National Terrestrial Carbon Sinks Assessment 2020

SUMMARY FOR POLICY MAKERS

environment, forestry & fisheries
Department:
Environment, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
of the Federal Republic of Germany

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FOREWORD

The National Land Cover is a proxy for land use and management, thus can be used to assess drivers of carbon stocks changes and fluxes. Since the development of the first National Terrestrial Carbon Sinks Assessment (NTCSA 2014), South Africa 's ability to understand land cover changes has improved due to the development of new land cover products; 2014 and 2018. As methodologies for estimating Greenhouse Gas emissions (GHG) and removals from the Agriculture, Forestry and Other Land use (AFOLU) sector requires basic understanding of how land use, changes and management drive and also provide opportunities for reducing GHG emissions, there was a need to update carbon stock data and information based on updated datasets.

The NTCSA 2020, hereafter referred to as the sinks assessment, was developed against a backdrop of international policy imperatives including Nationally Determined Contributions and Enhanced Transparency Framework, coupled with domestic policies - the development and operationalisation of the economy wide climate change mitigation system including the AFOLU sector. Moreover, the sinks assessment was developed to create better understanding of carbon stocks, their dynamics, drivers and climate change mitigation and adaptation opportunities as well as the reporting thereof.

In addition, the sinks assessment was accompanied by an update of the Carbon Sinks Atlas (CSA). The CSA is a web-based data and information tool aimed at providing the spatial distribution of carbon stocks and fluxes across South Africa. Improvements to the previous version include updated search and discovery of data, updated carbon stocks maps and baseline datasets at 1x1km resolution, as well as newly available soil organic carbon datasets including organic carbon pool profiles for South Africa's district municipalities. The online CSA is available at https://ccis.environment.gov.za/carbon-sinks/#/.

Most of the carbon in South African natural ecosystems is found in the soil, accounting for an estimated 89% of the country's total terrestrial carbon stock. It is therefore important to understand the magnitude, determinants and how land-use options will either lead to an increase or decrease of soil carbon storage over time. Further, mitigation actions including Conservation Agriculture and use of soil amendments, biochar can be beneficial to reducing GHG emissions and enhance carbon sinks. It is in this context that vertical integration can be strategic in fostering implementation of sustainable soil and land management through policies including, Spatial Planning and Land Use management (SPLUMA) and Conservation Agriculture, Resources Act (CARA) and mainstreaming of the climate change agenda in municipal plans and strategies.

Although the independent research and findings contained in this report do not necessarily represent the views, opinions and/or position of government, the Department of Environment, Forestry and Fisheries believes that this research is critical to enhance our understanding of how land use and changes affect the potential of natural ecosystems to act as carbon sinks. Hence, the department is happy to make this work publicly available and accessible.

CONTENTS

LIST OF ABBREVIATIONS

AGB	Above ground biomass
AGW or AGB_{woody}	Above ground woody biomass
AGH or AGB_{herb}	Above ground herbaceous biomass
AFOLU	Agriculture, Forestry and Other Land Use
ARC	Agricultural Research Council
B	Biomass
BGB	Below ground biomass
BGW or BGB_{woody}	Below ground woody biomass
BGH or BGB_{herb}	Below ground herbaceous biomass
C	Carbon
CF	Carbon fraction
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DEFF	Department of Environment, Forestry and Fisheries
g	Gram
Gg	Gigagram (one thousand million grams)
Gt	Gigatonne (one thousand million tonnes)
GIS	Geographic information system
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPS	Global positioning system
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
LiDAR	Light detection and ranging
LU	Land unit
M	Million
m	Metre
m^2	Metres squared (area)
m^3	Metres cubed (volume)
NTCSA 2019	this report – i.e. 2019 National Terrestrial Carbon Sinks Assessment
NTCSA 2014	2014 National Terrestrial Carbon Sinks Assessment

O_2	Oxygen
R	Root: shoot ratio
RP	Reporting period
SANBI	South African National Biodiversity Institute
SOC	Soil organic carbon
SOM	Soil organic matter
t	Tonne (Metric i.e. 1 000kg)
tC	Tonne of carbon
tCO_2e	Tonne carbon dioxide equivalent
Tg	Teragram
TJ	Terajoule
VCS	Verified Carbon Standard
y	Year
Δ	Change in

COMMON CONVERSION FACTORS

1 gC/m^2 = 0.01 tC/ha	:	1 tC/ha = 100 gC/m^2
1 kg/m^2 = 10 t/ha	:	1 t/ha = 0.1 kg/m^2
1km^2 = 100 ha	:	1 ha = 0.01 km^2
1 tonne = 0.000001 Tg	:	1 Tg = 1 000 000 t i.e. 1 Tg is a million tonnes
1 Tg = 10^{12} g	:	1g = 10^{-12} Tg, i.e. 1 Tg is a million million grams
1 Gg = 1 000 000 000 g	:	1g = 0.000 000 001 Gg, i.e. 1 Gg is a billion grams

DEFINITIONS AND TERMS

Biomass: living or recently-dead organic matter of biological origin. Most is plant matter, which could specifically be called phytomass. For the purposes this report biomass refers to standing or cut plant material only, naturally fallen material is called litter. Biomass is expressed as oven-dry mass of per unit area (usually g/m^2, kg/m^2, kg/ha or t/ha or Tg (when summed over the country).

Carbon pools: stores of carbon that when summed make up the total carbon content of the AFOLU sector that include:

- Above and below ground biomass, which is predominantly woody matter
- Dead wood and leaf litter
- Soil organic carbon SOC

Carbon sequestration: the process of the capture (fixing) and storage of atmospheric carbon into terrestrial carbon pools over time that may either be part of the natural process or enhanced through management measures. It is measured in carbon per unit area per unit time and often expressed as $tCO_2e/ha.yr$ (tonnes carbon dioxide equivalent per hectare per year).

Conservation agriculture: a concept that combines a number of land-use management practices to ensure overall agricultural sustainability and soil health.

Cropland: a land use-activity that concentrates and grows plants (cultivation) that are cropped (either whole plants or fruits) for use by humans and domesticated animals, primarily as a food source. Croplands include a variety of plants such as hay, vegetables, cereal crops, sugarcane, orchards and vineyards.

Ecological Recovery/Regeneration: the restoration of natural ecosystems through the natural cyclic processes of renewal of species and their populations (Del Marco *et al*, 2004).

Fynbos: the fynbos biome as per the South African National Biodiversity Institute (SANBI) 2012 VEGMAP (based on Mucina and Rutherford; 2006 and 2014).

Grassland: the grassland biome as per the South African National Biodiversity Institute (SANBI) 2012 VEGMAP (based on Mucina and Rutherford; 2006 and Mucina, *et al.*, 2014).

Humic soils: soils with organic carbon values >1.8% and having a low base reserve (Soil Classification Working Group, 2018; p15).

Karoo: the Nama- and succulent karoo biomes as per the South African National Biodiversity Institute (SANBI) 2012 VEGMAP (based on Mucina and Rutherford; 2006 and 2014).

Land-use activities: any activity upon the land that makes use of the earth surface such as cultivation, grazing, mining, urban development, etc.

Land-use management: any practice used to manage land-use activities, such as tillage, burning regimes, crop rotation, fertilisation, etc.

Mineral soils: soils that do not have a high SOC (<10%.) and cannot be classified as organic or peat .

Organic carbon: carbon that "enters the soil through decomposition of plant and animal residues, root exudates, living and dead micro-organisms and soil biota" (Edwards *et al.*, 1999) i.e. carbon within the soil from a biological source.

Organic soils: soils with a pronounced accumulation of humified organic materials where the surface horizon averages between 10% and 20% SOC and are subjected to extended periods of water saturation (permanent / near permanent). This soil type occurs mainly in valley bottoms and high-altitude plateaux / mountainous regions (Soil Classification Working Group, 2018).

Pasture: is prepared land (ploughed and fertilised) and covered (vegetated) with grass and / or other low plants suitable for grazing of primarily domesticated animals. As such the flora content and density of pastures is managed to ensure benefit for the grazing animals (appropriate grass species, legume species or root crops). Pastures may be annual or perennial, and maybe grazed or cropped (i.e. mown and baled).

Peat soils: soils where the organic carbon content is >20% and are subjected to water inundation or extended periods of water saturation – this is a rare wetland type (Soil Classification Working Group, 2018).

Primary grasslands: Grasslands that have not been significantly modified from their original state and that still retain their essential ecological characteristics and functions; even though they may no longer have their full complement of naturally-occurring species. They have not undergone significant and/or irreversible modification, (Mucina *et. al*, 2014). Essentially these are species-rich grasslands which survive today in a few isolated areas that are generally of no interest to present day anthropogenic activities and seem to have remained so for hundreds if not thousands of years (Bredenkamp *et.al*, 2006).

REDD+ reducing emissions from deforestation and forest degradation.

Rehabilitation: any attempt to restore elements of structure or function to an ecological system without necessarily attempting complete restoration to any specific prior condition (Meffe and Carroll, 1997).

Restoration: the return of a community to its pre-disturbance or natural state in terms of abiotic (non-living) conditions, community structure and species composition (English and Blyth, 1999).

Re-vegetation: replanting vegetation or sowing of seed (may be part of a restoration project).

Savanna: the savanna biome as per the South African National Biodiversity Institute (SANBI) 2012 VEGMAP (based on Mucina and Rutherford; 2006 and 2014).

Secondary grasslands: grasslands that have undergone modification (e.g. through overgrazing, incompatible burning practices (i.e. season / frequency), cultivation / ploughing) but have then returned to grassland through re-colonisation by indigenous grasses (Mucina *et al.*, 2014).

Soil: weathered rock (mineral particles) mixed with decayed organic matter (humus) that contains living matter (supporting a wide range of biotic communities) and is capable of supporting plants (retaining water, providing nutrients).

Soil carbon sink: the value of the pool / accumulation / storage of carbon in the soil and is effectively the calculation of SOC.

Soil organic carbon (SOC): the carbon fraction that is stored in SOM (Edwards *et al.*, 1999); also sometimes referred to as "total organic carbon" in the literature. SOC is the main source of energy for soil microorganisms with 1% SOC content (SOCc) equating to approximately 1.72% SOM per 100 g soil (Edwards *et al.*, 1999; Soil Classification Working Group, 1991).

