Scotland's Environment.
Scottish Government (2019a) 2018 Agricultural Census Available online: (https://www.gov.scot/publications/results-june-2018-scottish-agricultural-census/pages/1/) last accessed 29.09.2020
Scottish Government (2019b). FCS National Forest Estate (WMS). Available online (https://data.gov.uk/dataset/44dcf360-3af9-407c-8d1e-5d2a8b5a3a2b/fcs-national-forest-estate-wms) last accessed 21.01.2020
Scottish Government (2017) *Weekly local level income estimates by income bandings: 2014* Available online: (*http://www.gov.scot/publications/weekly-local-level-income-estimates-by-income-bandings-2014/*) last accessed 04.09.2020.
Shrubsole, G. (2019) *Who Owns England?: How We Lost Our Green and Pleasant Land, and How to Take It Bac*k, William Collins.
Teytelboym, A. (2019) Natural Capital Market Design, *Oxford Review of Economic Policy*, 35(1): 138-161.
UN (2020) *System of Environmental-Economic Accounting – Ecosystem, Accounting. Draft for the Global Consultation on the complete document*, October 2020. United Nations, SEEA. Available online: https://seea.un.org/content/global-consultation-complete-draft [last accessed 29.10.2020].
UN (2014) *System of Environmental-Economic Accounting 2012 – Experimental Ecosystem, Accounting*, United Nations, New York.
UN (2009) *System of National Accounts 2008*, United Nations, New York.
Vallecillo, S. La Notte, A. Ferrini, S. and Maes, J. (2019) How Ecosystem Services are Changing: An Accounting Application at the EU Level, *Ecosystem Services*, 40.
Valluri-Nitsch, C. Metzger, M.J. McMorran, R. and Price, M.F. (2018) My land? Your land? Scotland? Understanding sectoral similarities and differences in Scottish land use visions, *Regional Environmental Change*, 18: 803–816.

Van den Ven, P., Edens, B. and Obst, C. (2019) *Accounting Treatments when Integrating Ecosystem Accounts in the SNA*, Discussion Paper 5.3, Working Group 5: Valuation and accounting treatments, UNSD/ SEEA, New York.

Vincent, J.R. (2015) *Valuing Environmental Services in the SNA*, Report prepared for the Policy and Technical Experts Committee (PTEC) of the Wealth Accounting and Valuation of Ecosystem Services (WAVES), The World Bank, Washington D.C.

Walker, G. (2012) *Environmental Justice: Concepts, Evidence and Politics*, Routledge, London.

Wightman, A. (1996) *Who Owns Scotland?*, Canongate, Edinburgh.

Who Owns Scotland (2015) property map. Last update (2015). Online resource: http://www.whoownsscotland.org.uk/index.php [last accessed 29.10.2020].

ANNEX: FURTHER INFORMATION

A.1 Landownership mapping

Andy Wightman *Who owns Scotland* map (2015) has been updated in order to include some additional public properties belonging to the Scotland's Nature Agency (previously called Scottish Natural Heritage) and Crown Estate properties. This data base has been further reviewed to identify different type of private ownership, including private companies, individual owners, trust, and charities. The former three ownership categories accounting each for about one third of private landownership. Table A.1 shows the share of total land mass mapped by the Who owns Scotland map by type of landowner. The share of land mapped is higher in areas used for grassland-based farming, rough grazing and woodlands used mainly for livestock breading, forestry, and sporting (FigA. 1 and 2 of the main text).

Table A.1: Distribution of mapped land properties in Scotland by type of landowner and local authority (partial cover)

