c

National terrestrial carbon sinks assessment 2020: summary for policy makers

Final Report

Proposal prepared for:

GIZ

Prepared by:

CSIR Smart Places

Meiring Naude Rd

Pretoria, 0001 in conjunction with

SAEON, The Cirrus group, Wits university and Liesl Wiese.

Authors: Graham von Maltitz, Tony Knowles, Bob Scholes

Date: 24 February 2020

Table of Contents

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/m2 = 0.01 tC/ha	:	1 tC/ha = 100 gC/m2
1 kg/m2 = 10 t/ha	:	1 t/ha = 0.1 kg/m2
1km2 = 100 ha	:	1 ha = 0.01 km2
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/ m2, 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.

1. Background

The contribution of the AFOLU sector to global GHG emissions and mitigation requirements

The recent IPCC Special Report on Climate Change and Land (2019), reiterated the importance of intact landscapes to humankind and the important interaction between land and climate. Approximately 23% of all anthropogenic GHG emissions generated over the period 2007 to 2016 were from activities within the AFOLU sector (IPCC 2019). These accounted for 13% of all carbon dioxide (CO_2), 44% of all methane (CH_4) and 81% of all nitrous oxide (N_2O) emissions globally. If emissions associated with pre- and post-production activities within the global food system are included, the estimated amount of GHG emissions attributable to AFOLU increases to 21-37% of total net anthropogenic GHG emissions. Importantly, land-use based regulatory and management responses are crucial if both global climate change mitigation and adaptation targets are to be met. Whereas the combustion of fossil fuel remains the largest source of anthropogenic GHG emissions and urgently needs to be addressed, addressing land degradation is also a crucial component to limiting global warming to 1.5-2.0 ^oC (IPCC 2019). Furthermore, in terms of contributing to humankind's ability to adapt to climate change, in world where approximately 70% of global fresh water is used for the production of crops, the restoration of degraded land and its associated ecosystem services, such as the sustained yield of high-quality water, is viewed as an essential component of humankind's ability to adequately adapt to climate change. Adaptation to climate change through the restoration of degraded land is particular pertinent in Southern Africa, where climate change projections indicate warming and drying over the next century.

Although reversing land-use based emissions is seen as critical for reducing global emissions, it is important to emphasise that this activity on its own cannot come close to solving the problems of global climate change, neither in South Africa nor globally. If global warming is to be limited to 1.5-2.0 ^oC, it needs to be accompanied by substantively reduced fossil fuel emissions (IPCC 2019).

Contribution of the AFOLU sector to South Africa's national GHG emission profile South Africa's National Inventory Report reported the AFOLU sector was a net source of GHG emissions in 2000, accounting for approximately 6% of country's total GHG emissions at the time. The sequestration of carbon within the sector was reported to have increased to the extent that in the years 2016/2017, the net GHG emissions from the AFOLU sector fell below zero (National Inventory Report (NIR) 2017, in DEA 2019). The GHG emissions from Livestock and Aggregated and non-CO_2 emissions amount to an estimated 46 600 $GgCO_2e$ per year (IPCC National Inventory Classes 3A and 3C), the net emissions from Land (3B) are approximately -53 700 $GgCO_2e$. The reason for this was attributed to carbon sequestration within certain biomes, particularly Forest Land[1], accounting for 70% of sequestration, and Grasslands accounting for 27%. However the tier 1 and 2 IPCC methodologies used to calculate these changes relied on a number of assumptions that may not be true in the South African situation. The validity of these conclusions is questionable.

In the IPCC National Inventory Framework (2006, 2019), carbon sequestration is reflected in two broad ways. Firstly, through the conversion of a land cover class with lower carbon stocks to one with larger carbon stocks (for example, the conversion of Bareland to Grassland or Grassland to Forest). Secondly, through a net increase in carbon stocks within a land cover class. The latter is applicable where vegetation is still in the process of growing and sequestrating carbon. In a mature, intact ecosystem, for example a primary grassland or old-growth forest, there will not be a net sequestration of carbon, since annual inflows match outflows on average. In contrast, a rehabilitating system (i.e. one recovering from prior disturbance) will show a net increase in carbon stocks over time as vegetation and soil organic carbon increase towards their mature, equilibrium state.

In the South African national GHG reports, the conversion of the "other land use" classes to Forest Land is responsible for 45% of reported carbon sequestration within the Forest class. The remainder is due to an increase in carbon stocks within the Forest Class (Forest Land remaining Forest Land). The net amount of carbon within the Grassland class has remained consistent over the reporting period. Where Grassland replaces the "Bareland" class this leads to an increase in carbon stocks, as is the case where there is a shift from Grassland to Forest (including bush, woodlands and thicket). However, these transactions change the spatial extent of grasslands and hence should reflect in the amount of carbon in the Grassland Class. There are a number of limitations in the methodology used, chief amongst these being land cover class changes between national land cover (NLC) products. In particular, the NLC products are poor at resolving boundaries between visually similar, but carbon stock different natural vegetation classes (Thompson 2014). In addition, mean carbon stock values are used for entire class – a grassland changing to a forest therefore changes from the grassland mean to the forest mean (in accounting terms, instantaneously although in fact there is a time delay). In the South African situation there is a carbon stock continuum between classes such as shrubland, thicket, savanna and forest. Therefore the parcel of land that has changed class from a land cover classification

---

[11] Note that 'Forest Land' in this context follows the Marrakesh Accord definition, which is more than 10% cover by woody plants taller than 2 m. This means that for GHG accounting purposes most of the South African and surface are classified as forests, including the fynbos, thickets, karoo and savanna biomes. Vegetation ecologists, forest legislation in South Africa and the general public would not consider most of this area to be forests.

perspective may have undergone very limited change from an ecological and carbon perspective (e.g. may have changed canopy cover by 1 %, from just below the threshold to just above). Further, the methodology fails to account for natural vegetation reaching an equilibrium state. It assumes that it continues to grow with carbon uptake offset by fire and harvesting. Both these latter parameters are poorly quantified at the biome level and change in intensity across a biome, despite uniform factors typically being applied to the entire biome.

Climate change mitigation opportunities within South Africa's AFOLU sector

The National Terrestrial Carbon Sink Assessment 2014 (NTCSA 2014) (DEA 2015) identified nine principle climate change mitigation opportunities within the AFOLU sector (DEA 2015)(table 1). If implemented at a full national scale, climate change mitigation within the sector was estimated to be able to reach 14 Million tCO2e per year. Although this may be a small fraction of required GHG emission reductions to meet South Africa's Voluntary National Contributions, most of the opportunities come with a set of further climate change adaptation, ecosystem service and socio-economic benefits. In particular, many provide employment opportunities in rural areas through the restoration of degraded landscapes. The restoration and sustainable management of landscapes, be they open rangelands, forests or areas under commercial agriculture, requires a broad set of activities to be implemented and sustained over time, for example, the implementation of erosion control measures, replanting degraded areas, and monitoring and reporting over time. Each of these presents an opportunity for skill development and employment over the long-term in remote rural areas. In addition, the sustainable management of landscapes will improve water services to local residents and downstream urban and industrial sectors as well as improve production, be it livestock or crops within the commercial and informal sectors.

The national Carbon Sinks Atlas is particularly important in understanding the potential spatial extent of certain activities, for example, the restoration of sub-tropical thicket and scarp and coastal forest. If repeated on regular basis over time, it has the potential to provide useful data into the national forest reference levels (FREL/FRLs) required for the development of a national REDD+ program and to understand further background baseline trends, for example, bush encroachment or the clearance of alien invasive plants, that may influence the magnitude and nature of South Africa's terrestrial carbon stocks. Further, the use of biomass from clearing of bush encroached areas and also from clearing of alien invasive plant species to rehabilitate ecosystems and also through creation of value added industries.

Table 1 AFOLU sector climate change mitigation opportunities within South Africa as identified in the 2014 National Terrestrial Carbon Sink Assessment (DEA 2015)

Activity	Sub-class	Spatial extent (ha)*	Reduction per unit area per yr (tC)	Emission reduction per yr (tCO_2e)	Reduction in emissions over 20yr (tCO_2e)
Restoration of sub-tropical thicket, forests and woodlands	Sub-tropical thicket	500 000	1.2	2 200 000	44 000 000
	Coastal and scarp forests	8 570	1.8	56 562	1 131 240
	Broadleaf woodland	300 000	1.1	1 210 000	24 200 000
Restoration and management of grasslands	Restoration - Erosion Mesic	270 000	0.7	693 000	13 860 000
	Restoration - Erosion Dry	320 000	0.5	586 667	11 733 333
	Restoration- Grassland Mesic	600 000	0.5	1 100 000	22 000 000
	Avoided degradation mesic	15 000	1.0	55 000	1 100 000
Commercial small-grower afforestation	Eastern Cape	60 000	1.5	330 000	2 750 000
	KwaZulu-Natal	40 000	1.5	220 000	1 833 333
Biomass energy (IAPs & bush encroach.)	Country-wide			1 990 316	39 806 316
Biomass energy (bagasse)	Country-wide			328 955	6 579 099
Anaerobic biogas digesters	Country-wide			3 642 408	72 848 160
Biochar		700 000	0.3	641 667	12 833 333
Conservation Agriculture		2 878960	0.1	1 055 619	21 112 373
Reducing deforestation and degradation		*unknown*			
Total				**14 110 193**	**275 787 189**

Background to terrestrial carbon pools and the adopted methodology

Dry biomass and soil organic matter are both approximately 47% carbon (IPCC 2006). On a day-to-day basis plants take up carbon dioxide from the atmosphere through the process of photosynthesis. Most of is released back into the atmosphere shortly thereafter through the process of plant respiration. However, a small fraction is assimilated to form the carbohydrate 'building blocks' of plant matter. As it would be inefficient to measure all the flows of carbon (fluxes), including photosynthesis, respiration, fire, litterfall, herbivory, harvest and so forth on a short-term basis such as daily or even seasonally, a "stock-based" approach is used to understand the net change in carbon over time. The amount of carbon located within biomass and soils is typically estimated once every few years. The difference in carbon stocks between two times is reported as the net flux (expressed annually, but dividing by the number of years between estimates). The frequency at which estimates are made is determined by the frequency with which the data needed for the estimates is produced, which major cost considerations. In the case of South Africa, The National Land Cover (NLC) is a key driver of the carbon stock estimates. In the past, the NLC has been sporadically produced, or average about every five years. It is anticipated that it will be produced at two-yearly intervals in the future.