Soil organic matter (SOM): the organic fraction of soil ranging from undecayed plant and animal tissue through ephemeral products of decomposition to fairly stable amorphous brown to black material, known as humus, which bears no trace of the anatomical structure from which it was derived (Soil Classification Working Groups, 1991; pg 233) i.e. does not include non-decomposed plant and animal residues, but does include organic carbon, organic nitrogen, organic phosphorus etc. – nutrients in organic form. SOM has a number of pools based on turnover time or rate of decomposition, namely:

- Labile pool – fresh residues with relatively rapid turnover (<5 years).
- Resistant residues pool - physically or chemically protected residues that are
- Slower to turn over (20-40 years).
- Stable pool - protected humus and charcoal components that are effectively stable from a human life span perspective (100s to 1000s of years to turnover).

Soil system:	a dynamic system that includes the soil type, classification, chemistry, texture, soil activities and environmental setting that impact on land use, function and carbon sequestration.
Stocking rate:	the number of animals (wild or domestic) of a particular class (often defined by weight and function) allocated to a unit area of land for a specified period (usually the growing period of the vegetation type in question). It can be expressed either in terms of animal numbers per unit of land (animals/ha) or as land area available for each animal (ha/animal) and is usually converted to a standard animal mass, the Large Stock Unit (LSU).
Subsoil:	mineral horizon/s below the topsoil that is/are usually characterised by a diverse range of properties including the accumulation and concentration of quartz in the clay and silt fractions, lower colloidal matter and obliteration of the rock structure. Defined as the soil layer from 0.3 to 1 m depth in this report.
Thicket:	the Albany thicket biome as per the South African National Biodiversity Institute (SANBI) 2012 VEGMAP (based on Mucina and Rutherford; 2006 and 2014).
Topsoil:	the surface horizon, usually mineral, with a greater or lesser amount of humified organic matter. Defined as the top 0.3m soil layer from this report.
Vegetation cover:	the fraction of the land surface covered by vegetation.
Vegetation structure:	the physical nature of the vegetation such as height, the mix of plant forms such as trees, shrubs, grass, the degree of woodiness etc.
Veld / grassland management:	refers to the stocking rate and burning regime applied to an area of grassland or savanna.

INTRODUCTION

The 2020 National Terrestrial Carbon Sinks Assessment (NTCSA 2020) updates and improves on the original 2014 NTCSA (NTCSA 2014) in two important ways. Firstly, it is uses updated and improved datasets on which the assessment is based, and secondly it runs the assessment for three time periods, 1990, 2014 and 2018 allowing for the assessment of rates of change over these periods. A detailed technical report for both the NTCSA 2020 and NTCSA 2014 provide details on methodology and findings and should be consulted in conjunction with this summary report when more detail is required. The full results in digital format, as well as the technical reports, can also be downloaded from the updated South African Carbon Sinks Atlas https://ccis.environment.gov.za/carbon-sinks/. In addition, a QGIS plugin, downloadable from the atlas, has been developed to simplify re-running the carbon sinks assessment as new data becomes available. A full description on the use of the plugin is given in NTCSA 2020.

South Africa's National Greenhouse Gas (GHG) inventory for the period 2000 to 2015 found South Africa's AFOLU sector to contribute 9.3% of total and 4.1% of net national GHG emissions, mostly from the livestock sector, with the land sector being a net sink. This was largely due to increased afforestation of grasslands. Climate change mitigation opportunities within the AFOLU sector resulting from land use and land management change are discussed in section 4.

The NTCSA 2014 and NTCSA 2020 were developed to create a better understanding of the country's mitigation opportunities in the land component of the AFOLU sector. The approach taken is a high resolution, "wall-to-wall" assessment of the country's terrestrial biomass carbon stocks. As far as we are aware, only Australia has attempted a similarly ambitious process. The IPCC (2006, 2019) guidance on National GHG Inventories recommends that parties attempt to move to a more accurate and country-specific Tier 3 approach to monitoring and reporting GHG emissions and changes in terrestrial carbon stocks as soon as possible. It allows for a better understanding of carbon stocks, their dynamics, drivers and climate change mitigation and adaptation opportunities as well as the reporting thereof. As shown in Australia and New Zealand, this requires the development of higher resolution country-specific carbon maps that are a departure from the default IPCC Tier 1 approach. The NTCSA approach is a significant step towards a Tier 3 level and was developed to best suit the South African situation and the ecological data that we have available for the country. It used biomes as its key unit of analysis rather than the land cover classes as adopted by the IPCC National GHG Inventory Guidance. The biomes can, if necessary, be aggregated to the coarser IPCC guideline classes, but we recommend that the base data is reflected at biome level as well. This is consistent with the tier three principle of allowing considerable flexibility in response to the availability of higher quality data and deeper process understanding.

The National Terrestrial Carbon Sinks Atlas is particularly important as it allows the country to track many land-based activities and their impact on carbon stocks. It uses change in land cover as the main determinant of carbon stocks, but supplements this with estimates of standing woody biomass. It can also be used for scenario analyses to understand the carbon outcomes of changes in the spatial extent of certain activities, for example, the restoration of sub-tropical thicket, or biomass from clearing of bush encroached areas or clearing of alien invasive plant species to rehabilitate ecosystems. The method as used in the NTCSA 2020 is poorly suited for tracking individual climate change mitigation projects implementation, as it would require spatial locations of all individual projects before this would be possible. This is due to the slow rate of carbon accumulation and the fact that SOC cannot be directly assessed from available satellite-based sensors. Despite the National Terrestrial Carbon Sinks Atlas making provision for the inclusion of management interventions (such as conservation agriculture), currently there is no map of the spatial locality and extent of such activities.

Background to terrestrial carbon pools and the adopted methodology

The terrestrial environmental carbon stock can be divided into carbon pools to aid with the estimation and reporting of terrestrial carbon stocks. The NTCSA2020 uses the same carbon pool breakdown as used in NTCSA 2014: i.e. Above Ground (AGW) and Below Ground (BGW) Woody biomass carbon, Above Ground (AGH) and Below Ground (BGH) Herbaceous biomass carbon, Litter biomass carbon as well as Soil Organic Carbon (SOC). These pools were calculated for each 1 x 1 km^2 land unit of South Africa (see Figure 1). Changes in land use and land cover can cause changes in the terrestrial carbon stocks. For NTCSA 2020 the 1990, 2014 and 2018 national land cover products were used as the main driver to determine change in SOC. For example, activities such as deforestation or the ploughing and turnover of soils can greatly reduce the SOC carbon pool over time.

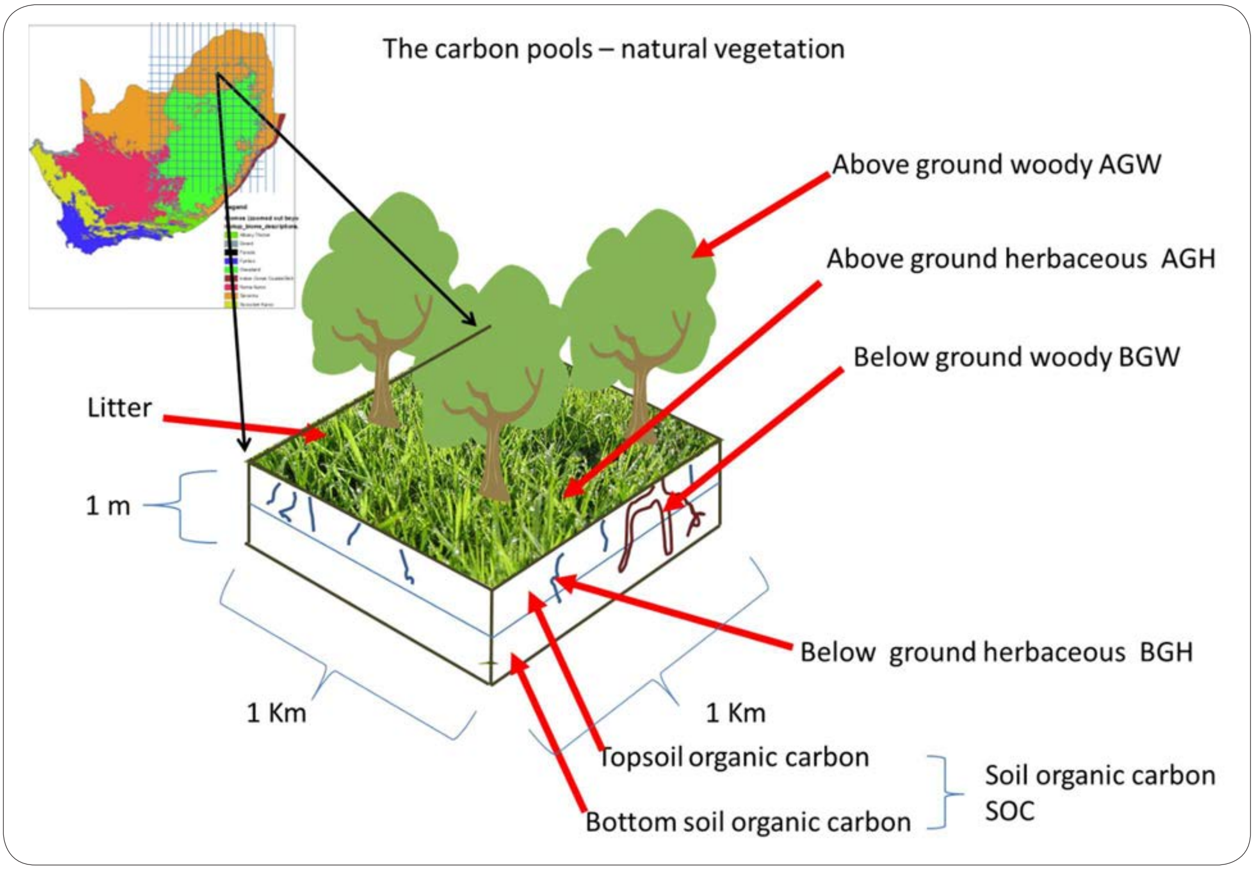

Figure 1: Illustration of the carbon pools analysed per land unit. The entire South Africa is divided into 1 x 1 km^2 land units.

Biomes as the basis of ecological processes

Terrestrial carbon stocks are largely determined by a combination of climate and the nature of the vegetation growing in an area. The vegetation itself is also determined by abiotic factors including soil, processes such as fire and climatic parameters such as the amount of rainfall, the seasonal timing of the rainfall and temperature. Globally, and within South Africa, it is well established that vegetation types that show similar structural and functional features, such as being dominated by grass (grassland) or being dominated by trees (woodland or forest), can be grouped together into groups referred to as biomes. The biomes are also associated with unique envelopes of climatic conditions (Mucina and Rutherford 2006). The dynamics of carbon accumulation in both the plant and soil carbon pools tends to be similar within a biome, making biomes an ideal grouping for the analysis of carbon stocks.