Local Authority	Land area (ha)		Share of total land covered (%)	Share of land by type of private ownership (%)			
	Total land mass	Mapped (private land)		Private company	Individual owner	Trust	Charity
1. Aberdeen City	18,830	16	0.1	1.7	97.7	0.6	0.0
2. Aberdeenshire	633,994	243,352	38.4	9.5	32.4	57.8	0.3
3. Angus	220,385	77,539	35.2	23.5	21.4	55.1	0.0
4. Argyll and Bute	716,145	438,873	61.3	34.3	38.8	25.3	1.5
5. City of Edinburgh	27,303	0	0.0	0.0	0.0	0.0	0.0
6. Clackmannanshire	16,392	101	0.6	99.3	0.0	0.7	0.0
7. Dumfries & Galloway	645,710	158,793	24.6	51.5	22.7	25.2	0.6
8. Dundee City	6,029	0	0.0	0.0	0.0	0.0	0.0
9. East Ayrshire	127,033	31,819	25.0	46.6	53.4	0.0	0.0
10. East Dunbartonshire	17,449	1,473	8.4	20.8	79.0	0.2	0.0
11. East Lothian	68,315	43,993	64.4	27.6	53.1	19.3	0.0
12. East Renfrewshire	17,423	0	0.0	0.0	0.0	0.0	0.0
13. Falkirk	29,839	689	2.3	0.0	100.0	0.0	0.0
14. Fife	135,718	0	0.0	0.0	0.0	0.0	0.0
15. Glasgow City	17,645	0	0.0	0.0	0.0	0.0	0.0
16. Highland	2,624,818	2,016,993	76.8	34.9	35.3	27.1	2.6
17. Inverclyde	17,363	1	0.0	39.9	60.1	0.0	0.0
18. Midlothian	35,527	12,828	36.1	0.2	23.4	76.5	0.0
19. Moray	225,663	71,154	31.5	54.5	13.2	29.3	3.0
20. Na h-Eileanan an Iar	297,721	47,991	16.1	0.0	0.0	100.0	0.0
21. North Ayrshire	89,561	31,835	35.5	12.5	33.0	47.2	7.3
22. North Lanarkshire	47,222	2,702	5.7	60.3	39.7	0.0	0.0
23. Orkney Islands	106,957	0	0.0	0.0	0.0	0.0	0.0
24. Perth and Kinross	541,970	310,928	57.4	26.7	34.4	37.4	1.6
25. Renfrewshire	26,922	0	0.0	100.0	0.0	0.0	0.0
26. Scottish Borders	474,265	194,784	41.1	48.1	34.2	17.7	0.0
27. Shetland Islands	149,202	0	0.0	0.0	0.0	0.0	0.0
28. South Ayrshire	123,467	21,174	17.1	49.7	16.6	32.7	1.1
29. South Lanarkshire	177,404	67,445	38.0	27.5	70.9	1.6	0.0
30. Stirling	225,472	114,675	50.9	34.1	42.9	18.2	4.8
31. West Dunbartonshire	18,276	1,062	5.8	0.1	99.9	0.0	0.0
32. West Lothian	43,145	3,679	8.5	87.6	12.4	0.0	0.0
(not identified)		3,321					
Total	**7,923,165**	**3,897,219**	**49.2**	**33.3**	**34.8**	**29.9**	**2.0**

Source: *Own elaboration* based on Andy Wightman's *Who owns Scotland* map (2015), and the Ordnance Survey (OS) Local Authority boundaries map.

A.2 Spatial distribution of air pollution removal monetary values

Estimations are based on ONS maps for air pollution removed by vegetation in 2015 and avoided health damage costs (in £/person over the same year). Air pollution removal is estimated with a one square km resolution for six pollutants in the UK. Air pollution removal physical and economic estimates are based on a Centre of Ecology and Hydrology (CEH) study (Jones et al., 2017)

The monetary value associated to air pollution removal (data for 2015, updated to 2016 prices using the GDP deflator) is estimated also using ONS (2018) data on avoided health damage costs (£ per person) by wider area (mainly based on local authority areas) in Scotland. We have estimated the avoided health damage cost by local authority, considering directly ONS (2018) data or when the monetary data are referred to specific areas belonging to more than one local authority, we use 2011 Census data to estimate the share of total local area population living in these specific districts or areas. In case, there is more than one monetary data per local authority, we estimate the weighted average avoided health cost data using the mid-year population data as a weighting factor (see Tables A.2- A.4).