Terrestrial carbon stocks take a number of forms. The main ones are the biomass of trees and herbaceous plants, their litter and dead wood, and the soil organic carbon. Stocks such as the carbon in animals are small by comparison, while stocks such as microbial biomass are already included in soil organic carbon. As each of these forms has different dynamics in terms of size, growth and turnover, ecologists consider the terrestrial carbon stock as a system of distinct, but linked *carbon pools* (Figure 1). Typically, the first separation is between biomass and soil organic carbon. Thereafter, biomass carbon is separated into woody plants (trees and shrubs), herbaceous plants (including grasses), litter and dead wood. Often in the course of carbon accounting or modeling exercises, the woody and herbaceous pools are further separated into their above- and below-ground components.

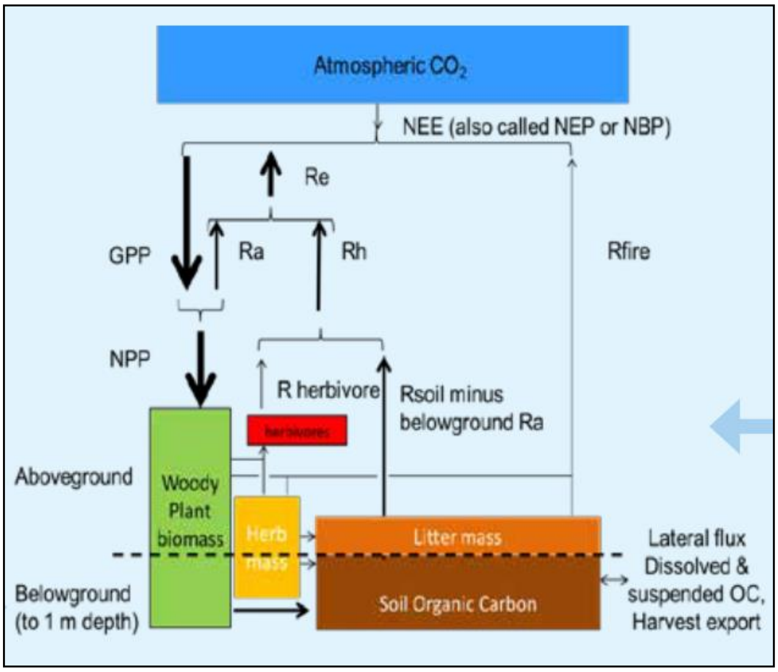


Figure 1. Components of a generalized terrestrial carbon cycle, with box sizes (representing stocks) and arrows (representing fluxes) roughly indicative of their relative size in South Africa, where NEE = Net Ecosystem Exchange; NEP = Net Ecosystem Productivity; NBP = Net Biome Productivity; GPP = Gross Primary Production; Ra = Autotrophic Respiration; Rh = Heterotrophic Respiration; Re = Ecosystem Respiration; Rfire = Fire Emissions (Department of Environmental Affairs, 2015)

The separation into defined carbon pools aids with the estimation and reporting of terrestrial carbon stocks. It also assists in understanding and monitoring changes in carbon stocks over time. This change may be due to natural processes, for example, primary production, fire or grazing, or anthropogenic drivers such as deforestation or the ploughing and turnover of soils, which do not impact all pools in a consistent manner, but rather impact particular pools. For the reason, the process of developing the Carbon Atlas considers each primary carbon pool separately.

For analysis the NTCSA 2019 divides the country into land unites (LU) of 1km by 1 km in size. The magnitude of the carbon pools for SOC, above and below ground woody plants, above and below ground herbaceous vegetation and litter is computed for each LU (Figure 2).

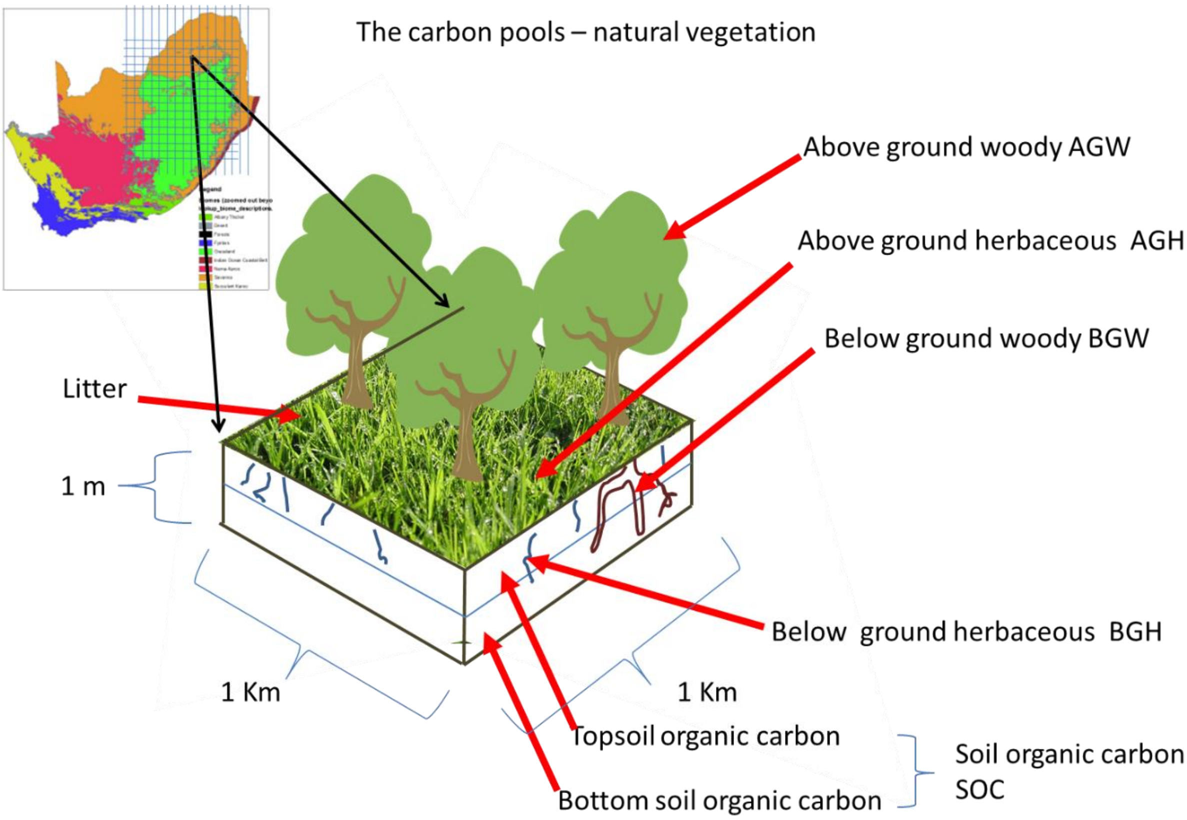
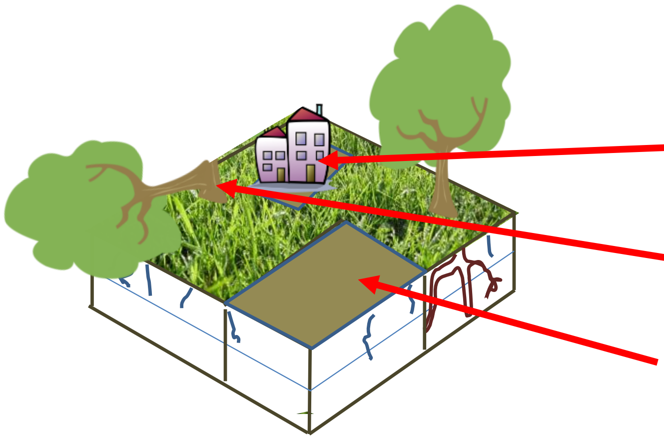


Figure 2. Illustration of the carbon pools analysed per land unit. The entire South Africa is divided into 1 km by 1km land units.

NLC products are either at 30m resolution (1990, 2014) or 20m (2018 and subsequently) and are used to determine the area of each land cover within each LU (Figure 3). This data was used to identify land cover changes that may have impacted on the carbon stock of the vegetation. A reduced set of 17 land cover classes (out of up to fifty) were identified that were shared between all three NLC products used (NTCSA 2020).



.

Figure 3. Examples of anthropogenic activities that can reduce the terrestrial carbon stocks.

Biomes as the basis of ecological processes

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 (Figure 4, Mucina and Rutherford 2006). Each of these vegetating types has unique ecological characteristics that determine their growth forms, standing biomass, ratio of trees to grasses, 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. The Fynbos and Succulent-Karoo receive winter rainfall, whilst the remaining biomes have largely summer rainfall. The Desert biome and the two Karoo biomes are arid and as such often appear as barren land on land cover products. The extent of the barren land class as identified by the land cover product changes from year to year based on the past season's rainfall. In these areas low and variable vegetation cover is simply the natural state, and is not necessarily an indication of human induced disturbance or rehabilitation. The Albany-thicket biome, although it occurs in relatively arid areas, can receive rainfall at any time of the year and has a disproportionally high woody biomass for its apparent aridity.