South Africa recognises nine terrestrial biomes: Desert, Succulent-Karoo, Nama-Karoo, Fynbos, Albany Thicket, Grassland, Savanna, Forest, Indian Ocean Coastal Belt, as well as small areas of azonal vegetation such as riparian strips and ephemeral pans (Mucina and Rutherford 2006). Each of these vegetation types has unique ecological characteristics that determine their growth forms, standing biomass, ratio of trees to grass, ratio of plants with different physiologies and fire regimes. Some of these biomes are fire dependent, and in others, fire is much less frequent. These biomes also differ greatly in their response to disturbances and the time required to recover from disturbances.

Estimating and monitoring changes in soil organic carbon (SOC) over time.

The soil organic carbon (SOC) pool is the principle carbon pool in the majority of South African ecosystems (NTCSA 2014), accounting for an estimated 89% of the country's total terrestrial carbon stock. It therefore important to understand its magnitude, determinants and how land-use options either lead to an increase or decrease over time.

The reference SOC is the anticipated SOC of the intact, undisturbed natural vegetation. This was obtained from the World Soils Information's (ISRIC) world soils database which uses a contemporary statistical model to predict the spatial distribution of soil carbon based on an extensive set of South African soil pit data linked to a set of co-variates, including slope, aspect, temperature and rainfall. The methodology is viewed as world class and fortunately South Africa has a relatively large set of soil data for calibration. The loss of SOC due to land cover change (for example from grassland to dryland cultivation) **was modelled based on a refined set of loss factors developed for the NTCSA 2020**. As additional South African soil and carbon dynamics data is collected, it will be easy to improve on both the baseline and loss estimates.

SOUTH AFRICAN TERRESTRIAL ORGANIC CARBON STOCKS

Total terrestrial carbon

It is estimated that South Africa had a total terrestrial carbon stock of approximately 9 258 Tg C in 2018[1]. Of this, approximately 89% was in the form of soil organic carbon, 4% and 5% in the above- and below- ground woody pools respectfully, and only about 1% in each of the remaining pools: litter, above- and below- ground herbaceous vegetation (Figure 2 and 3). Most of the national terrestrial carbon stock was located in the grassland and savanna biomes. Together they accounted for over 66% of total carbon; this matched fairly closely the fraction of the South African land area that they occupied. The stocks in the forest biome (as defined in South Africa to be only indigenous closed canopy forest) may be under-represented in the current estimate due to the method saturating above 120 t/ha standing biomass However, the area of the forest biome is small, so the contribution will remain under 2% even if this known undercounting is rectified. In contrast, the carbon stocks of the Nama-Karoo, Succulent Karoo and Desert biomes are quite small, despite their large extent, due to their hot and arid nature (Figure 3).

It is not possible to accurately estimate the total change in South African terrestrial carbon stocks as a consequence of anthropogenic activities, either against a natural reference or against historic baselines, as there is currently no robust historic estimate of tree cover, and tree biomass makes up about 9% of the total change. However, changes in total SOC *can* be estimated, based on land use. Since SOC forms 87% of total terrestrial carbon, this is the carbon pool that most impacts on national carbon dynamics. It is also important to note that although some areas of the country experienced deforestation decades and centuries ago, deforestation is not a major contemporary driver of land cover change in South Africa (FAO 2016). In this regard, South Africa differs substantially from many other African countries where deforestation contributes extensively to carbon loss (Kutsch *et al.*, 2011). There are however, 28 municipalities where the land cover data **indicates a 54 000 ha loss of indigenous forest between 1990 and 2018 (results per municipality are available from the atlas). 92 districts show an increase in indigenous forest totalling 57 000 ha**. In NTCSA 2020 woodland tree biomass is estimated directly for the year 2014. This direct measure of tree biomass improves on NLC data which has a poor ability to differentiate between natural vegetation classes with different tree densities (GTI 2015). Although woodland cover is known to have increased nationally (Stevenson *et al*, 2016) it is also known that there is a decline in areas **close to rural villages as a consequence of fuelwood harvesting** (Wessels *et al*., 2011).

Most of South African terrestrial carbon is found in natural or semi-natural regions (as opposed to croplands or urban areas). Natural and semi-natural lands constitute 70% of the land area and 73% of the carbon stock. Extensive **areas of semi-natural vegetation are used as rangeland for the farming of livestock and wildlife**. In addition, approximately 8% of the national area is dedicated to wildlife and conservation. Crop agriculture is a relatively small proportion of the total landscape (about 11%), but one of the largest contributors to carbon loss. The 2018 land cover estimates that dryland crops cover 10.2 % and irrigated crops 0.8% of the country. In addition, 3% of the total national land area is classified as fallow cropland. Further transformed land includes urban, industrial and mining areas (2.9%) and plantations of exotic trees (1.7%). Historic and current rates of transformation vary substantively by location and this data is available for each municipality in the atlas.

1 Details of the methodology are given in the more detailed technical report of the NTCSA 2020

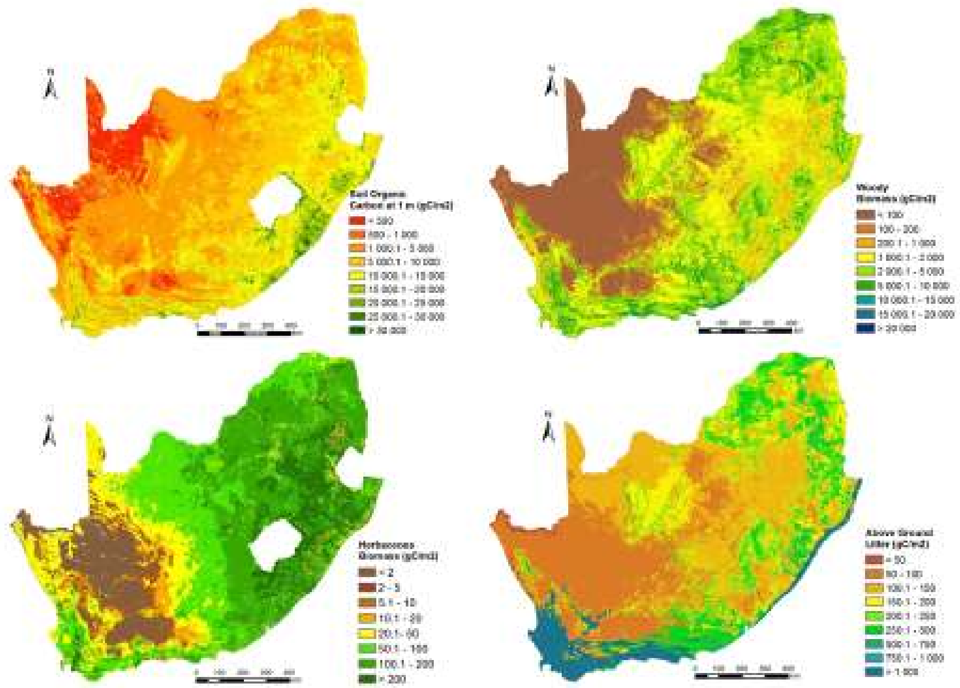

Figure 2: Maps of organic carbon by carbon pool based on the ISRIC reference soil carbon data and 2018 land cover.

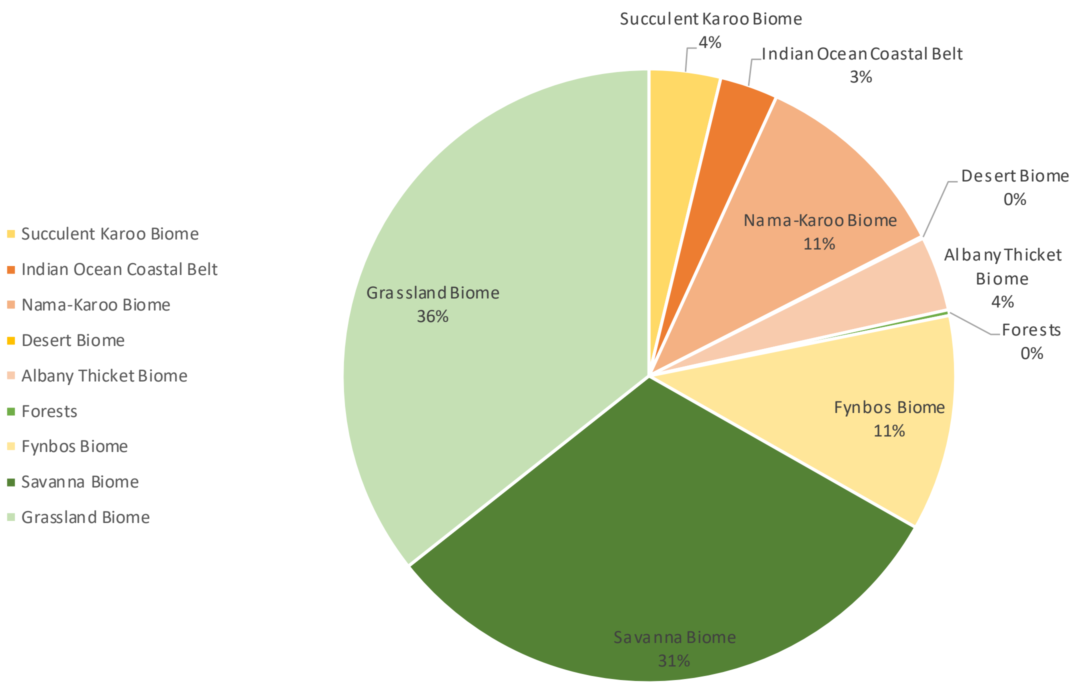

Figure 3: Total organic carbon split by biome using 2018 land cover data and ISRIC reference soils data.

Total soil organic carbon

SOC is the major contributor to total carbon, and the overall patterns of SOC are very similar to those of total organic carbon. Changes in SOC between the dates of the three NLC indicate relatively limited change in SOC between 1990 and 2018 (Table 1), when compared with the substantive changes that took place prior to 1990. Based on land cover change between the 1990 and 2014 NLC products, South Africa had a 0.335 Tg C / yr increase in the top 30cm soil layer (Section 3). The 2018 NLC includes a new land cover class for fallow land. When assumed SOC loss associated with fallow land is included into the 2018 total, this gives an appearance of extensive SOC loss between 2014 and 2018, but this is a misinterpretation of the data as this loss would have taken place over decades and not during that short time period. **The methods we used here (i.e. using NLC data to drive the model) cannot be used to account for soil carbon loss due to land degradation except where the degradation is so severe as to map in the NLC as gullies or bare soil classes**. Potential long term changes in the reference soil values driven by climate change, CO_2 fertilization impacts and changes in rates of nitrogen deposition are not considered.