Table A.2 Avoided health damage cost by wider areas in Scotland (2015 values)

Code	Name of the wider area	Value (£ per person)
S1	Aberdeen and Aberdeenshire	9.08
S2	Inverness & Nairn and Moray, Badenoch & Strathspey	8.73
S3	Lochaber, Skye & Lochalsh, Arran & Cumbrae and Argyll & Bute	10.63
S4	Caithness & Sutherland and Ross & Cromarty	7.59
S5	Angus and Dundee City	9.54
S6	Perth & Kinross and Stirling	10.28
S7	Clackmannanshire and Fife	10.52
S8	Edinburgh, City of	10.35
S9	West Lothian	12.68
S10	East Lothian and Midlothian	10.1
S11	Scottish Borders	13.14
S12	South Lanarkshire	12.92
S13	East Ayrshire and North Ayrshire mainland	12.84
S14	South Ayrshire	11.46
S15	Inverclyde, East Renfrewshire and Renfrewshire	11.26
S16	East Dunbartonshire, West Dunbartonshire and Helensburgh & Lomond	12.58
S17	Glasgow City	11.95
S18	North Lanarkshire	13.28
S19	Falkirk	11.69
S20	Na h-Eileanan Siar (Western Isles)	3.01
S21	Orkney Islands	3.96
S22	Shetland Islands	0
S23	Dumfries & Galloway	14.55

Source: Own elaborations based on ONS (2018).

Avoided health cost used by the ONS to value air pollution removal are drawn from Jones et al. (2017). This makes use of exposure-response functions relating ambient pollution to mortality and morbidity derived from epidemiological studies in the UK, USA, Europe and elsewhere. This is combined with data on underlying incidence of health outcomes from UK national statistics on mortality and hospital admissions. The unit values describe a monetary equivalent of health impacts are provided by local authority or district, and these include up to three elements describing productivity lost, healthcare costs and the ‘utility lost’ (the value people place on living a healthy and long life).

Table A.3 Estimation of air pollution removal avoided health damage costs for the Highlands, North Ayshire and Argyll and Bute (2015 values)

Area and local authority	Population Census 2011 [1]		Share	Code APR	Value (£/person)	Weighted average (£/person)
	Locality	Council	(%)			
Inverness and Nairn	86191	233,508	37%	S2	8.73	3.22
Skye, Lochabel	70,149	233,508	30%	S3	10.63	3.19
Badenoch and Strathspey [2]	3,910	233,508	2%	S2	8.73	0.15
Lochalsh (Kyle of)	650	233,508	0%	S3	10.63	0.03
Caithness, Sutherland and Ross	71,882	233,508	31%	S4	7.59	2.34
Cromarty	726	233,508	0%	S5	9.54	0.03
Highland	**233,508**	**233,508**	**100%**			**8.96**
Arran[3]	4,629	138,146	3%	S3	10.63	0.36
Great Cumbrae [4]	1,376	138,146	1%	S3	10.63	0.11
Rest of North Ayshire	132,141	138,146	96%	S13	12.84	12.28
North Ayshire	**138,146**	**138,146**	**100%**			**12.74**
Helensburgh	14220	88,166	16%	S16	12.58	2.03
Rest of North Argyll and Bute	73,946	88,166	84%	S3	10.63	8.92
Argyll and Bute	**88,166**	**88,166**	**100%**			**10.94**

Notes: [1] Census data obtained online: https://www.scotlandscensuA.gov.uk/ods-web/area.html (April 2020), (2) Estimated considering the localities included in the district of Badenoch and Strahspey (https://en.wikipedia.org/wiki/Badenoch_and_Strathspey), which are subtracted from the Parliamentary Constituency of Skye, Lichabel and Badenoch; [3] Estimated population of Arran: https://en.wikipedia.org/wiki/Isle_of_Arran
[4] Estimated population of Great Cumbrae: https://en.wikipedia.org/wiki/Great_Cumbrae,

Table A.4 Estimation of air pollution removal avoided health damage costs by local authority (2015 values)