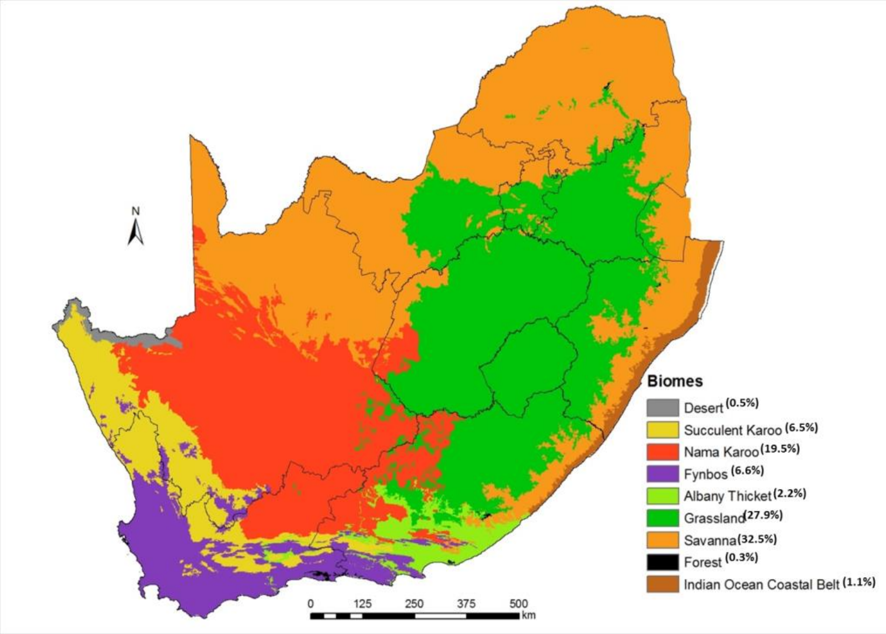


Figure 4. The biomes of South African based on Musina and Rutherford 2006. The latest 2018 version of the vegmap will be used for all analysis.

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

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

To understand the magnitude of SOC in an intact, non-disturbed state, the ISRIC dataset adopted in this study is based on a contemporary statistical model that predicts the spatial distribution of soil carbon based on an extensive set of South Africa soil pit data linked to a set of co-variates, including slope, aspect, temperature and rainfall. The methodology is viewed as world class luckily South Africa has a relatively large set of soil data for calibration.

To estimate the likely impact of change in land-use on SOC, this study has significantly expanded the initial review undertaken during the NTCSA 2014. Particular focus has been paid to how cultivation and land degradation (as represented by bare and eroded land cover classes) may impact SOC under different climatic and soil conditions. For a particular land-use class in the NLC 2018 (for example dryland cultivation) a general SOC change factor was applied to the ISRIC baseline data. This factor was determined based on South African specific data if available, or IPCC guidelines when no local data was available. The review and adopted SOC change factors can be found in the spreadsheet that accompanies this report.

These improvements and moving to an IPCC Tier 3 level based on local carbon stock and change estimates is a substantive improvement on previous estimates, but the current process still has limitations. These are not necessarily limited by scientific understanding, but by the availability of required input datasets and resources as illustrated in the three South African contexts: croplands, rangelands and urban areas discussed in greater detail below.

Croplands -

The conventional ploughing and turnover over of soils leads to the release of sequestered carbon into the atmosphere. The general "rule of thumb" based on global meta-analysis and reviews by the IPCC (2006) is that conventional ploughing leads to the release of 50% of the SOC pool in the top 30cm of soil. This source of carbon emissions can, to a certain extent, be reversed through the adoption of the principles of conservation agriculture (CA), that is, minimal soil disturbance (no tillage), maintaining organic cover year round, and planting a variety of commercial and cover crops.

Estimating both the initial release of soil carbon and potential carbon sequestration following the adoption of CA are dependent on understanding a number of factors. To understand the magnitude of the initial release, data is required on soil type, soil depth, ploughing method and potential additional of organic inputs. To estimate the potential impact of CA, an understanding of the soil type, soil depth, tillage type, crop types and planting and management regimes is required. Whereas the general crop planted in each field is known in limited areas, for example, the Western Cape, there is no national scale understanding of the type of crop planted in each field as well as planting and tillage regimes. It is therefore not possible to estimate the current impact of CA on SOC in South Africa, nor to track it over time, especially in a spatially explicit manner. Whereas the model could be expanded in future to include these processes, the principle limiting factor is available input data, especially records that are updated on regular basis to allow the impact of CA to be tracked over time.

Rangelands -

Due to their relative extent, the majority of South Africa' terrestrial carbon stock is located below ground in the form of SOC in open grassland and savanna ecosystems (NTCSA 2014). In a similar manner to croplands, the ISRIC dataset provides a robust estimate of carbon stocks in an intact, non-disturbed state.

In terms of understanding the impact of disturbance on SOC in rangelands, the Mararakanye and Le Roux (2011) map of gully erosion shows areas where it can be safely assumed that the whole top soil layer and associated SOC have been removed. The NLC products also identify areas of extreme degradation as given by erosion and bare land classes. It is, however, known that extensive degradation of natural vegetation take place that is not mapped by the land cover products. Attempting to map this land degradation in South Africa has proved challenging and at present there is no available product to show the extend of this degradation. Aboveground biomass and primary production estimates using satellite based remote sensing have found that impacts from rainfall variability mask impacts from land degradation (Wessels et al 2009). Von Maltitz et al (2018) has shown that the global indicators for land production as recommended by the UNCCD for monitoring land degradation neutrality (LDN) do not pick up rangeland degradation in the South African context. Certain proxies have been proposed as indicators of changes in soil carbon, for example, basal cover, but these remain to be tested and mapped at a significant scale.

In addition to mapping changes in soil carbon, greater knowledge is required of the each driver of SOC and how they interact, for example, grazing and fire. Whereas intense overgrazing in dry periods can impact basal cover and soil carbon over time, changes in grazing intensity within a typical commercial management range, has little impact on soil carbon over time. Further research is required on the relationship between SOC and grazing and fire regimes in a South African context to understand potential additional measures that will deliver a real climate change mitigation benefit.

Lastly, the avoided degradation of grasslands has been suggested as a potential mitigation activity within the country. In a similar manner to "traditional REDD+" focussed on forests, halting and reducing the degradation of rangelands is at least 10 times more efficient than allowing them to be degraded and then implementing restoration measures thereafter (IPBES 2018). However, significant research is required to develop baseline scenarios and reference levels, before such projects can be realised.

Urban areas -

The IPCC 2019 guidance on National GHG Inventories provides a range of estimates of changes in SOC following conversion to settlements. Whereas it is assumed that 20% of SOC is released from areas under hard surfaces (e.g. paved, roads, buildings), is also assumed that there is a 14%-17% increase in areas converted to lawns, parks and so forth. As data on the exact ratio of hard surfaces to gardens, parks and golf courses is not known in South African urban areas, it has been conservatively assumed that it is approximately a 50/50 relationship and that the net impact of urban areas on SOC is zero. However, this is an area that requires future research.

Improvements over the NTCSA2014

NTCSA2020 has made substantive improvements in terms of baseline data compared with the NTCSA 2014. These are summarised in Table 2.

Table 2. Comparison of data and methods between NTCSA 2014 and NTCSA 2020

Property	NTCSA2014	NTCSA 2020
Soil Carbon reference	Used a beta version of the 1km AfSIS database	Used the ISRIC 250m database. This is an updated and improved version of AfSIS
Soil carbon loss factors	Used a common factor for each land cover	Uses specific values for different biome and climatic regions
Land cover drivers	Used a single land cover database (SANBI 2009) which was a composite of multiple year data	Used the NLC 1990, 2014 and 2018 products
Change detection	No	Compares 3 time periods 1990, 2014 and 2018. Has detailed land cover change per 1km pixel or summarised by municipality, district province or nationally.
Tree cover	Used crude estimate based on tree high and cover, using 1km products.	Totally new estimate bases on satellite aperture raider, with Lidar and ground correlation sites. Based on 20m data.
Modelling	Proprietary program	Open source programing interface allowing for user defined scenario analysis. Uses proportional land cover data per 1km pixel.
Herbaceous cover	Based on models for natural vegetation and municipal crop data	As in 2014 but with detailed cover change impacts included
Litter data	Based on biome	Based on biome, but with estimates of woody dead biomass included.

2. South African terrestrial organic carbon stocks

The NTCSA 2020 follows a similar methodology to the NTCSA2014, but in a number of places is able to use new and updated data sources. In particular, it uses a newly available soil database from the International Soil Resources information Centre (ISRIC) in The Netherlands. This in effect is an updated version of the AFSiS database which was used in NTCSA2014, but was only available in a trial version at that stage. NTCSA 2020 also includes far greater detail on soil carbon change as a consequence of land use change, based on an improved methodology to model the management impacts as well as improved baseline data. Further, the NTCSA 2020 has more detailed tree biomass products that have greater fundamental resolution than the models used in NTCSA2014.

NTCSA2014 was based on a composite set of land cover products that had been acquired between 2000 and 2005. This meant that different parts of the country had slightly different methodologies applied, and the data spanned multiple years. For NTCSA 2020, we have used the 2014 and 2018 National Land Cover (NLC) products as well as NLC1990, which has been retrospectively recomputed to match the classifications applied in the NLC2014. NTCSA2020 therefore replaces the estimates from the NLC2014 and provides data for three time periods so that the extents and rates of change can be detected. This allows for better understanding of mitigation options based on both historic (pre 1990) and more recent land use changes.

Since much of the base data used was derived in a different manner to the NTCSA2014, it is not advisable to directly compare the results. The 1990 to 2014 to 2018 comparison *within* NTCSA 2020 is valid.

The NTCSA2014 and NTCSA 2020 were developed to assist in better understanding the country's mitigation opportunities in the AFOLU sector. The approach taken is a "wall-to-wall" assessment of the country's terrestrial biomass carbon stocks, at high resolution. As far as we are aware, only Australia has attempted a similarly ambitions process. Although the approach was not designed as a monitoring and assessment methodology for national reporting, in many ways it could be the foundation for a tier three IPCC GHG emissions evaluation. 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 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 we have available for the country. As such, 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 that the base data is reflected at biome level as well. This is entirely consistent with the tier three principle of allowing considerable flexibility in response to the availability of higher quality data and deeper process understanding.