The reference value used in the soil carbon model is the SOC that would be expected under natural vegetation. Loss compared to the reference value is the historic loss **of SOC due to anthropogenic land transformation**. An estimated 277 Tg of SOC have been lost in South Africa since the advent of crop agriculture and other related anthropogenic disturbances, To put this into perspective, this would be equivalent to the above ground biomass of 42 million hectares of tall forest with 150 tonnes per hectare of standing woody biomass. Much of this loss would have been in the second half of the 20th century, but the current rate of loss is much less in many regions, since the agricultural and forestry land area, in most regions, has been stable for decades.

The provinces with large expanses of crop agriculture are where the highest loss in SOC is observed compared to the reference (Table 1 and 2). **The Free State shows a 12.7% loss of SOC in the top 30 cm soil profile compared to the natural reference**, a total of 55 Tg lost. Other provinces with high losses include Kwazulu-Natal (8.4% 53 Tg), Eastern Cape (6.0% 50Tg), Gauteng (9%, 6tg), North West (10.7% 25Tg) and Mpumalanga (8.2%, 33 Tg). The arid Northern Cape has the lowest loss (2.0%, 11 Tg) and the Western Cape (5.5% 24Tg) and Limpopo (5.8% 24Tg) loss. The difference in size of the provinces coupled with the intensity of agriculture results in the vastly different SOC losses. **The mean reduction in SOC for the country due to cultivation of cropland soils is 7.0%**. The change in SOC in the top 30 cm soil between 1990 and 2014 is relatively small and positive in most provinces, when compared to the full historic loss from reference values. This is explained by the fact that most existing agricultural fields were established by 1990 (often long before), with only relatively small changes in the extent of agriculture since 1990 (Table 1).

Table 1: Total topsoil carbon and % carbon loss from the reference for 1990, 2014 and 2018, by province. The reference carbon is derived from the ISRIC 0-30 cm carbon values. *Note: the carbon loss model only assumes loss from topsoil, not the full soil profile, so the absolute values will be a small underestimate.*

Elements	Reference	1990	2014	2018	Reference - 1990	1990 - 2014	2014 - 2018	Reference - 2018
Province	Total topsoil carbon in Tg				% change			
Northern Cape	537	530	530	527	-1.32	-0.13	-0.58	-2.02
Mpumalanga	407	381	383	374	-6.42	0.66	-2.49	-8.15
KwaZulu-Natal	627	590	585	574	-5.88	-0.96	-1.78	-8.44
Gauteng	66	62	62	60	-7.53	0.24	-2.03	-9.19
Free State	432	382	383	377	-11.74	0.41	-1.53	-12.74
Eastern Cape	830	790	797	781	-4.85	0.78	-1.99	-6.02
Western Cape	436	418	417	413	-4.42	-0.14	-1.03	-5.54
North West	237	216	219	212	-9.11	1.26	-2.97	-10.70
Limpopo	425	409	410	402	-3.97	0.45	-2.11	-5.57
Total	**4 001**	**3 777**	**3 785**	**3 720**	**-5.60**	**0.21**	**-1.73**	**-7.03**

Table 2: SOC by district comparing the reference value and NLC derived results for 1990, 2014 and 2018. Expected losses of SOC from fallow fields has been switched both on and off in the model to show the implications of this new land cover class in the 2018 NLC data.

	SOC amount						% change			
	Reference Soil Carbon Gt	1990	2014	2018	2018 fallow off	Loss from ref 2018	Reference - 1990	1990 - 2014	2014 - 2018	2014-2018 With fallow off
District	Gt						%			
Alfred Nzo	173	168	168	165	168	-8	-3.07	-0.07	-1.59	0.04
Amajuba	81	80	80	79	80	-2	-1.72	-0.20	-0.78	0.25
Amathole	323	317	317	314	318	-9	-1.69	-0.08	-1.07	0.09
Bojanala	119	116	116	114	117	-5	-2.88	0.45	-1.72	0.13
Buffalo City	44	43	43	42	43	-2	-2.84	0.17	-1.09	-0.25
Cacadu	460	447	453	452	453	-8	-2.92	1.33	-0.16	0.05
Cape Winelands	198	196	195	194	194	-4	-0.90	-0.33	-0.73	-0.63
Capricorn	147	144	145	142	144	-4	-1.74	0.21	-1.41	-0.14

	SOC amount						% change			
	Reference Soil Carbon Gt	1990	2014	2018	2018 fallow off	Loss from ref 2018	Reference - 1990	1990 - 2014	2014 - 2018	2014-2018 With fallow off
District	Gt						%			
Central Karoo	195	193	194	193	193	-2	-0.67	0.07	-0.29	-0.24
Chris Hani	374	368	369	367	368	-7	-1.50	0.16	-0.59	-0.20
Cape Town	24	24	24	23	23	-1	-2.80	0.17	-0.71	-0.46
City of Johannesburg	14	14	14	14	14	0	-1.45	0.67	-1.21	-0.04
City of Tshwane	46	45	45	44	45	-2	-2.71	-0.21	-1.04	0.21
Dr Kenneth Kaunda	88	82	82	81	82	-7	-6.88	0.78	-1.60	0.16
Dr Ruth Segomotsi Mompati	121	117	118	116	118	-6	-3.93	0.79	-1.43	-0.05
Eden	257	252	252	251	251	-6	-2.05	-0.02	-0.44	-0.25
Ehlanzeni	305	302	302	300	302	-5	-1.09	0.03	-0.53	-0.14
Ekurhuleni	16	16	16	16	16	-1	-3.94	0.71	-1.10	-0.22
eThekwini	32	31	31	31	31	-1	-2.55	-0.25	-1.78	-0.03
Fezile Dabi	141	129	130	129	130	-11	-7.86	0.19	-0.53	0.10
Frances Baard	64	62	63	63	63	-1	-1.60	0.50	-0.07	-0.09
Gert Sibande	376	360	362	356	361	-19	-4.15	0.44	-1.46	-0.26
Harry Gwala	198	194	193	192	194	-6	-2.11	-0.50	-0.35	0.46
iLembe	55	52	52	51	52	-3	-4.72	-0.69	-0.77	-0.24
Joe Gqabi	302	298	298	295	296	-7	-1.35	0.04	-0.90	-0.65
John Taolo Gaetsewe	55	55	55	55	55	0	-0.13	-0.10	-0.25	-0.02
Lejweleputswa	177	163	164	163	164	-14	-8.00	0.53	-0.63	0.12
Mangaung	66	63	63	63	63	-3	-4.37	0.17	-0.67	-0.22
Mopani	135	134	134	133	134	-3	-1.13	0.05	-0.84	-0.04
Namakwa	370	366	365	363	364	-7	-1.08	-0.26	-0.46	-0.36
Nelson Mandela	19	18	18	18	18	-1	-3.70	0.28	-0.66	-0.10

	SOC amount						% change			
	Reference Soil Carbon Gt	1990	2014	2018	2018 fallow off	Loss from ref 2018	Reference - 1990	1990 - 2014	2014 - 2018	2014-2018 With fallow off
District	Gt						%			
Ngaka Modiri	96	89	90	89	90	-8	-7.01	0.70	-1.58	0.05
Nkangala	162	155	156	153	155	-9	-4.47	0.55	-1.71	-0.14
O.R.Tambo	202	196	196	192	196	-10	-3.05	-0.10	-1.84	0.04
Overberg	145	140	140	139	140	-6	-3.83	-0.14	-0.24	-0.13
Pixley ka Seme	491	490	490	489	490	-2	-0.29	0.02	-0.16	-0.08
Sedibeng	36	34	34	34	34	-2	-5.80	-0.11	-0.63	0.48
Sekhukhune	123	121	121	119	120	-4	-1.99	-0.02	-1.44	-0.70
Mofutsanyane	317	298	298	295	298	-22	-5.98	0.05	-0.98	-0.23
Ugu	106	103	103	100	103	-6	-2.99	-0.53	-2.26	-0.05
Umgungundlovu	161	156	156	155	156	-5	-2.68	-0.36	-0.30	0.34
Umkhanyakude	180	170	169	168	169	-11	-5.56	-0.59	-0.17	0.39
Umzinyathi	108	105	105	104	105	-4	-2.24	-0.36	-1.04	0.25
Uthukela	135	132	132	131	132	-4	-1.92	-0.36	-0.75	0.12
Uthungulu	147	143	143	142	143	-6	-2.68	-0.31	-0.89	-0.03
Vhembe	175	173	173	172	173	-3	-1.11	0.31	-0.80	-0.21
Waterberg	297	288	289	287	290	-10	-2.85	0.34	-0.83	0.30
West Coast	152	146	146	145	146	-6	-3.72	0.08	-0.49	-0.37
West Rand	32	31	31	31	31	-2	-4.66	0.33	-1.03	0.45
Xhariep	211	207	208	207	207	-4	-1.75	0.11	-0.38	-0.07
Z F Mgcawu	150	150	149	149	149	-1	-0.50	-0.04	-0.28	-0.24
Zululand	183	180	179	177	179	-6	-1.91	-0.38	-0.96	0.24
Total	8 584	8 355	8 363	8 298	8 357	-286	-2.67	0.10	-0.78	-0.08

Most SOC is found in the Savanna and Grassland biomes. It is in grasslands where the single largest SOC pool is to be found. **Given that SOC is 89% of the total terrestrial carbon pool, it is clear that grasslands are the most important carbon pool in the country, despite the absence of trees. Savanna is the second most important vegetation type in this regard.** Most carbon is found in **natural and semi-natural vegetation types**, with cropland, plantation forests and urban areas contributing a relatively small (about 17%) amount to the countries total carbon stocks (Figure 4).