Local Authority	Mid-year population (2015)	Value (£/person)	Total value (£)	Total pollutants removal (kg)	Value per air pollutant removed (£/kg)
Aberdeen City	230,350	9.08	2,091,578	1,050,675	1.99
Aberdeenshire	261,960	9.08	2,378,597	35,376,325	0.07
Angus	116,900	9.54	1,115,226	11,844,971	0.09
Argyll and Bute	86,890	**10.94**	950,968	27,613,572	0.03
City of Edinburgh	498,810	10.35	5,162,684	1,113,000	4.64
Clackmannanshire	51,360	10.52	540,307	940,466	0.57
Dumfries and Galloway	149,670	14.55	2,177,699	41,621,000	0.05
Dundee City	148,210	9.54	1,413,923	324,029	4.36
East Ayrshire	122,060	12.84	1,567,250	7,212,229	0.22
East Dunbartonshire	106,960	12.58	1,345,557	21,186,644	0.06
East Lothian	103,050	10.1	1,040,805	4,464,319	0.23
East Renfrewshire	92,940	11.26	1,046,504	793,408	1.32
Falkirk	158,460	11.69	1,852,397	1,481,000	1.25
Fife	368,080	10.52	3,872,202	7,786,534	0.50
Glasgow City	606,340	11.95	7,245,763	413,000	17.54
Highland	234,110	**8.96**	2,097,078	101,209,428	0.02
Inverclyde	79,500	11.26	895,170	790,643	1.13
Midlothian	87,390	10.1	882,639	2,321,681	0.38
Moray	95,510	8.73	833,802	13,098,000	0.06
Na h-Eileanan Siar	27,070	3.01	81,481	13,613,000	0.01
North Ayrshire	136,130	**12.74**	1,734,832	5,084,771	0.34
North Lanarkshire	338,260	13.28	4,492,093	2,217,000	2.03
Orkney Islands	21,670	3.96	85,813	4,730,000	0.02
Perth and Kinross	149,930	10.28	1,541,280	27,236,857	0.06

Local Authority	Mid-year population (2015)	Value (£/person)	Total value (£)	Total pollutants removal (kg)	Value per air pollutant removed (£/kg)
Renfrewshire	174,560	11.26	1,965,546	1,225,949	1.60
Scottish Borders	114,030	13.14	1,498,354	30,588,000	0.05
Shetland Islands	23,200	0	0	7,279,000	0.00
South Ayrshire	112,400	11.46	1,288,104	7,977,000	0.16
South Lanarkshire	316,230	12.92	4,085,692	9,848,000	0.41
Stirling	92,830	10.28	954,292	11,331,143	0.08
West Dunbartonshire	89,590	12.58	1,127,042	22,190,356	0.05
West Lothian	178,550	12.68	2,264,014	2,513,000	0.90
Scotland	**5,373,000**	**11.10**	**59,628,693**	**426,475,000**	**0.14**

A.4 Spatial distribution of carbon sequestration

Forest carbon uptake reported by Clilverd *et al*. (2019), utilise to estimate carbon sequestration inf forestland by local authority, is assessed using National Forest Inventory data, and the CARBINE carbon accounting model. This latter model accounts for gains and losses of carbon in standing trees, litter, and soils, and due to harvesting of wood products. Net changes in carbon stock at any one time depend on the balance between carbon accumulation rates in tree biomass and soils, woodland planting, and wood harvesting.