Total terrestrial carbon

It is estimated that South Africa has a total terrestrial carbon stock of approximately 9 258 Tg C in 2018. Of this, approximately 89% is 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 5 and 6). Most of the national terrestrial carbon stock is located in the grassland and savanna biomes. Together they account for over 66% of total carbon; this matches fairly closely the fraction of the South African land area that they occupy. 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 7). The amount of carbon per province is a function of the spatial extent of the province, its rainfall and its vegetation type (Figure 8).

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

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. However, changes in total SOC *can* be estimated, as discussed in the following section. 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 that have 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 area, however, 28 municipalities were the land cover data indicates 54 000 ha loss of indigenous forest between 1990 and 2018 (these are listed in table XX). 92 districts show an increase in indigenous forest totalling 57 000 ha. In NTCSA 2020 woodland tree biomass is estimated directly, and not from land cover change. Although woodland cover is known to have increased nationally (Stevenson et al, 2016) it is also known to be declining 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 is 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 summarised by municipality in Appendix 1 and 2). District level summary data is provided as district data sheets in the web based version of the atlas.

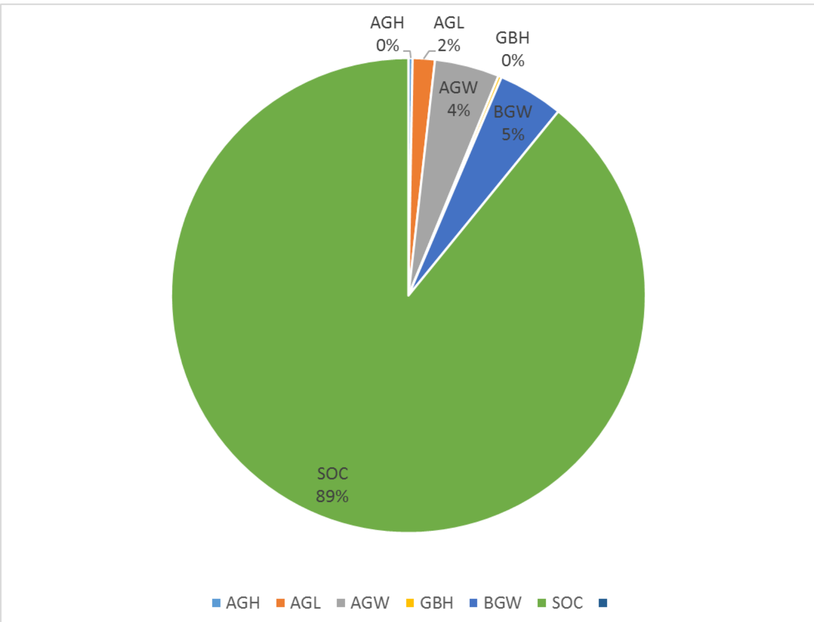


Figure 5. Organic carbon by carbon pool based on the ISRIC reference soil carbon data and 2018 land cover.

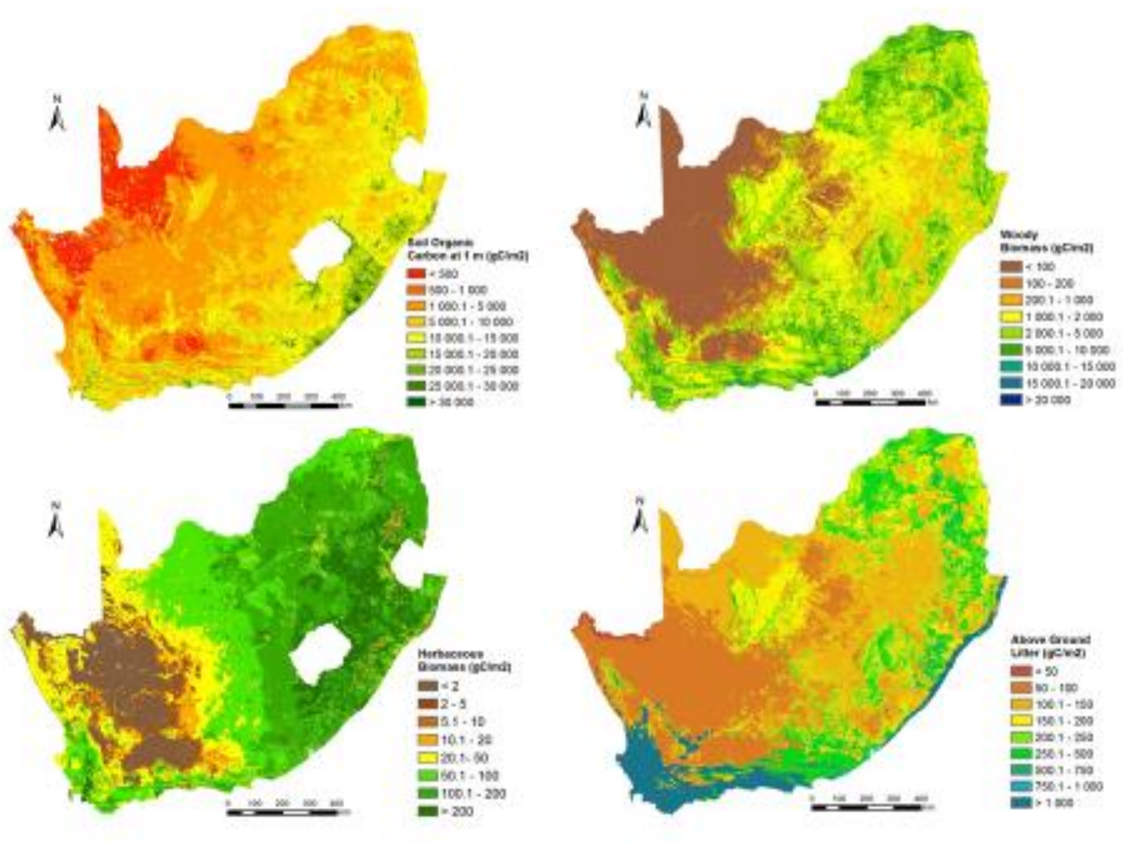


Figure 6. Maps of organic carbon by carbon pool based on the ISRIC reference soil carbon data and 2018 land cover.

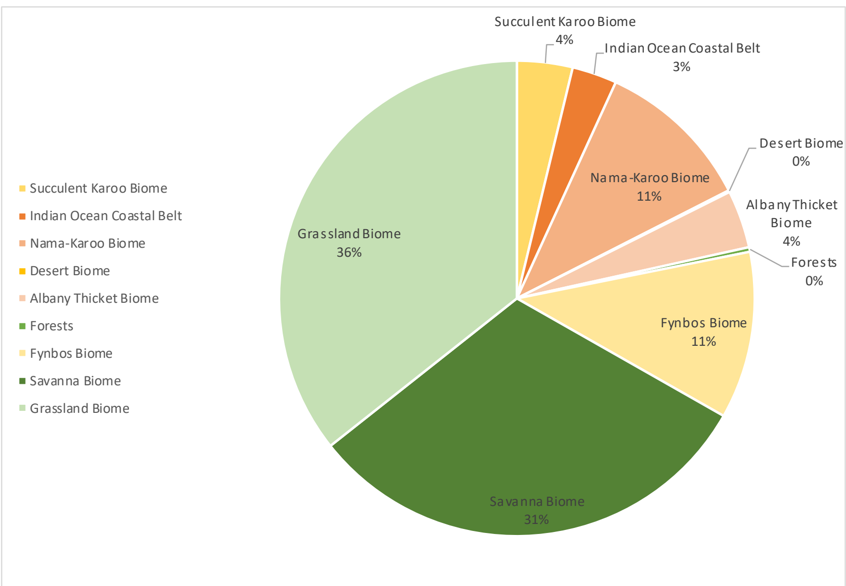


Figure 7. Total organic carbon split by biome using 2018 land cover data and ISRIC reference soils data.

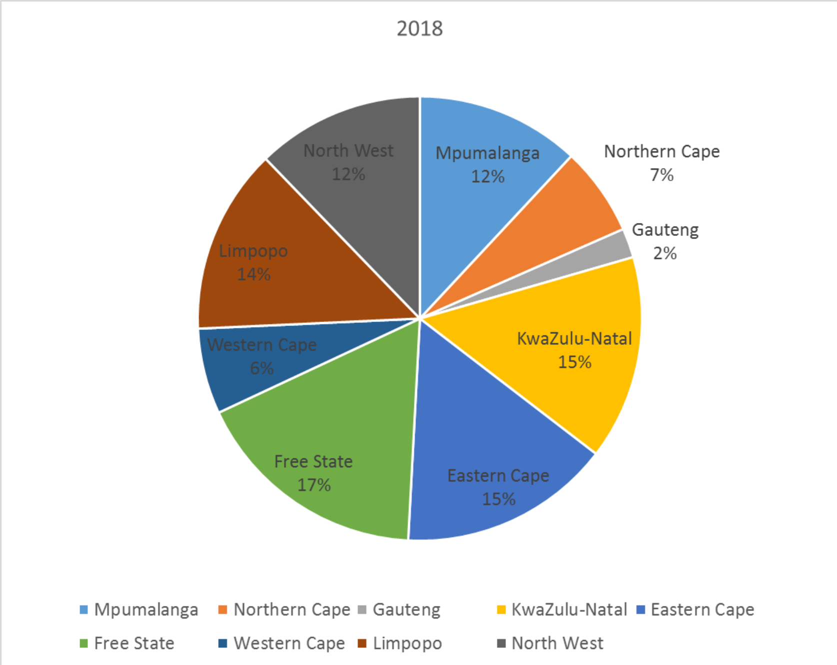


Figure 8. Total organic carbon split by province using 2018 land cover data and ISRIC reference soils data.