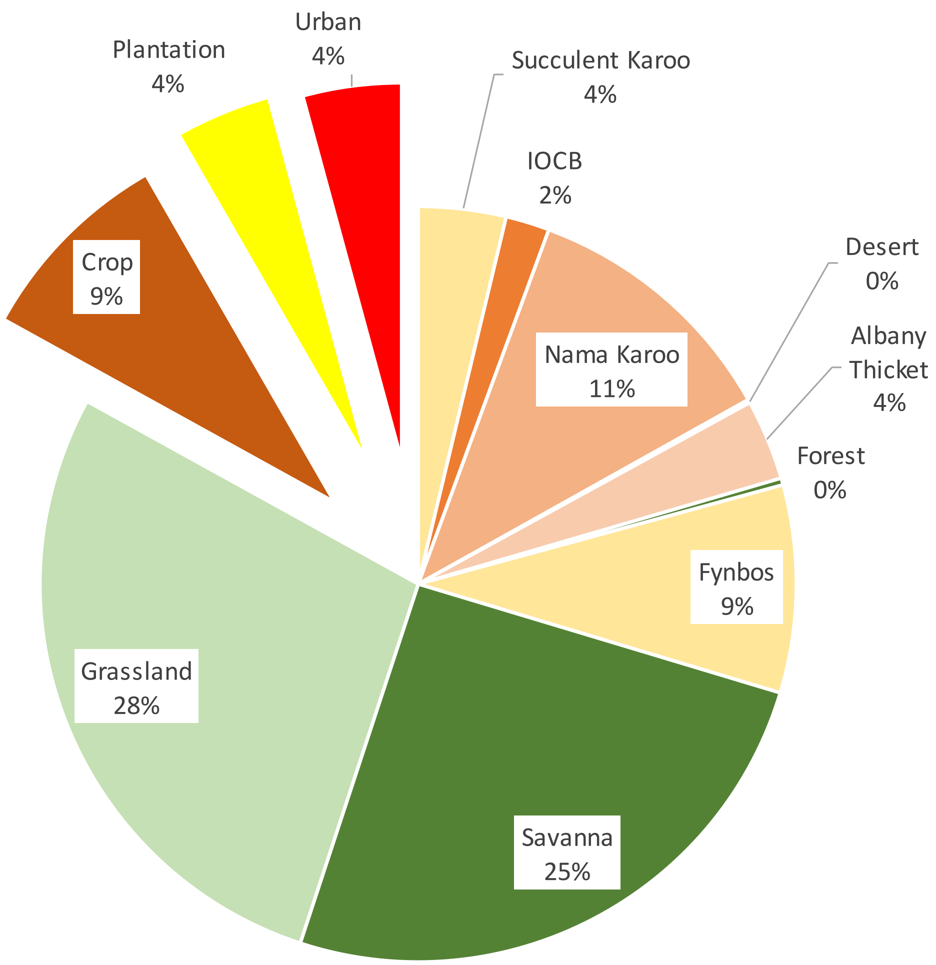

Figure 4: Total organic carbon split by biome, but with transformed classes calculated independently of the natural vegetation of the biome using 2018 land cover data and ISRIC reference soils data.

Total organic carbon in woody biomass

Estimates of carbon in woody biomass are shown in Figure 1. NTCSA 2020 uses a more detailed assessment of woody biomass than what was available in the NTCSA 2014. This new method still has a high variance (i.e. potential error) and this will make detection of small changes difficult. It also overestimates biomass in hilly terrain in arid areas (which have been corrected as per the detailed methods).

The NTCSA 2020 total tree biomass estimates (based on 2015 calibration data) are substantially higher than the NLC 2014 estimates, but as the methodology is fundamentally different, a direct comparison should not be made. It is also noted that the new methodology reaches its maximum value at approximately 120 t/ha biomass. Therefore the biomass of dense tall natural forest and mature plantations may be under-represented. Given the low spatial area of such forests and plantations, the impact on the total national carbon stock is very small, but the local impact (for instance on the carbon stored in individual compartments in a plantation) can be larger. A twenty five-year old eucalyptus or pine plantation may reach a biomass of 180 t/ha. This impact is estimated to be applicable between 0.5 and 1 % of the country's area and may, in the worst case, reduce estimates by a third in these areas. However, over most of the affected area, the under-accounting is likely to be much less than this.

Total carbon in herbaceous biomass

The herbaceous biomass carbon pool in NTCSA 2020 is based on the same methodology used for the NTCSA 2014. The equation estimates natural vegetation herbaceous biomass based on precipitation, soil type and fraction tree cover. In addition, it includes agricultural statistical data on mean crop yields and crop mix per municipal district to estimate the crop biomass on low stature, short duration croplands (Figure 6). The overall contribution of the above ground and below ground herbaceous matter is only about 2%, of the total carbon pool.

Total carbon in plant litter

Litter mass estimates are based on published values per biome, with an additional amount added for dead wood, and are based on a proportion of standing woody biomass. This is assumed to be 10% for natural woodlands, but are reduced to 2% in areas of communal tenure where there is a high demand for fuelwood. Dead wood biomass is typically excluded from litter measurements, which instead focuses on dead fallen leaves, flowers, fruits and small twigs. The total carbon in plant litter including dead wood is approximately 1 % of the total national carbon stock.

BASELINES AND MITIGATION OPPORTUNITIES

NTCSA 2020 provides change data over a 24 or 28 year period which can be used to determine rates of change in SOC stock[2]. It also allows for a comparison against a reference value that assumes no land transformation, but since the reference period is not linked to a specific point in history, no rates of change can be assumed between the reference period and 1990 (Figure 5). **The 1990 to 2014 (i.e. 24 year) change data is based on land cover data that used identical classes and is therefore well suited to developing a baseline of change**. The 1990 to 2018[3] time period, though longer, uses land cover that has slightly different class definitions and is less suited to a baseline. However, the 2018 data standard is likely to be used into the future and is likely to be the data standard against which to monitor future change. In particular, the 2018 NLC data included a new fallow land class that is missing from the 1990/2014 data. Inclusion of soil carbon loss from this fallow class is considered an improvement in the understanding of the national SOC dynamics, but since this class was absent from previous land cover products, **it cannot be used reliably for determining rates of loss**.

NLC 2020 has chosen land cover classes that best represent the common denominator between the 1990/2014 and 2018 NLC classes. When "switching off fallow" and assuming the fallow to have the same values as natural vegetation, data is largely comparable between the **1990/2014 and 2018[4] land cover products**. Baselines based on 2018 data (with fallow excluded) are very similar to the 2014 derived data.

Change in topsoil SOC over the 1990 to 2014 period shows a slight uptake of SOC of 0.335Tg C/yr, but this varies by biome[5], with Grassland and Thicket showing the highest gains, and Fynbos, Desert, Indian Ocean Costal Belt (IOCB) and Succulent Karoo showing losses (Table 3). If the 2018 data is used for the baseline (with fallow impacts ignored), then the overall trends remain very similar, with overall gains slightly reduced to 0.098 TgC/year.

Table 3: Annual changes in the topsoil (to 30cm) carbon stocks per biome between 1990 and 2014 and between 1990 and 2018 (with fallow switched off)

Biome	Annual C change in Tg	
	1990-2014	1990-2018
Savanna	0.0678	0.0965
Nama-Karoo	0.0750	0.0726
Succulent Karoo	-0.0030	-0.0450
Desert	-0.0001	0.0003
Albany Thicket	0.1677	0.1270
Fynbos	-0.0326	-0.1266
Forests	0.0003	0.0010
Indian Ocean Coastal Belt	-0.0513	-0.0448
Grassland	0.1113	0.0173
Total	**0.3352**	**0.0984**

2 Because only 30 cm topsoil is assumed to change in the model, it makes sense to report the results simply for the topsoil and not the full soil profile.

3 The 2014 to 2018 period is considered too short for detecting meaningful change. Also, it is very susceptible to small changes brought about by methodological changes between the 2014 and to18 data.

4 This is important because future land cover is likely to follow the 2018 standards.

5 Data by province and district is available in the main technical report.

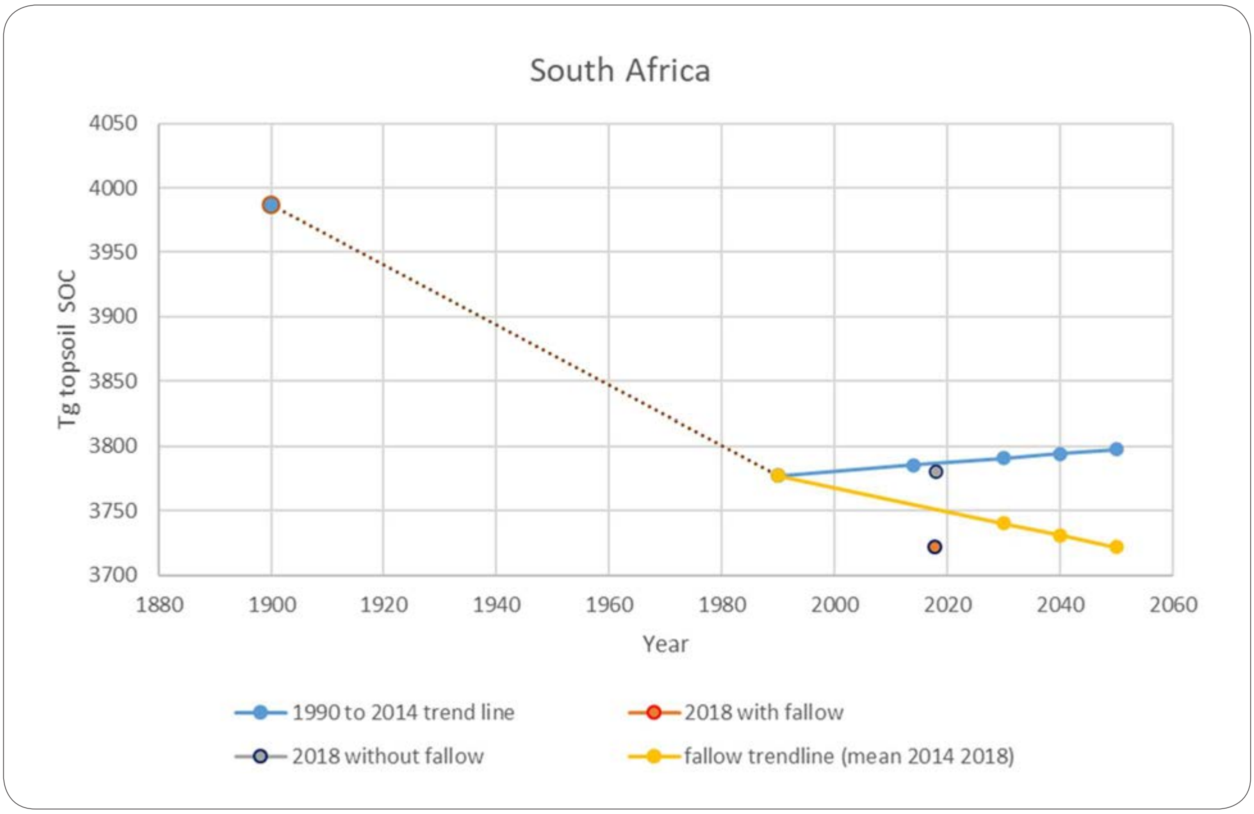

Figure 5: Graph showing national baseline projections based on the 1990 to 2014 trends (blue line). The yellow line is based on 2018 data with fallow land impacts included and is calculated as the mean change between 2014 and 2018. However, since the age of fallow lands is not known, this is not recommended as a baseline.