A.5 Income distribution and inequality in Scotland

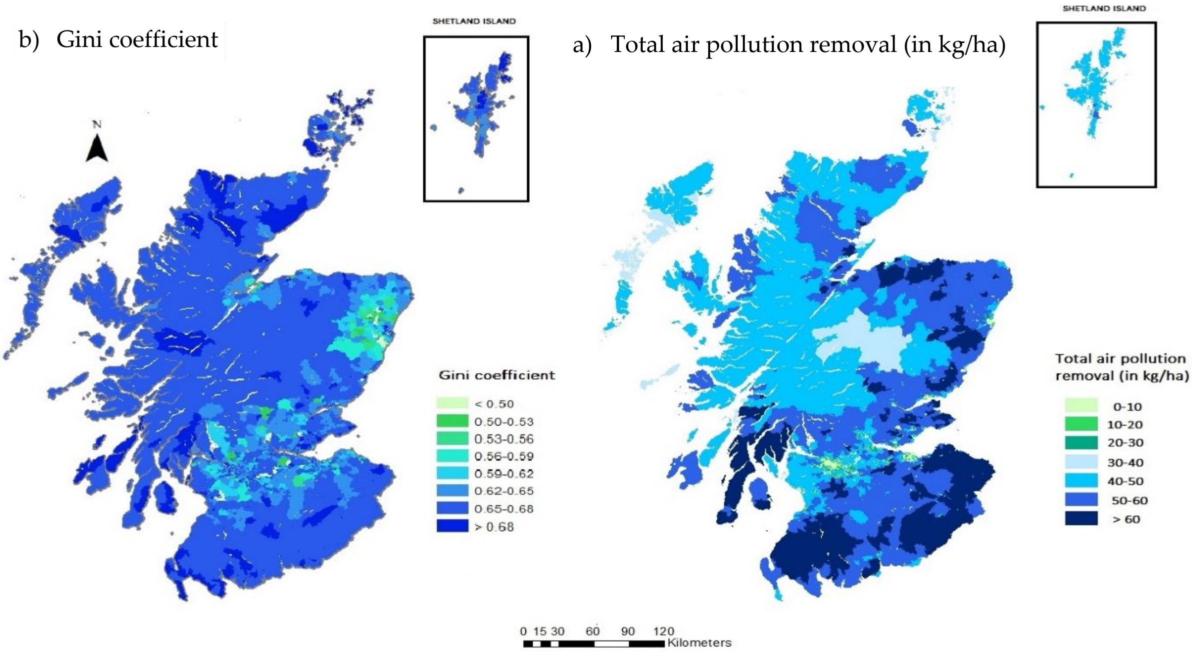
Income distribution in Scotland was estimated using information of weekly gross income levels by the 2011 Data Zone in 2014 (Scottish Government, 2017). The income estimates for 2014 have been produced for the purposes of updating the Scottish Government Housing Need and Demand Assessment (HNDA)Tool[15], which aims to estimate future additional housing. The income data covers total income received by all adult members of a household, including welfare benefits, tax credits and housing benefit. The estimates reflect total income before any deductions are taken off for income tax, national insurance contributions and council tax etc. These gross income levels range from £50 per week to £2,000 per week, accounting for 18 gross income categories in total.

Using these gross weekly households' income data, we have further estimated the Gini coefficient (Fig. A.1) considering the total number of households by 2011 Data Zone and income category defined by the Scottish Government (2017) report. This information has been rearranged by quintiles of population (here represented by the number of households, assuming due to the lack of data that households over the population quintiles have a similar average size) to estimate the number of households by quintile, and the total aggregated income by quintiles. Total income by quintile is estimated as the weighted median income for each population quintile for the share of households represented by each quintile. The median income is estimated for each of the 18 gross income categories as the number that occupies the central position over each income category range.

[15] More information available at: http://www.gov.scot/Topics/Built-Environment/Housing/supply-demand/chma.

Income distribution information by quintiles of population was used to estimate the Lorenz curve and Gini coefficients for each one of the 6970 zones. The Lorenz curve is a graphical representation of income or wealth distribution in a population. Basically, this curve shows the cumulative proportion of income against the cumulative proportion of the population. The Gini coefficient is estimated as the ratio of the area that lies between the line of equality (a 45°-degree line) and the Lorenz curve over the total area under the line of equality.

Table A.5 presents the correlation matrix among median gross income, Gini coefficient, total air pollution removal by pollutant and its monetary value, using 2011 Data zone values for each one of the variables above referred. The results of this simple correlation analysis show that there is a strong negative linear relationship between the Gini coefficient and gross income, which indicates that at higher income levels the income is better distributed (lower Gini coefficient) is observed. There is, nonetheless, a relatively weak positive relationship between gross income and total air pollution removed, which indicates a higher air quality control services in areas of higher incomes, which in Scotland correspond to the denser populated areas. There is basically no relationship between the monetary value associated to air pollution removal gross income and income distribution.