Total soil organic carbon

Soil organic carbon (SOC) was estimated from two reference soil datasets, the ISRIC data and a map of soil carbon in South Africa developed using a completely different approach by Schulze and Schutte (2018). The Schulze and Schutte (2018) data is in a native vector (polygon) format and had to be re-sampled to the 1km grid, causing loss of detail. Further, the Schulze and Schutte (2018) data was incomplete for many areas, especially non-agricultural areas, where soil profile data was not available. A comparison between the ISRIC and Schulze and Schutte (2018) data is seen by comparing Figure 8a Schulze and Schutte and Figure 8(b) (ISRIC), where it is clear that although similar soil carbon patterns are observed across the country, overall the Schulze and Schutte (2018) data reports lower values than the ISRIC data for the wetter east and higher values than the ISRIC data for the lower rainfall west. If the data is to be run at higher resolution (e.g. at 1 ha resolution), perhaps for a high soil carbon storage potential area, then the Schulze and Schutte (2018) data may well be more appropriate, but at a national level, the ISRIC data is considered more consistent and easier to use. Based on the above, the ISRIC data was adopted in this national analysis. Although absolute values will change dependent on which soil data is used, overall trends will stay the same regardless of which high-quality dataset and approach is used.

Since SOC is the major determinant of total carbon, the overall patterns of SOC either by biome or by province are very similar to those of total organic carbon. Changes in SOC between the dates of the three land cover products indicate relatively limited change in SOC between 1990 to 2018 (Table 1), when compared with the substantive changes that took place prior to 1990. A large change in soil organic carbon is observed between the 2014 and 2018 period due to the inclusion of a fallow land class. This is an important improvement in understanding past disturbance history and locating areas where restoration (and mitigation) activities might be appropriate. It is important to realise that this seemingly large change between 2014 and 2018 in fallow carbon is not a loss that took place during that two year period, but a loss that mostly occurred far earlier, in many cases even before the 1990 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 as gullies or bare soil (this will be discussed further in section 4). Possible 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.

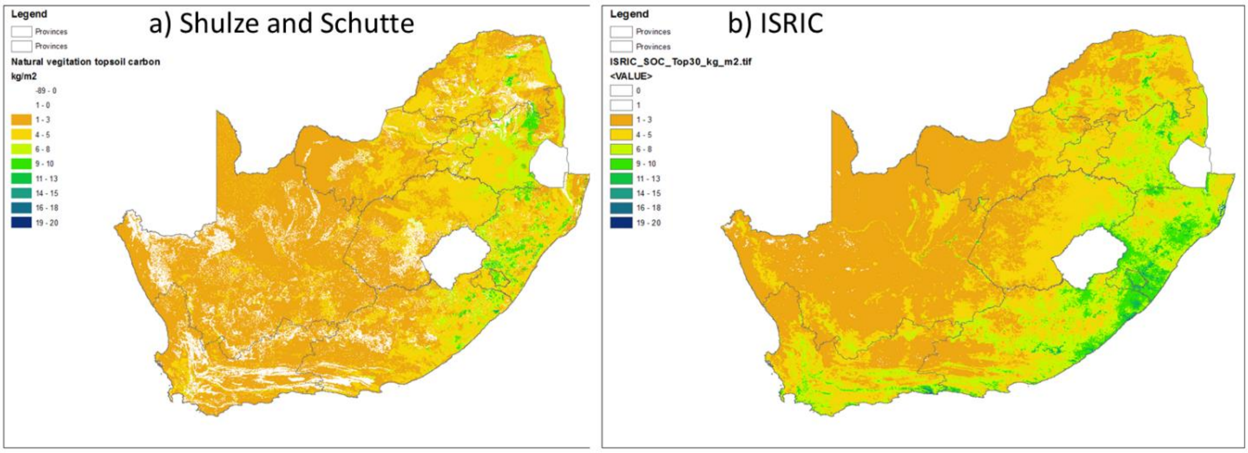


Figure 9 (a and b). Comparison of the ISRIC and Schulze and Schutte 2019 estimates of reference soil carbon stocks.

The reference value in the soil carbon model is the SOC that would be expected under natural vegetation. A comparison can be made of loss of carbon compared to the reference values. This represents the historic loss of SOC due to anthropogenic land transformation. It is estimated, based on the ISRIC soil data, that 277 Tg of SOC have been lost in South Africa since the beginning of the colonial period, as a consequence of land based activities including land degradation (as represented by the gully and bare soil classes excluding bare soil in the Karoo and Desert biomes). 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 thought to be much smaller, since the agricultural land area has been almost stable for decades, as has the forest area.

As expected, it is the provinces with large extents of crop agriculture are where the largest loss in SOC is observed compared to the reference (Table 3 and 4). 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). 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 loss in SOC in the top 30 cm soil between 1990 and 2014 (as computed based on land cover change) is relatively small in comparison to the full historic loss. 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. The larger change between 2014 and 2018 is due to the inclusion of the fallow land cover class in 2020 (which was previously mostly classified as natural vegetation). When the fallow land cover class was excluded, the SOC loss rates in the pre-2014 and 2014-2018 periods were similar (Table 4).

Table 3. Total topsoil carbon and % carbon loss from the reference for 1990, 2014 and 2018, by province. The reference carbon are 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

	reference	1990	2014	2018	reference -1990	1990-2014	2014-2018	reference - 2018
	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	4001	3777	3785	3720	-5.60	0.21	-1.73	-7.03

Table 4. SOC by district comparing 1990, 2014 and 2018 values derived from land cover against the reference value (i.e. expected carbon without land cover change). Expected losses of SOC from fallow fields has been switched both on and off to show the implications of this new land cover class from 2018.

	SOC amount						% change			
DISTRICT Name	Reference Soil Carbon Gt	1990	2014	2018	2018 fallow of	Loss from ref 2018	Ref-1990	1990-2014	2014-2018	2014-2018 With fallow off
	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
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
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. It is also clear that most carbon is found in natural and semi-natural vegetation types, with cropland, plantation forests and urban areas contributing a relatively small (about 17%) to the countries total carbon stocks.

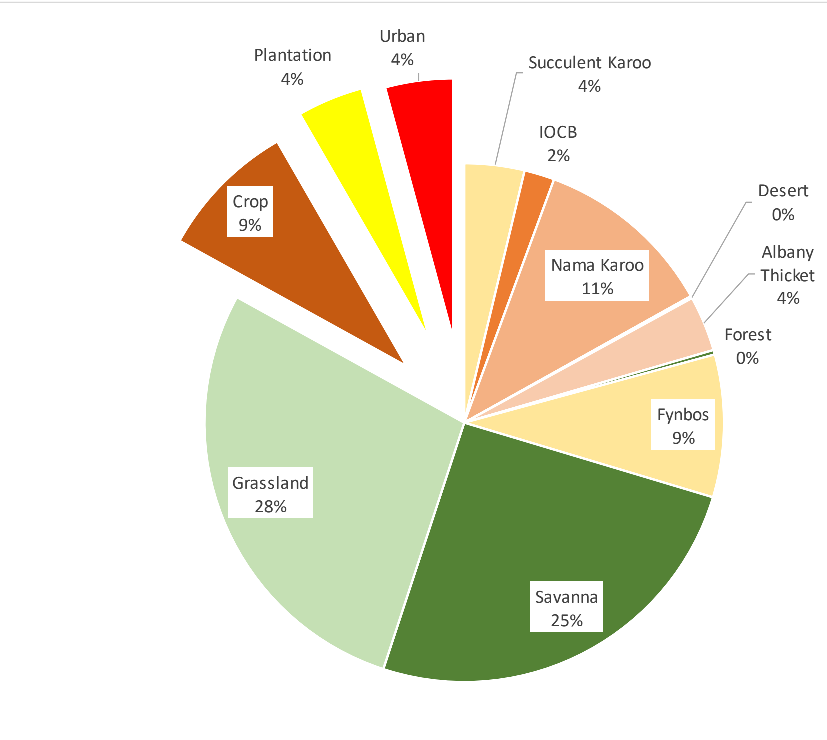


Figure 9. Total organic carbon split by biome, but with transformed classes calculated independent of natural vegetation of the biome. Using 2018 land cover data and ISRIC reference soils data

Total organic carbon in woody biomass

Estimates of carbon in woody biomass are shown in Figure 1 and Table 5. NTSCA 2020 uses a far more detailed assessment of woody biomass than was available in the NTCSA 2014. This new method still has a high variance (i.e. potential error range) and this will make detection of small changes difficult. It also overestimates biomass in hilly terrain in arid areas. For this reason a mask has been used where areas with lower than 2.5% tree canopy cover, and the woody biomass values were assigned as follows: Tree cover from 0 to 0.5% = 0.1 t/ha, 0.5 to 1.5% = 0.5 t/ha and 1.5 to 2.5% = 1 t/ha.

The new total tree biomass estimates (based on 2015 calibration data) are substantially higher than the NLC2014 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 to 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.

Table 5. Estimate of carbon in woody biomass by biome.

	AG woody biomass carbon Tg	BG woody biomass carbon Tg
Succulent Karoo Biome	13.8	28.3
Indian Ocean Coastal Belt	15.9	4.2
Nama-Karoo Biome	22.5	42.7
Desert Biome	0.0	0.1
Albany Thicket Biome	20.0	26.4
Forests	2.6	0.8
Fynbos Biome	49.3	63.0
Savanna Biome	159.9	160.3
Grassland Biome	129.5	93.9
TOTAL	413.5	418.8

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 statistics 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 herbaceous matter to the total carbon pool is only about 2%, when considering both the above ground and below ground components.

Total carbon in plant litter

Litter mas estimates are based on published values per biome, with an additional amount added for dead wood, based on a proportion of standing woody biomass. This is assumed to be 10% for natural woodlands, but 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 focus 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.

3. The carbon atlas and model as tools for understanding opportunities in the land sector for mitigating carbon

3.1. Carbon Sinks Atlas

A digital atlas containing both the spatially-explicit input files used in determining South African carbon stocks, as well as the carbon stock per carbon pool, has been developed and is available at https://ccis.environment.gov.za/carbon-sinks/#/..

Simple analysis can be undertaken directly in the atlas, and all data can be downloaded for detailed analysis in a GIS program such as QGIS.