POLICY IMPLICATIONS

Drivers and trends in soil carbon

The Carbon Atlas confirms that the overwhelming majority of South Africa's terrestrial carbon pool is **located below ground, in the form of soil organic carbon (89%).** It further shows that 36% is in the Grassland biome and 31% in the Savanna biome. The driver of carbon loss as computed in the NTCSA 2014 and NTCSA 2020 is a change in land cover. This means that carbon is lost when a biome is changed from its natural state to a transformed state. The proportional loss of natural vegetation per biome is given in Table 4 and Table 5. In terms of large-magnitude climate change mitigation potential, the key questions are whether these natural landscapes are under threat of degradation; and if there is good opportunity to restore already-degraded areas within these biomes to their natural state. We are currently unable to quantify carbon loss due to degradation within natural vegetation unless it results in bare ground or a new and transformed land cover. **Data sheets are provided on the Atlas interface page for each district municipality.** These sheets specify the amount and rate of change of key land use classes). Data per local municipality can be substantially different from national trends and is provided in the online Atlas. Some of the largest changes between 1990 and 2018 (as identified from the respective land cover products) are an increase in fallow land 3 710 470 ha)[6], increased built up areas (547 165 ha) and increased pivot agriculture (790 013 ha, though much of this is from areas of existing dryland agriculture). Mines, though they are increasing rapidly, only account for a loss of 5 525 ha. Some land uses, such **as commercial agriculture** (- 1 4449 231 ha) have actually declined nationally during this period, **despite increasing in 18 municipalities.**

6 It is possible some of this fallow land might have existed before 1990 since the 1990 land cover did not include a fallow class.

Table 4: The extent of loss of natural vegetation per biome and the land cover that has replaced the natural vegetation based on 2018 national land cover data. Top km² and below as a percent of the biome area.

		Natural vegetation	Natural vegetation and bare ground	Crop agriculture	Plantations	Urban and mines	Bare ground	Fallow	Water bodies
Albany Thicket	km^2	26 504	27 416	2 298	77	745	912	744	180
	%	*84.2*	*87.1*	*7.3*	*0.2*	*2.4*	*2.9*	*2.4*	*0.6*
Desert*	km^2	1 461	7 169	19	0	108	5 708	13	38
	%	*19.9*	*97.6*	*0.3*	*0.0*	*1.5*	*77.7*	*0.2*	*0.5*
Forests	km^2	935	937	39	97	3	3	7	6
	%	*85.8*	*86.0*	*3.6*	*8.9*	*0.3*	*0.2*	*0.7*	*0.6*
Fynbos	km^2	56 733	60 821	18 536	1 068	1 508	4 087	2 667	626
	%	*66.6*	*71.4*	*21.7*	*1.3*	*1.8*	*4.8*	*3.1*	*0.7*
Grassland	km^2	201 773	208 186	74 882	13 947	12 553	6 413	13 291	2 572
	%	*62.0*	*64.0*	*23.0*	*4.3*	*3.9*	*2.0*	*4.1*	*0.8*
Indian Ocean Coastal Belt	km^2	7 974	8 191	2 677	1 354	2 843	217	833	646
	%	*48.2*	*49.5*	*16.2*	*8.2*	*17.2*	*1.3*	*5.0*	*3.9*
Nama-Karoo*	km^2	169 751	254 601	3 032	37	807	84 850	1 131	598
	%	*65.2*	*97.8*	*1.2*	*0.0*	*0.3*	*32.6*	*0.4*	*0.2*
Savanna	km^2	327 499	332 948	32 801	3 954	16 538	5 449	17 407	1 270
	%	*80.9*	*82.2*	*8.1*	*1.0*	*4.1*	*1.3*	*4.3*	*0.3*
Succulent Karoo*	km^2	60 878	83 434	1 742	7	662	22 555	1 014	95
	%	*70.0*	*96.0*	*2.0*	*0.0*	*0.8*	*25.9*	*1.2*	*0.1*

* Note, in the Desert and Karoo biomes bare ground (as mapped by NLC), may well represent the natural state and is not necessarily a degradation.

Table 5: Change in area of land use over the 1990 to 2018 period based on NLC data. A negative represents a reduction in the land use class, with a positive number an increase.

Land use class	National change in the area of the land use class in ha. 1990 - 2018
Natural Vegetation	-2 517 011
Bare degraded	-923 674
Built-up	547 165
Fallow	3 710 470
Water	-31 498
Wetlands	-471 527
Indigenous Forest	57 963
Commercial Agriculture	-1 449 231
Pivot Agriculture	790 013
Orchards	-8 909
Viticulture	-19 748
Pineapple	-7 262
Subsistence Agriculture	71 495
Sugarcane Irrigated	14 067
Sugarcane Dry	55 834
Plantation Forest	139 182
Mines	5 524

The NLC products recognise bare ground (which includes gullies) as a class, but the extent of carbon loss associated with this class is poorly understood. Furthermore, the extent of this bare ground class is strongly impacted by rainfall patterns in the year prior to assessment; thus areas classified as bare one year may be vegetated the next, and little change in carbon stock will have occurred. A substantial analysis is required to understand the full opportunity for ecosystem and carbon stock rehabilitation. To achieve carbon gains also requires an understanding of the **social, governance and economic issues that constrain the actual opportunity to change land use and management practices**. In a similar manner, an analysis of current and future drivers is required to develop a reference level for the **grassland and savanna** biomes to be able to implement an avoided degradation program at a national scale.

Required supporting policy and legislation, already exists as a considerable set of national policies and plans aimed at maintaining intact landscapes and restoring rangelands where they are degraded. These include the **Conservation of Agricultural Resources Act 1983** and the **National Environmental Management Act**

2002. The National Development Plan 2030, one of the country's main strategic policies, states:

"Long-term ***planning to promote biodiversity and the conservation and rehabilitation of natural assets*** *is critical, and should be complemented by a strategy for assessing the environmental impact of new developments as an important component of overall development and spatial planning. Where damage cannot be avoided or mitigated, and where* ***the social and economic benefits justify the development, a commensurate investment in community development and the rehabilitation and conservation of biodiversity assets and ecosystem services is required."*** (NPC, n.d: 201).

Further, the country has committed to the United Nations Convention to Combat Desertification (UNCCD's). South Africa has set restoration targets, that if achieved would all simultaneously achieve mitigation objectives (DEFF 2017).

Despite strong policy support, implementation frequently falls short, both in terms of the roll-out of on-the-ground restoration activities, as well as the governance of practices that lead to the loss of soil carbons. Examples of this are the inappropriate allocation of licences to plough grasslands, or a lack of policing of unlicensed new field creation. Substantial additional emphasis needs to be placed on both the formulation of appropriate policies, and the resources and mechanisms to ensure that governance and enforcement takes place. The provision of incentives for land stewards to manage rangelands in a sustainable manner is another area that deserves attention. An example is the expansion of the Biodiversity Stewardship Program, currently being led by the South African National Biodiversity Institute (SANBI), to address carbon stocks. In the case of the LDN targets it is of concern that with the possible exception of the clearing of Invasive Alien Plants (IAPs), there is no clarity given on the spatial location of where interventions will take place, or the mechanisms (both policy and implementation) that will be used to achieve the objectives (von Maltitz *et al.* 2019).

Soil carbon and conservation agriculture

A recent analysis by Findlater *et al.* (2019) noted that full conservation agriculture (CA) is currently been implemented across 14% of the 4.4 million hectares of cultivated area in South Africa with partial implementation over an even wider area. Furthermore, implementation is concentrated in certain provinces, for example, the Western Cape, and is lacking in others.

There is an opportunity to enhance and expand the implementation of CA across the country. Implementation has the potential to reduce atmospheric GHG emissions and ameliorate the impacts of climate change in several ways. Not only does CA generally increase soil organic carbon stocks, but it requires substantially less diesel for traction and in certain cases, can decrease nitrogen fertiliser requirements.

Based on evidence to date, a national policy foundation has been created. The Conservation of Agricultural Resources Act 1983 strongly supports measures that improve soil health and reduce erosion. More specifically, a Draft Conservation Agriculture Policy was published in February 2018 by the Department of Agriculture, Forestry and Fisheries (DAFF) which provides a vision, principles and an implementation plan for CA. The growing emphasis on CA is not only due to its potential climate change mitigation benefits, but also its positive benefits with respect to soil health, soil erosion, water services and the cost of production. Within the climate change response space, it is often viewed as a key climate change adaptation opportunity, in addition to reducing GHG emissions.

In terms of understanding the spatial extent of the opportunity, the current Carbon Atlas provides an indication of the total extent of ploughed lands. In order to fully understand and develop CA at a national scale, more detailed mapping of commodity types and agronomy practices is required. Furthermore, the impact of CA is not the same across all soils, climate, crop types and agronomic practices. Additional monitoring and research is required to understand its full potential, cost and climate benefits at country scale.

Use of trees for sequestering carbon

Re-afforestation and tree planting in general is seen globally as a mechanism to increasing carbon sequestration. However, in the South African context tree planting (or increasing of tree density) needs to be considered contextually and although there are a number of situations when it may be appropriate, there are also many situations when it is an inappropriate mitigation measure (Cherlet 2018). A **key environmental and biodiversity consideration in South Africa is IAPs and the impact they have on the flow of ecosystem benefits including reducing available water**. In this regard, the country has initiated wide scale clearing of IAPs (van Wilgen *et al.* 2001, Le Maitre *et al* 2002, 2016). Further bush encroachment also potentially threatens ecosystem services and is being actively cleared in many places. In the context of carbon stocks tree planting should occur following a systematic approach such as REDD+ with the aim to reduce deforestation and reduction of GHG emissions from degradation of natural forests, woodlands and thickets.