Source: *Own elaboration* based on (a) Own estimated Gini coefficient; and (b) ONS (2018) air pollution removal data set by 2011 Data Zone. Reproduced with the permission under the Open Government Licence v 2.0.

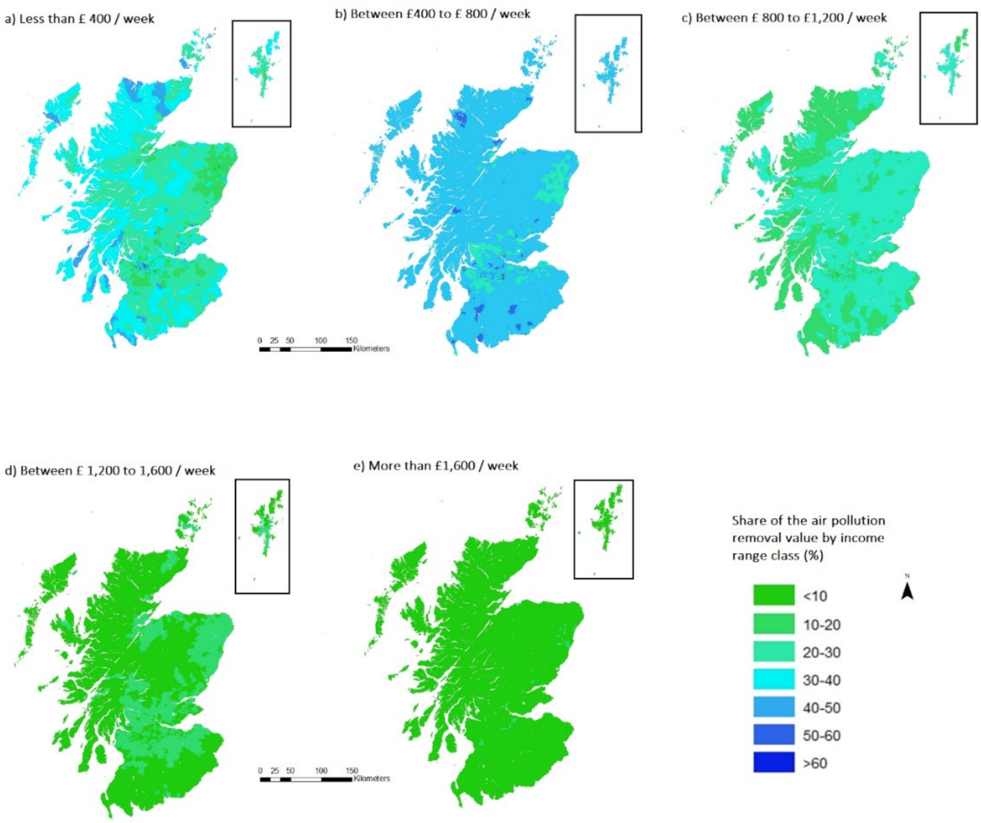
Figure A.1: Spatial distribution of the Gini coefficient compared to the total air pollution removal (in kg per hectare) **in Scotland**

In Table A.6, we have estimated the estimated the share of air pollution value (in monetary terms) attributed to the number of households by local authority and weekly gross income range. Local authority total air pollution removal data (aggregated kg of pollutants) are estimated by aggregating the 2011 zone total pollutants removals, and those were multiplied by the monetary value for kg of pollutant removed, which is estimated at the local authority level Table A.4), with the Shetland Islands having a zero value, as no avoided health cost are provided for this area in the ONS (2018) data base. Figure A.2 shows the spatial distribution across Scotland of the share of air pollution removal value by each income range class.