QGIS Plugin

A QGIS plugin 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. The plugin can be downloaded from the carbon atlas website https://ccis.environment.gov.za/carbon-sinks/#/. The plugin require QGIS 3, using version 3.8 or lower.

4. 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. In terms of large-magnitude climate change mitigation potential, the key questions are whether these landscapes are under threat of degradation; and if there is good opportunity to restore already-degraded areas within these biomes. Data sheets are provided on the Atlas interface page for each district municipality. These specify the amount and rate of change of key land use classes (Table 6). Data per local municipality can be substantially different from national trends and is provided in Appendix 1. Some of the largest changes between 1990 and 2018 are an increase in fallow land (though this might have been fallow prior to 1990) (3 710 470 ha), increased build up area (547 165 ha), increase 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.

Table 6 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 national map of gully erosion compiled by Mararakanye and Le Roux (2011) estimated that there are approximately 600,000ha of deep erosion gullies across the country, the majority of which are within the grassland and savanna biomes. Although the gully analysis is a significant start, it does not include areas of other forms of land degradation. The NLC products recognise bare ground as a class, but the extent of carbon loss associated with this class is poorly understood. Further, the extent of this bare ground class is strongly impacted by the 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 across the two biomes. 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.

In terms of required supporting policy and legislation, there already exists 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) land Degradation Neutrality by 2030 target. This is also a target of the Sustainable Development Goal 15. South Africa has set the following land reclamation targets (DEFF 2017)(Table 7).

Table 7. South Africa's LDN targets

LDN at the national scale

- LDN is achieved by 2030 as compared to 2015 (no net loss).
- LDN is achieved by 2030 as compared to 2015 and an additional 5% of the national territory has improved (net gain).

LDN at the sub-national scale (if applicable/done)

- LDN is achieved in the grassland biome by 2030 as compared to 2015 (no net loss)
- LDN is achieved in the thicket biome by 2030 as compared to 2015 (no net loss)

Specific targets to avoid, minimize and reverse land degradation

- Improve productivity and SOC stocks in 6 000 000 hectares of cropland by 2030
- Rehabilitate and sustainably manage 1 809 767 hectares of "forest"[2] by 2030
- Rehabilitate and sustainably manage 1 349 714 ha of fynbos by 2030
- Rehabilitate and sustainably manage 87 621 ha of thicket by 2030
- Rehabilitate and sustainably manage 2 436 170 ha of grassland by 2030
- Rehabilitate and sustainably manage 2 646 069 ha of savanna (< 5m) by 2030
- Rehabilitate and sustainably manage 149 877 ha of Succulent Karoo by 2030
- Rehabilitate and sustainably manage 528 632 ha of Nama Karoo by 2030
- Rehabilitate and sustainably manage 76 525 ha of desert by 2030
- Rehabilitate 61 900 ha of wetlands by 2030,
- Clear 1 063 897 ha of alien invasive species by 2030
- Clear 633 702 ha of bush encroached land by 2030,and
- Rehabilitate 350 000 ha of artificial areas by 2030.

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. As an example, the inappropriate allocation of licences to plough grasslands, or a lack of policing of unlicensed new field creation. Substantial additional emphasis is needed 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. The study noted that whereas further parties have implemented a subset CA, for example, reduced tillage, few have implemented all three principles in full - no tillage, maintaining organic cover throughout the year and cultivating a diversity of food and cover crops. Furthermore, implementation is concentrated in certain provinces, for example, the Western Cape, and is lacking in others.

There is 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. But 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 implementation plan for CA. The growing emphasis on CA is not only due to its potential climate change mitigation benefits, but in addition, 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 in-appropriate 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 is initiating 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 situations.

Rehabilitation of degraded forests and woodlands

There are a number of localised situation in the country where indigenous forest and woodland has 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. It must be born 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 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 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 note that the area where tree planting (or naturally allowing trees to re-establish) 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, the contribution to the national GHG budget will be relatively small.

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 under overbrowsing, with 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*)[2] 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 the woody biomass carbon pool is lost, and a large fraction of the soil carbon pool (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 ambitions 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

[2] 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 revegetation 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 restively 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)

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 former grasslands, referred to in South Africa as bush encroachment, has been documented in many areas (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 (Turpie et al 2018). Skowno et al (2016) found that approximately 57000 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 57000 (8%) and 130000 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 NTCS2018, but cannot be separated from non-encroached woody components, except if the encroachment occurred between 2014 and 2018. 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 (Barger et al 2011).

Turpie et al. (2018) found that in almost all cases woody 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), have a relatively low efficiency of conversion of biomass to benefit, 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.

Invasive alien plants

South Africa, through the Working for Water program (WfW) is actively clearing 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. 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.

Using the NLC2018 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 overall contribution to the national carbon stock remains relatively small. Estimates done for NLC2014 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.

Plantation 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. Assuming the forest industry is in approximately steady-state, on average the fraction of plantations in different age classes stays relatively constant, and the biggest losses (or gains) to carbon sequestration will come from increasing (or reducing) the spatial extent of the industry. The opportunity to do this is very limited[3]. 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 21.5Tg of carbon. This is only about 2.4 % 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 of 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 would be a policy option.

Tree planting

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 are already increasing tree biomass in some areas, with negative consequences to stream flow, biodiversity and other ecosystem services. Rising atmospheric CO_2 concentrations may be favouring tree growth even in areas not considered encroached (Bond and Midgley 2011). Further, as Bond et al. (2019) note, 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 situation 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. Extensive tree planting in natural grasslands, motivated as a climate mitigation activity, should not be permitted.

---

[3] 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 in 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.

5. Constraints of analysis

The Carbon Atlas provides a robust estimate of terrestrial carbon stocks at a national scale. 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, for example, aboveground 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 current not an 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 technique 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 the fire and herbivory regime. 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 in this regard. The NTCA 2018 has not attempted to update this data, though the modelling interface could be used in this regard 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 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 do in future, is pivotal to understanding the opportunity for REDD+ and avoided rangeland degradation programmes, and thus to quantify the potential and develop the required reference levels.

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 certain areas.

Further to identifying the areas with biophysical opportunity for mitigation projects, further 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

As noted above, currently we have no method of reliably and repeatedly detecting degradation in situations where the severity is less than the bare and eroded land cover classes. We also have 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.

6. References

Bond, W.J., and Midgley, G.F., 2012. Carbon dioxide and the uneasy interactions of trees and savannah grasses. Philosophical Transactions of the Royal Society B: Biological Sciences, 367(1588): 601–612

Bond, W.J. Stevens, N. Midgley, G.F. Lehmann C.E. The trouble with trees: afforestation plans for Africa. Trends Ecol. Evol. (Amst.) (2019), 10.1016/j.tree.2019.08.003.

DEA. (2015). The South African National Terrestrial Carbon Sink Assessment. Pretoria, South Africa.

DEFF, 2019, Strategic approach towards the management and enhancement of carbon sinks in the agriculture, forestry and other land-use (AFOLU) sector in South Africa. Draft Synthesis Report on National Circumstances, Department of Environment, Forestry and Fisheries, Pretoria, South Africa.

Findlater, K. M., Kandlikar, M., & Satterfield, T. (2019). Misunderstanding conservation agriculture: Challenges in promoting, monitoring and evaluating sustainable farming. Environmental Science and Policy, 100(May), 47–54. https://doi.org/10.1016/j.envsci.2019.05.027

IPCC. (2006). IPCC Guidelines for National Greenhouse Gas Inventories; Vol.4 Agriculture, Forestry and Other Land-Use; Prepared by the National Greenhouse Gas Inventories Programme. (S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe, Eds.). Kanagawa: IGES, Japan, http://www.ipcc-nggip.iges.or.jp.

IPCC. (2019). Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. (E. Calvo Buendia, K. Tanabe, A. Kranjc, J. Baasansuren, M. Fukuda, N. S., … S. Federici, Eds.) (Vol. 4). Switzerland: Intergovernmental Panel on Climate Change. Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

IPCC. (2019). Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. (P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H. O. Portner, D. C. Roberts, … J. Malley, Eds.). Intergovernmental Panel on Climate Change.

Mangwale, K., Shackleton, C. M., & Sigwela, A. (2017). Changes in forest cover and carbon stocks of the coastal scarp forests of the wild coast, South Africa. Southern Forests, 79(4).

Mararakanye, N., & Le Roux, J. J. (2011). Manually Digitizing of Gully Erosion in South Africa Using High Resolution: SPOT 5 Satellite Imagery at 1:10 000 scale. Pretoria.

Stevens, N.; Erasmus, B.F.N.; Archibald, S.; Bond, W.J. Woody Encroachment over 70 Years in South African Savannahs: Overgrazing, Global Change or Extinction Aftershock? Philos. Trans. R. Soc. B Biol. Sci. 2016, 371, 20150437.

Mills AJ, Robson A. Survivorship of spekboom (Portulacaria afra) planted within the Subtropical Thicket Restoration Programme. S Afr J Sci. 2017;113(1/2), Art. #a0196, 3 pages. http://dx.doi.org/10.17159/sajs.2017/a0196

VanderVyver,M.L.,2017.Factors affecting effective ecological restoration of Portulacaria afra (spekboom)- rich subtropical thicket and aboveground carbon end-point projections. PhDThesis. Nelson Mandela University

Wessels, K.J. Mathieu, R. Erasmus, B.F.N. Asner, G.P. Smit, I.P.J. van Aardt, J. Main, R. Fisher, J. Marais, W., Kennedy-Bowdoin, T. Knapp, D.E. Emerson, R. and Jacobson J. 2011. ct of contrasting land use on woody vegetation structure in the Lowveld savannas of South Africa. Forest Ecology and Management, 261 (1). 19-29.

Appendix 1a. Change in land cover of natural vegetation per municipality between 1990 and 2018 sorted by reduction in natural vegetation.