Rehabilitation of degraded forests, woodlands and grasslands

There are a number of localised situations in the country where indigenous forest and woodland have been degraded, or totally destroyed. Restoring these areas could form part of the South African REDD+ program and would enhance biodiversity and carbon sequestration. For example, the restoration of **tall indigenous forest in the costal belt between Pongola and Port St Johns would be appropriate** as there are good records that the forest has been destroyed in this area. It must be borne in mind that the contribution that can be gained from tree planting is a fraction of the magnitude that can be gained from increasing carbon through the restoration of soil organic carbon. However, in degraded areas there is a double benefit, since tree planting will also enhance soil carbon. Tree planting within natural grassland has a relatively limited effect on soil carbon (either positive or negative) in South Africa, though this finding is based on only a few studies. Tree planting might be appropriate in the following areas:

- Reforestation within the historic extent of the forest biome, using location-appropriate species.
- Parts of the Indian Ocean Coastal Belt that were historically indigenous forest and woodland and have become degraded.
- Afforestation or reforestation in urban (including rural semi-dense settlement) areas which where deforested through fuelwood collection.
- Degraded woodlands in areas of the former homelands (an example is the area around Bushbuck Ridge) where fuelwood collection has reduced woody cover (Wessels *et al* 2014).

It is important to point out that the area where tree planting (or naturally allowing trees to reestablish) can be used as a mitigation strategy is relatively limited. Although this strategy can have high localised impacts on carbon stocks, and co-benefits in terms of livelihoods and ecosystem services, their contribution to the national GHG budget will be relatively small.

Rehabilitation of grasslands

The grassland biome is extensively used for livestock rearing and has been degraded through mismanagement over vast areas. NTCSA 2014 identified grasslands as a key restoration opportunity. This is due both to the high SOC potential of grasslands as well as the perceived high levels of degradation. Although grassland transformation to other land use is easily mapped, grassland condition and grassland SOC content cannot be derived from NLC or other current satellite data products. NTCSA 2014 estimates of the extent of mitigation opportunities based on expert opinion. Despite some restoration initiatives, there is no evidence of change in this opportunity between 2014 and 2020.

Grassland are also susceptible to both invasive alien plants and bush encroachment. Both these impacts are considered degradation from a biodiversity perspective, but both may lead to increased above ground carbon stocks, and potentially increased SOC. Trade-offs between meeting carbon versus biodiversity and livestock production objectives may be unavoidable (see sections below).

Rehabilitation of thicket vegetation

Thicket has an unusually high woody biomass and SOC for its rainfall (Mills and Cowling 2010, van der Vyver and Cowling 2019). Woody carbon stocks can reach 80tC / ha (van der Vyver and Cowling 2019) with SOC reported to be as high as 133 t /ha (Mills *et al.* 2005), although the results of this Carbon Atlas study indicate that the average levels of both soil and biomass carbon across the biome are much less. Thicket and especially spekboom-rich thicket has the tendency to collapse with over browsing, resulting in an associated substantive losses of carbon. The thicket does not spontaneously recover in reasonable time periods (Acocks, 1953, Lechmere-Oertel *et al.*, 2005a, Lechmere-Oertel *et al.*, 2005b, Stuart-Hill, 1992, Mills and Cowling 2006). Numerous studies have found that artificially establishing spekboom (*Portulacaria afra*)[7] can help initiate a recovery process (Mills and Robson 2017, Panter and Ruwanza 2019). Thicket has also been cleared for crop agriculture, and this trend continues. When thicket is converted to cropland, not only the woody biomass gets lost, but in addition there is a substantive reduction in SOC (van der Vyver and Cowling 2019). Restoring this vegetation, either from former fields or from a degraded state therefore has the ability to sequester significant amounts of carbon.

A number of ambitious programs have been initiated to restore thicket. Progress to date has been mixed (Mills and Robson 2017, Panter and Ruwanza 2019). The ability to rapidly sequester carbon through thicket rehabilitation may well have been exaggerated in the past. Nevertheless, restoring **thicket remains an attractive option from a biodiversity, ecosystem services and carbon sequestration perspective, even if gains are slow**. Rates of between 1 and 2.3 t C/ha/y are realistic based on assessment of a range of projects, with higher rates possible in favourable habitats (van der Vyver 2017, van der Vyver and Cowling 2019). Since the upper limit of the total thicket carbon stock per hectare is likely on average to be of the order of 100 tC/ha, and recovery begins from a base of about 40 tC/ha (mostly in the soil), this rate of per-hectare carbon assimilation can be expected to last for around 30 to 60 years on a given site.

Bush encroachment

Increased woody plant biomass in savannas and grasslands, referred to in South Africa as bush encroachment, has been documented over vast areas of both biomes (Ward 2005, O'Connor *et al*, 2014 Skowno *et al.*, 2016, Stevens *et al.* 2016). This phenomenon is widespread, though neither the spatial extent nor the spatial location of the problem has been accurately determined, especially for within the savannas (Turpie *et al.* 2018). Skowno *et al* (2016) found that approximately 57 000 km^2 (17%) of grassland are impacted by bush encroachment, but estimates for the area affected in savannas are speculative, since these areas always contained trees. Turpie *et al.* (2018) reviewed the available literature, and suggest that between 57 000 (8%) and 130 000 km^2 (17%) of the combined **savanna and grassland** areas are impacted, though none of the studies they quote claim to provide anything other than an expert-judgement estimates. The biomass consequences of bush encroachment are captured as part of the **total above** and **below ground woody** component in the NTCS 2020, but cannot be separated from non-encroached woody components. Much of the reported encroachment occurred decades ago, starting in the early part of the 20th century.

Bush encroachment clearly increases standing woody biomass. It also probably also increases soil carbon, though local studies on this are scarce and international studies suggest impacts can be in either direction, dependent on rainfall (Barger *et al.* 2011).

Turpie *et al.* (2018) found that in almost all cases woody

7 Spekboom (Portulacaria afra) is a drought hardy, succulent plant common to the thicket biome. It can alternate between the standard C3 photosynthetic pathway, and the more drought-resistant CAM pathway. Although using spekboom as a mechanism for re- vegetation thicket is appropriate, the use of spekboom for carbon sequestration in other biomes will probably show limited or no success, and biome-appropriate species are a better approach. Although spekboom can be easily established under favourable conditions, overall establishment success rates are low. It is slow growing (in terms of amassing woody biomass), as is common with most CAM plants. The stems have a low wood density with high water content meaning that even a relatively large spekboom plant has a low dry biomass and low carbon content. Spekboom planting should not be encouraged as a mitigation option outside of the thicket biome (and selected areas on the Nama-Karoo where spekboom historically occurs) as it is likely to sequester carbon at slower rates than many other tree species. The exceptionally high rates of spekboom carbon assimilation reported in popular literature appear to be an exaggeration and need scientific assessment. Many studies suggest that rates of carbon assimilation by spekboom are more modest (Smart 2016, van der Vyver and Cowling 2019, Panter and Ruwanza 2019)

encroachment, though potentially beneficial from a carbon sequestration perspective, has a net degrading impact in the sense that it reduces the net flow of other ecosystem benefits, grazing in particular. Clearing of bush encroachment is therefore likely to continue in South Africa.

Finding mechanisms to permanently capture the sequestered carbon in bush encroached areas represents a mitigation opportunity. Opportunities include offsetting fossil fuel consumption by burning biomass from the clearing of encroached lands **for power generation; space heating; industrial heat and cooking; or partly charcoaling the biomass and using it as a soil supplement in the form of biochar**. Note, that all these options (with the possible exception of space heating and combined heat and power), have a relatively low efficiency of conversion of biomass to benefit[8], and **other life cycle emissions** may be involved, meaning the total fossil fuel offset or amount sequestered will be substantially less than the carbon in the original biomass. The economics of these mitigation options are not presently favourable from a commercial perspective in most cases (Stafford *et al.* 2018).

Invasive alien plants

South Africa, through the Working for Water program (WfW) actively clears Invasive Alien Plants (IAPs) throughout South Africa (van Wilgen *et al.* 2001, Le Maitre *et al.* 2002, 2016). These plants often have a large woody component and their clearing represents an emission of carbon from the woody carbon pool. A 2011 estimate done by Le Maître and Forsyth 2011, based on the data from Kotze *et al.* (2010) suggests that woody alien invasive plants may account for as much as 168 Tg of woody biomass. These IAP are scheduled for eradication and if all were eradicated this would result in 80,6 Tg of emitted carbon. However some of this carbon could, potentially, be captured in other carbon pools for instance in agricultural soils or as mulch or stems and could be used to stabilise degraded lands and enhance carbon stocks. This biomass could also be used as fuel and hence offset fossil fuel use as with bush encroachment (Stafford *et al.* 2018). The biomass carbon of these plants is included in the woody biomass pools in the NTCSA 2020 and cannot be separated from other woody biomass pools using available data. The same logic applies to IAPs as to bush encroachment in terms mitigation opportunities.

Plantation forest

According to Forestry South Africa (FSA 2017) there are 1 212 383 ha of plantation forest within South Africa. The NLC 1990 NLC 2014 and NLC 2018 put plantations at 1 867 169 ha and 2 053 327 ha respectively. This apparent increase in plantation area between 2014 and 2018 is a consequence of **classification methodology rather than a true change**. The difference between the land cover product estimate and FSA statistics is not explained, but probably relates to some under-reporting of FSA by small growers, as well as the many afforested areas that are not commercial forestry **(such as wattle thickets established as woodlots**). **FSA has indicated that the formal forestry industry has shrunk from a peak of 1.5 m ha in 1996/97**. It does, however, still produce as much timber due to the use of faster growing trees and probably has a very similar standing biomass, despite its slightly reduced area. Some areas in the **Western Cape are being de-commissioned as forests and returned to fynbos vegetation, a loss of standing biomass and carbon**. In the remainder of the country the industry appears to be relatively constant.

Using the NLC 2018 data, plantations only cover 1.68% of the South African land surface, and although they can have a high standing biomass of wood at maturity, their

8 A highly efficient biomass to electricity plant is likely to only achieve 20 to 25% efficiency, where combined heat and power (CHP) is involved about 80% efficiency can be achieved, however a domestic or industrial use for the heat is required and it is a far mor complex system (Padinger *et al.* 2019).

overall contribution to the national carbon stock remains relatively small. Estimates done for NLC 2014 found the standing woody biomass carbon from the forestry industry to be in the region of 42 Tg C. **This is about 33 t/ha carbon averaged over the industry**.