Table A.5 Correlation matrix income and air pollution removal indicators

Class	Gini coefficient	Household income	Air Pollution Removal (APR)							Monetary value APR
			$PM_{2.5}$	PM_{10}	NH_3	NO_2	O_3	SO_2	Total	
Gini coefficient	1.00									
Household income (£/week)	**-0.77**	1.00								
$PM_{2.5}$ (kg/ha)	-0.10	0.18	1.00							
PM_{10} (kg/ha)	-0.08	0.17	0.99	1.00						
NH_3 (kg/ha)	-0.13	**0.23**	0.66	0.60	1.00					
NO_2 (kg/ha)	-0.16	0.19	0.40	0.33	0.55	1.00				
O_3 (kg/ha)	-0.12	**0.29**	0.63	0.63	0.72	0.35	1.00			
SO_2 (kg/ha)	-0.12	**0.20**	0.62	0.57	0.74	0.77	0.61	1.00		
Total APR (kg/ha)	-0.13	**0.29**	0.68	0.68	0.76	0.41	1.00	0.66	1.00	
Monetary value APR (£/ha)	-0.04	-0.06	0.12	0.09	0.09	**0.42**	-0.05	0.22	-0.02	1.00

Notes: Household income refers to gross median weekly income.



Source: *Own elaboration* based on ONS (2018) air pollution removal and Scottish Government (2017) gross income distribution data by 2011 Data Zone. Reproduced with the permission under the Open Government Licence v 2.0.

Figure A.2: Spatial distribution of the estimated share of air pollution removal value (in percentage) **by income range class in Scotland**

Table A.6 Share of air pollution removal value attributed to households by income range

Local authority	Gross income (mean) £/week (2015 value)	Income range (in gross £ per week)				
		< 400	400-800	800-1200	1200-1600	>1600
		Percentage of air pollution removal value (%)				
Aberdeen City	742.82	22.0	31.1	24.5	14.8	7.5
Aberdeenshire	851.67	22.9	33.1	24.9	13.3	5.9
Angus	655.09	26.9	36.6	22.7	10.0	3.8
Argyll and Bute	642.73	34.5	37.6	18.9	6.9	2.2
City of Edinburgh	717.00	27.5	33.0	22.1	11.9	5.4
Clackmannanshire	664.28	26.6	32.8	21.7	12.4	6.4
Dumfries and Galloway	616.88	33.5	37.7	19.1	7.2	2.4
Dundee City	570.58	23.4	34.1	24.6	12.6	5.4
East Ayrshire	648.51	24.6	35.3	23.8	11.5	4.7
East Dunbartonshire	827.55	24.4	32.7	23.9	13.1	5.9
East Lothian	748.32	25.5	32.3	23.5	12.9	5.8
East Renfrewshire	847.22	25.5	31.9	23.4	13.2	6.1
Falkirk	690.81	29.8	35.0	21.4	10.0	3.9
Fife	656.67	29.6	35.6	21.4	9.7	3.7
Glasgow City	585.37	33.9	36.0	18.8	8.2	3.2
Highland	702.19	32.2	37.1	20.1	7.9	2.7
Inverclyde	624.58	22.4	33.4	24.8	13.4	6.1
Midlothian	733.19	24.4	32.4	23.9	13.3	6.0
Moray	688.78	28.5	37.5	21.9	9.0	3.1
Na h-Eileanan an Iar	669.46	34.8	37.1	18.8	7.0	2.3
North Ayrshire	619.05	34.1	36.7	18.9	7.6	2.7
North Lanarkshire	669.33	28.8	35.0	21.4	10.3	4.5
Orkney Islands	682.05	34.5	35.2	19.6	7.9	2.7
Perth and Kinross	710.65	28.3	35.1	22.0	10.4	4.1
Renfrewshire	649.96	24.2	31.4	24.0	13.9	6.5
Scottish Borders	640.57	28.3	36.7	22.0	9.5	3.5
Shetland Islands	751.03	-	-	-	-	-
South Ayrshire	655.83	33.0	37.6	19.6	7.4	2.4
South Lanarkshire	694.57	26.5	34.4	23.0	11.4	4.8
Stirling	763.72	26.8	32.3	22.6	12.5	5.7
West Dunbartonshire	602.31	32.4	36.2	20.0	8.4	3.0
West Lothian	741.47	25.1	32.0	23.4	13.3	6.3
Scotland	**680.58**	**28.6**	**34.8**	**21.7**	**10.5**	**4.4**

Source: *Own elaboration* based on ONS (2018) and Scottish Government (2017) data.