Municipality	Natural Vegetation	Bare degraded	Fallow	Water	Wetlands	Indigenous Forest
Hantam (NC065)	-411354	408747	29967	-27982	-5594	3
Kai !Garib (NC082)	-185494	182392	1300	-9854	-4012	0
Emalahleni (EC136)	-178991	-2245	23526	1634	16125	0
Kamiesberg (NC064)	-110052	94074	17035	-121	-148	0
Witzenberg (WC022)	-101829	87730	19915	-1038	-4938	9
Senqu (EC142)	-97807	94349	6311	901	-7008	-1
Matzikama (WC011)	-90323	57996	37088	597	-1466	29
Greater Tubatse/Fetakgomo (LIM476)	-80886	34563	15881	823	-2197	42
Nama Khoi (NC062)	-75015	48914	23768	-270	-1249	0
Msukaligwa (MP302)	-73936	1334	46434	2030	11468	8
City of Tshwane (TSH)	-70605	7697	39528	1107	-1429	-1
Kagisano/Molopo (NW397)	-68767	9517	125298	234	-1523	0
Abaqulusi (KZN263)	-60656	2223	35775	405	2114	1346
Richtersveld (NC061)	-58039	53077	309	-651	-753	0
Molemole (LIM353)	-56679	920	47685	84	-746	-830
Mkhondo (MP303)	-55784	3388	16281	185	1514	630
Laingsburg (WC051)	-55745	51784	4586	-606	-1067	0
Emakhazeni (MP314)	-54703	3965	23610	808	6531	1274
Polokwane (LIM354)	-52292	468	42913	2	-1920	1
Modimolle/Mookgophong (LIM368)	-51953	9128	98944	679	-3450	0
Dr Pixley Ka Isaka Seme (MP304)	-51743	1605	38155	761	6672	966
Cederberg (WC012)	-51550	22207	31203	-134	-2830	0
Langeberg (WC026)	-51049	40685	15753	-119	-2855	0
Blouberg (LIM351)	-49974	1879	49116	163	-434	-1424
Rustenburg (NW373)	-49055	3671	40925	918	-1040	-221
Moses Kotane (NW375)	-47211	509	50744	136	-718	0
Makhuduthamaga (LIM473)	-45657	14748	8461	-76	-996	0
Lephalale (LIM362)	-45472	8797	44885	1420	283	0
Mogalakwena (LIM367)	-44707	4150	59639	526	-1858	0
Enoch Mgijima (EC139)	-43858	26698	22140	525	-10942	101
Chief Albert Luthuli (MP301)	-43659	3349	29822	529	3873	626
Mangaung (MAN)	-41779	23401	23435	-654	-10345	-241
Lekwa (MP305)	-41654	366	27547	1784	13770	0
Makhado (LIM344)	-41517	1581	45655	455	-2138	-7276
Mbizana (EC443)	-40688	734	36122	349	-1196	1730
Emthanjeni (NC073)	-40688	39259	11403	-1679	-10813	0
Mohokare (FS163)	-40375	27334	19061	1092	-10669	-156
Alfred Duma (KZN238)	-39941	1504	25897	795	1766	-586
Mnquma (EC122)	-39764	34	36658	533	-1309	1349
Nkomazi (MP324)	-39243	1813	13326	3108	2034	1886
Walter Sisulu (EC145)	-39105	30140	26051	2545	-20663	0

Elias Motsoaledi (LIM472)	-38316	8615	27179	1588	-3732	0
Steve Tshwete (MP313)	-37409	3139	38658	2812	4926	0
Greater Giyani (LIM331)	-37392	1351	37118	-278	-177	0
Kannaland (WC041)	-37100	36224	2706	52	-3291	0
Elundini (EC141)	-36639	3747	8251	888	-4754	842
Emadlangeni (KZN253)	-36551	1755	25656	548	3960	1485
Mhlontlo (EC156)	-36412	2475	26116	1441	-1086	4266
Swellendam (WC034)	-34566	23195	11559	-226	-2012	402
Mantsopa (FS196)	-34382	18823	21622	986	-3108	-2538
Msinga (KZN244)	-34302	5955	22544	602	441	41
Dr Nkosazana Dlamini Zuma (KZN436)	-34208	-1382	9929	1273	-767	3180
Umhlabuyalingana (KZN271)	-34175	9744	7492	-4705	2424	3594
Lepele-Nkumpi (LIM355)	-34144	10279	19395	78	-1695	-1477
Mbhashe (EC121)	-34048	1153	28468	1008	-648	2324
Breede Valley (WC025)	-33207	28292	10003	-193	-3984	8
Ditsobotla (NW384)	-33159	1891	45426	-47	-5363	0
Local Municipality of Madibeng (NW372)	-32926	2045	28336	1142	-3138	-403
Thembisile (MP315)	-32499	2693	23731	142	-192	0
Joe Morolong (NC451)	-30980	14867	11919	1067	-1535	0
Maluti a Phofung (FS194)	-30706	5770	22035	668	-5262	33
Ramotshere Moiloa (NW385)	-30557	-5904	50250	375	-2810	0
Ngquza Hill (EC153)	-29948	-1188	30605	565	-2104	907
King Sabata Dalindyebo (EC157)	-29822	2915	20245	863	-951	1437
Setsoto (FS191)	-29758	14389	17724	1015	-2229	-1881
Okhahlamba (KZN235)	-29341	587	14989	1439	1245	112
Ulundi (KZN266)	-28820	5458	25040	280	198	53
eThekwini (ETH)	-28228	796	18797	215	-53	5137
Hessequa (WC042)	-28184	11540	15079	347	-5320	337
Inkosi Langalibalele (KZN327)	-27942	3103	16990	716	7	150
Thabazimbi (LIM361)	-27886	4053	39462	1647	-2984	0
Ventersdorp/Tlokwe (NW405)	-27586	855	44091	292	-7586	0
Bergrivier (WC013)	-27492	10438	24272	-2165	-1562	0
Dr JS Moroka (MP316)	-26457	554	23295	318	-505	0
Bushbuckridge (MP325)	-26373	20832	5290	800	4306	980
Umzimkhulu (KZN435)	-26359	1249	16255	412	-88	3489
Lekwa-Teemane (NW396)	-26235	763	42948	159	-2067	0
Maquassi Hills (NW404)	-25933	536	49074	-260	-6040	0
eDumbe (KZN261)	-25855	1041	4617	945	28	151
Umzumbe (KZN213)	-24358	365	23375	321	-159	1177
Govan Mbeki (MP307)	-23825	366	23457	1468	3629	0
Dihlabeng (FS192)	-23342	11982	14510	828	-7955	-880
Matatiele (EC441)	-23104	2548	25190	1702	-6971	804
Nyandeni (EC155)	-22162	-183	17445	570	-487	2641
Engcobo (EC137)	-22113	2285	14464	695	-694	3584
Umvoti (KZN245)	-21825	2553	12678	150	357	76

Mafikeng (NW383)	-21394	1186	24239	395	-2105	0
Umzimvubu (EC442)	-21388	3639	13079	995	-809	1143
Newcastle (KZN252)	-21228	-4	10745	449	514	-258
Musina (LIM341)	-21167	-1276	10934	1469	-723	3033
uPhongolo (KZN262)	-21139	1519	14714	-1878	1078	55
Nqutu (KZN242)	-21066	5525	11036	311	319	3
Phumelela (FS195)	-20871	1376	26866	2099	-21354	-179
Sundays River Valley (EC106)	-20831	-5461	14398	396	-596	11795
Kgetlengrivier (NW374)	-20512	1010	25946	160	-1153	0
Ephraim Mogale (LIM471)	-20084	3619	5773	978	-1088	0
Ngqushwa (EC126)	-20078	508	19521	351	-459	267
Intsika Yethu (EC135)	-19955	3715	14871	576	-1832	610
Maruleng (LIM335)	-19939	7495	10883	279	-2687	-1249
Oudtshoorn (WC045)	-19854	17720	6590	70	-2832	2
Ratlou (NW381)	-19748	1511	37176	-239	-6207	0
Umdoni (KZN212)	-19556	104	16215	154	38	2426
City of Matlosana (NW403)	-19325	173	28861	-538	-4074	0
Tsantsabane (NC085)	-19208	14653	2993	-79	-3086	0
Ray Nkonyeni (KZN216)	-18334	718	13508	578	39	2030
Endumeni (KZN241)	-18315	-311	18017	382	-556	102
City of Johannesburg (JHB)	-18073	2338	8943	318	-53	0
Greater Kokstad (KZN433)	-17447	-71	9221	1005	-10	41
Ubuhlebezwe (KZN434)	-17296	220	12397	328	58	134
Greater Letaba (LIM332)	-17077	333	22078	45	-217	-1404
Jozini (KZN272)	-16980	1476	13591	-1260	-2513	3888
Ntabankulu (EC444)	-16213	-342	14739	540	-764	1299
Moretele (NW371)	-16204	4	21420	58	-2211	0
Victor Khanye (MP311)	-15901	703	12820	646	4369	0
Tokologo (FS182)	-15758	7390	52481	-17720	-6700	0
City of Cape Town (CPT)	-15740	3466	12442	635	-2222	-56
Sakhisizwe (EC138)	-15508	844	9128	288	-1186	119
Nongoma (KZN265)	-14987	5438	12714	-181	259	28
Naledi (NW392)	-14905	1142	32345	398	-2503	0
Thaba Chweu (MP321)	-14699	5879	16906	-22	1280	5687
Dannhauser (KZN254)	-14565	531	6776	178	1855	42
Dipaleseng (MP306)	-14395	711	10016	903	2777	0
Nkandla (KZN286)	-13733	1819	11025	313	2	396
Ekurhuleni (EKU)	-13566	1737	12659	1071	146	0
Big Five Hlabisa (KZN276)	-13278	1234	15963	-2535	4813	2400
Buffalo City (BUF)	-12964	838	12703	777	-1174	-3346
Swartland (WC015)	-12963	409	19831	239	-3430	0
Mpofana (KZN223)	-12928	336	6539	733	663	57
uMlalazi (KZN284)	-12606	1799	10252	-675	-5	-572
Moqhaka (FS201)	-12434	1889	29600	732	-12562	0
Thembelihle (NC076)	-12263	9337	1481	-2217	-2989	0
Ndlambe (EC105)	-12255	1754	8779	635	-329	2062