Plantations are grown in rotation. The rotation period can be as short as 6 years for Eucalyptus grown **for pulp, but may be 30 years or more for pine grown for saw-timber**. The forestry industry is in a relative equilibrium in terms of the fraction of plantations in different age classes and as such has a relatively constant carbon balance. To change the contribution of plantation forestry to carbon mitigation will require an increase **in the spatial extent of the industry**. The opportunity to do this is very limited[9]. A **300 000 ha** increase in the area planted by the industry (as has been suggested by increasing plantations in the Eastern Cape) would theoretically sequester approximately about **1010.8 Tg of carbon**. This is only about **2.88 % of the current national woody biomass**.

Changes in species choice or rotation length can make small changes to the carbon stocks in the plantation forestry sector.

Given that the area of plantation forestry is relatively stable in South Africa, and given its relatively low contribution to national carbon stocks, there is limited leverage in this sector other than through changing the area of land allocated to the sector, which is unlikely given water-use constraints. **Use of forestry biomass waste as a feedstock for power generation could make a substantive contribution to offsetting fossil fuel emissions.** There are currently substantial waste streams that are ineffectively used. Encouraging independent power producers using biomass waste and feeding electricity into the grid could be a policy option, but to date there is low uptake due to feeding tariffs and regulations.

Tree planting

Planting of trees can help sequester carbon from the atmosphere and is globally advocated as a mitigation opportunity. There are clear opportunities for the use of planting of trees for mitigation (as listed below), but the value of widescale and indiscriminate tree planting as a mitigation activity within South Africa has been questioned by Bond *et al*. 2019.

The planting of alien tree species (or even indigenous species, but out of their normal area of occurrence) over large parts of South Africa is a contentious issue. As pointed out above, both bush encroachment and IAP already increase tree biomass in some areas, with negative consequences to stream flow, biodiversity and other ecosystem services. Rising atmospheric CO_2 concentrations may favour tree growth even in areas not considered encroached (Bond and Midgley 2011). Furthermore, as Bond *et al*. (2019) notes, much of South Africa is naturally not covered in trees and should therefore not be converted to a tree-covered landscape.

Tree planting as a mitigation activity should therefore be limited to a few select situations such as:

- Restoration of degraded forest, thicket and woodland (using a range of indigenous species)
- Urban greening, where alien but non-invasive species are acceptable.

Tree planting must not be seen as a panacea for mitigation within the South African context. Tree planting in natural grasslands (other than as a component of commercial forestry), motivated as a climate mitigation activity, should not be permitted. As noted in the mitigation opportunities in NTCSA 2014, commercial forestry expansion opportunities are extremely limited due to water constraints.

9 Plantation forestry is considered as a water using activity and requires water licencing. Almost all catchments except a few in the Eastern Cape already have all their water allocated, meaning that additional plantation are not feasible.

Trade-offs between carbon mitigation and other objectives

Land restoration or rehabilitation can represent a win-win situation. In many situations, not only is carbon sequestered, but biodiversity is improved, livelihood opportunities are created and hydrological function is restored. There are, however, other situations in South Africa where increasing carbon stocks has negative consequences on other ecosystem services. Inappropriate tree growing, plantation forests, bush encroachment and IAP invasion all have negative impacts on biodiversity, streamflow and in some cases additional flows of ecosystem goods and services. Potential trade-offs and synergies need to be part of the consideration before large scale mitigation projects are contemplated.

Capturing biomass carbon as biochar

Biochar is an effect charcoal, though the pyrolysis process may be terminated before completion. If buried in the ground it can have a half-life reported to range from hundreds to thousands of years. Biochar can be beneficial to crop agriculture in many circumstances, increasing yields through interactions with fertilizer use and soil moisture. In many ways it seems a win-win for sequestering carbon from unwanted woody biomass such as from AIP and bush encroachment. There are, however, concerns that the benefits are situation dependent. They differ by crop, feedstock used to generate the biochar, method of pyrolysis and soil type. Clarity is needed on these aspects before widespread implementation is contemplated. Biochar was identified as a mitigation opportunity in NTCSA 2014. As yet no large scale projects have been initiated and the potential therefore is assumed to remain unchanged.

Anaerobic digesters

Impact of anaerobic digesters as a mitigation opportunity cannot be addressed from the NLC based modelling data, and needs to be obtained from an inventory of biogas digester uptake. Despite the high potential, it appears that actual uptake of biogas projects is relatively limited (Kemausuor *et al.* 2018, GIZ 2016, Mukumba *et al.* 2016, Mutungwaz *et al.* 2018). It is therefore assumed that this mitigation opportunity as identified in the NTCSA 2014 remains relatively unchanged as no data to the contrary could be found.

CONSTRAINTS OF ANALYSIS

The Carbon Atlas provides a robust estimate of terrestrial carbon stocks at a national scale, based on biome, tree cover and land cover data. However, as with any technique or process, it has its limitations, some of which can be relieved through future development.

Constraints to estimating carbon stocks

The methodology provides a more accurate estimate of carbon stocks in pools that are directly observable through remote sensing, such as above ground woody carbon stocks. There is opportunity to further improve these estimates, especially where a particular understanding of species, land management, level of degradation as well as a time dimension is required.

For example, in the context of estimating the impact of ploughing, land abandonment or conservation agriculture on soil organic carbon stocks, there is currently no understanding of the effect of time since abandonment or adoption of conservation agriculture. To undertake such an analysis, each parcel of ploughed land would need to be tracked over time, including data on crop type and form of agronomy. This would allow transition functions to be used to estimate the change in carbon stocks over time, rather than the step-wise change currently adopted.

A further example is understanding levels of degradation within a land cover class (e.g. within the Grassland or Forest). For example, although some forests of the Wild Coast may be severely degraded in their understory layers (Mangwale *et al.* 2017), the impact of this degradation on terrestrial carbon stocks will not be visible to current techniques based on canopy height and canopy cover. An additional understanding of the spatial extent and distribution of sub-canopy degradation, particularly the reduction in carbon stocks, is required to reflect this impact more accurately in national scale reporting.

Reference baselines of soil organic carbon continue to improve, but there is a need to have ongoing South Africa-specific validation of the reference values. The ISRIC model can be substantially improved through use of South Africa-specific predictive co-variables, and an increased number of South African soil profiles in the training and validation datasets, particularly for soils under natural vegetation.

How might carbon stocks change as a consequence of global change?

Climate change, including rising temperatures, precipitation changes and rising atmospheric CO_2 concentration, all impact the key processes of net primary production, respiration and decomposition, and have secondary impacts on fire and herbivory regimes. This means that the reference value of the natural vegetation will change over time. The NTCSA 2014 undertook some initial estimates of these likely changes, but due to the high degree of uncertainty of these estimates more research is needed. The NTCSA 2018 has not attempted to update this data, though the modelling interface could be used when new data sources and equations become available.

Constraints to informing and reporting climate change mitigation activities

The Carbon Atlas shows the current spatial distribution of terrestrial carbon stocks and their relative magnitudes, but does not necessarily reveal opportunities to reduce GHG emissions or sequestrate additional carbon. It guides the reader to those areas of the country where there are larger carbon stocks and to the larger pools, but more precise prioritisation of opportunities requires further understanding of carbon stock losses to date, as well as insights into the drivers of change. Understanding drivers and how carbon stocks have changed historically and may change in future, is pivotal to understanding the opportunity for REDD+ and avoid rangeland degradation programmes.

It is also important to understand the impact of mitigation measures on South Africa's net GHG emission profile, inclusive of phenomena such as bush encroachment, the adoption of conservation agriculture and the abandonment of small-grower agriculture in some areas.

Further to identifying the areas with biophysical opportunity for mitigation projects, an understanding of the land-use, governance, social and economic context is required in order to assess the acceptability and viability of such projects. Land based climate change mitigation often requires commitment to a significantly different form of land use for a period of 20 to 30 years. It therefore requires the development of full implementation and business plans that require a broad range of input data.

In conclusion, the Carbon Atlas provides crucial, world-class data for the South African national GHG inventory, and important information that allows national climate change mitigation and adaptation strategies to be developed in an informed manner. It has limitations in terms of understanding the full scope of opportunities and monitoring and reporting individual small-scale activities.

Constraints to identification of degradation impacts on soil carbon stocks

Many of the mitigation opportunities identified in NTCSA 2014 were based on expert estimates of carbon loss due to degradation of natural vegetation. These estimates are simple estimates on the proportion of different ecosystems that have been degraded and are neither mapped or location specific. Further, data on the extent of carbon loss, and especially SOC loss is poorly researched. The NTCSA 2014 did not account for this loss in its assessment of total carbon stocks (other than through the mapped woody biomass). This is also true for the NTCSA 2018. We currently have no mechanism to generate accurate baseline data or to measure progress on reaching the targets as identified in NTCSA 2014. Possible solutions to this are discussed below.

Monitoring land degradation based on satellite imagery within South Africa has proved to be exceptionally challenging (Wessels *et al* 2009, Prince *et al* 2018, Von Maltitz *et al* 2019). The main reason for this is that inter-seasonal rainfall responses of the vegetation tend to be of a far greater magnitude that the degradation signal. All of South Africa, and particularly our arid areas, have high inter-seasonal rainfall variability, often with periods of above or below average rainfall driven by El Niño-Southern Oscillation (ENSO). Many, even complex, degradation indices appear to track these climatic events rather than degradation (von Maltitz 2019).

As noted previously, we currently have no method of reliably and repeatedly detecting degradation except in situations where the severity of degradation results in the bare and eroded land cover classes in the NLC data. We also have an exceptionally limited understanding of soil carbon dynamics in these areas, although it is assumed that this level of degradation will lead to SOC loss. These areas are, however, the main target areas for many mitigation opportunities. Developing mechanisms to monitor vegetation and SOC changes in these areas remains a challenge.

Two possible solutions are suggested:

1. The use of a bottom up approach based on individually identified restoration projects. This would require restoration projects to determine their own baseline as well as to map their spatial extent. Individual projects could then report on progress which could be consolidated at the national level. This approach could be used for both natural vegetation as well as conservation agriculture projects.
2. Develop a meaningful and reliable satellite based degradation index for natural vegetation as well as a model of how this impacts on SOC. This index would have to account for climatic impacts and be able to distinguish between these climatic impacts versus degradation impacts. This would require substantive investment and extensive field verification. It is important to note that a number of attempts have been made in this regard in the past, but have failed. It is also important to note that international investment is also ongoing , and that collaboration with these initiatives is potentially better than attempting a local solution.

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