City of Mbombela (MP326)	-12211	2755	21155	560	-1530	3363
Ba-Phalaborwa (LIM334)	-11788	4015	4670	337	-994	0
Mamusa (NW393)	-11744	1467	25294	-76	-1187	0
Port St Johns (EC154)	-11704	-575	13530	734	-507	-587
Amahlathi (EC124)	-11700	-150	17374	1027	-2306	-7827
Renosterberg (NC075)	-10609	14457	1657	1230	-8411	0
Cape Agulhas (WC033)	-10561	5259	8710	-1925	-288	20
Tswelopele (FS183)	-10373	3032	25155	-7158	-9407	0
Siyancuma (NC078)	-10105	2534	5046	-299	-6758	0
Drakenstein (WC023)	-9554	2634	6256	316	-2022	23
uMuziwabantu (KZN214)	-9339	-59	6229	215	-114	1379
uMngeni (KZN222)	-9175	34	3315	1040	202	1280
Ga-Segonyana (NC452)	-8985	961	5641	-62	-2160	0
Saldanha Bay (WC014)	-8722	1738	15222	-76	-1659	0
Matjhabeng (FS184)	-8528	1976	23030	318	-8074	0
Gamagara (NC453)	-8217	3697	1915	88	-664	0
Mossel Bay (WC043)	-8213	1908	6559	235	-2639	755
Mkhambathini (KZN226)	-7990	45	6569	124	-234	284
Makana (EC104)	-7731	317	6615	521	-530	514
Richmond (KZN227)	-7711	-171	4405	269	-9	551
Mogale City (GT481)	-7642	1859	4331	120	-905	-4
Greater Taung (NW394)	-7616	-276	12031	486	-3641	0
Impendle (KZN224)	-7441	-2066	4552	342	69	852
Nketoana (FS193)	-7407	2249	11965	1645	-9429	0
Overstrand (WC032)	-7318	2939	5584	375	-1698	836
Masilonyana (FS181)	-7298	2832	16777	-715	-6914	-28
uMhlathuze (KZN282)	-7165	-18	7338	59	481	1616
The Msunduzi (KZN225)	-7140	-27	3455	25	-135	383
Mafube (FS205)	-6980	896	8784	1218	-6108	0
uMshwathi (KZN221)	-6203	521	4478	-364	321	1160
Mthonjaneni (KZN285)	-6178	1035	4276	-256	13	106
Midvaal (GT422)	-6100	766	7773	473	-3826	0
Lesedi (GT423)	-5792	1068	8296	308	-1112	0
Great Kei (EC123)	-5541	-246	5875	496	-183	601
Tswaing (NW382)	-5539	1925	18637	-397	-10574	0
Nelson Mandela Bay (NMA)	-5515	722	4461	1248	-419	51
Theewaterskloof (WC031)	-5298	5571	4695	-493	-4279	122
KwaDukuza (KZN292)	-5293	58	682	-167	339	427
George (WC044)	-4776	2318	17346	405	-5269	-978
Kouga (EC108)	-4739	1322	6453	847	-1922	362
Kou-Kamma (EC109)	-4232	2553	7356	824	-3837	-1236
Emfuleni (GT421)	-4135	575	5355	266	-2394	0
Greater Tzaneen (LIM333)	-4119	1596	14983	-820	-2328	-4065
Merafong City (GT484)	-4045	220	13094	112	-2730	0
Bela-Bela (LIM366)	-3851	1117	23340	202	-1209	0
New (LIM345)	-3802	207	11683	469	49	40

Sol Plaatjie (NC091)	-3736	-226	2370	278	-1675	0
Magareng (NC093)	-3438	-883	2208	455	-616	0
Rand West City (GT485)	-3097	512	12236	48	-1554	0
Metsimaholo (FS204)	-3067	-85	4593	1628	-4810	0
Mfolozi (KZN281)	-2943	-230	3575	-72	1681	1781
Maphumulo (KZN294)	-2773	21	4053	60	32	27
Letsemeng (FS161)	-2607	-3783	28458	-10040	-17289	0
Ndwedwe (KZN293)	-2435	367	2802	-52	16	343
Raymond Mhlaba (EC129)	-2381	-1024	18298	406	-2265	-11993
Mandeni (KZN291)	-2280	148	797	-223	-205	119
Kopanong (FS162)	-2224	18185	11929	2360	-37376	0
Prince Albert (WC052)	-1978	512	1676	-276	-1573	0
Nala (FS185)	-720	1188	10568	-1960	-8167	0
Bitou (WC047)	-234	-6	1165	301	-214	-494
Phokwane (NC094)	-85	26	584	155	-1479	0
Ngwathe (FS203)	729	2306	18039	676	-22571	0
Kgatelopele (NC086)	1356	224	630	-1793	-589	0
Stellenbosch (WC024)	1500	654	2364	632	-1250	4
Dikgatlong (NC092)	2704	-318	3856	165	-4266	0
Knysna (WC048)	3405	132	1323	225	-266	2536
Thulamela (LIM343)	4494	508	7184	1195	-857	-2675
Mtubatuba (KZN275)	6037	781	1957	-738	2994	6560
Umsobomvu (NC072)	15140	-5246	2355	711	-13808	0
KhÃƒÂ¢i-Ma (NC067)	24610	-20379	477	-7621	-2687	0
Inxuba Yethemba (EC131)	24902	-33606	6759	1323	-4391	0
Siyathemba (NC077)	26999	-30795	1606	-538	-1416	0
Dawid Kruiper (NC087)	63754	-56748	473	-18797	-897	0
!Kheis (NC084)	79592	-81512	637	-245	-1039	0
Karoo Hoogland (NC066)	95457	-109374	13793	-1025	-4450	0
Emalahleni (MP312)	130015	17574	9406	622	-13947	106
Blue Crane Rout/ie (EC102)	173460	-183403	3369	674	-1792	1799
Kareeberg (NC074)	185612	-196811	10099	-481	-948	0
Ubuntu (NC071)	637786	-645734	9526	-303	-2378	0
Beaufort West (WC053)	682707	-687838	6493	-119	-4547	0
Dr Beyers Naude (EC101)	767807	-770077	9211	124	-9830	0
TOTAL	-2 517 011	-923 674	3 710 470	-31 498	-471 527	57 963

Appendix 1b Change in land cover (in ha) of transformed land per municipality between 1990 and 2018 sorted by reduction in natural vegetation.

Municipality	Commercial Agriculture	Pivot Agriculture	Orchards	Viticulture	Pineapple	Subsistence Agriculture	Sugarcane Irrigated	Sugarcane Dry	Plantation Forest	Mines
Hantam (NC065)	-2902	400	12	0	0	126	0	0	371	307
Kai !Garib (NC082)	460	387	459	6599	0	0	0	0	18	576
Emalahleni (EC136)	63195	2602	7	0	0	-37681	0	0	6333	27188
Kamiesberg (NC064)	-203	2	0	0	0	-272	0	0	0	-1721
Witzenberg (WC022)	-1919	3338	214	-2208	0	0	0	0	-1955	25
Senqu (EC142)	-11228	11049	0	0	0	398	0	0	151	19
Matzikama (WC011)	-3352	2210	-5383	-1425	0	-587	0	0	265	1881
Greater Tubatse/Fetakgomo (LIM476)	-2967	3191	-1135	0	0	18274	0	0	-9	3353
Nama Khoi (NC062)	-133	26	171	-423	0	0	0	0	0	997
Msukaligwa (MP302)	-10612	3218	68	0	0	-121	0	0	18195	-1105
City of Tshwane (TSH)	-9459	5554	477	0	0	-39	0	0	-2729	-1058
Kagisano/Molopo (NW397)	-84835	16073	-173	0	0	-4467	0	0	656	1404
Abaqulusi (KZN263)	-4577	1927	-66	0	0	1598	0	174	18330	-349
Richtersveld (NC061)	-255	24	0	0	0	0	0	0	-60	3447
Molemole (LIM353)	-10501	14488	131	0	0	1519	0	0	-79	-536
Mkhondo (MP303)	-7912	3624	42	0	0	326	0	0	33573	-143
Laingsburg (WC051)	-1307	761	24	-11	0	0	0	0	34	81
Emakhazeni (MP314)	1157	2393	35	0	0	-1	0	0	12589	362
Polokwane (LIM354)	-5940	1241	-2297	0	0	1677	0	0	227	-1728
Modimolle/Mookgophong (LIM368)	-67778	10726	-505	0	0	17	0	0	340	-1247
Dr Pixley Ka Isaka Seme (MP304)	-6876	3044	95	0	0	-317	0	0	4414	151
Cederberg (WC012)	4615	18876	-22900	-195	0	-304	0	0	-535	-85
Langeberg (WC026)	-8005	4431	3485	-4468	0	0	0	0	-177	59
Blouberg (LIM351)	-20962	10908	166	0	0	6054	0	0	269	-247
Rustenburg (NW373)	-10706	1469	-2	0	0	131	0	0	2516	4257
Moses Kotane (NW375)	-4768	1	0	0	0	-5858	0	0	60	1224
Makhuduthamaga (LIM473)	-194	284	0	0	0	14492	0	0	-311	7
Lephalale (LIM362)	-33995	8263	12	0	0	8509	0	0	534	182
Mogalakwena (LIM367)	-22307	551	-1363	0	0	-3112	0	0	320	715
Enoch Mgijima (EC139)	-6701	6155	-375	0	0	239	0	0	763	-263

Chief Albert Luthuli (MP301)	-5553	588	134	0	0	-6258	0	-1	6211	1515
Mangaung (MAN)	-27350	13473	10	0	0	10425	0	0	3388	-311
Lekwa (MP305)	-9819	4569	6	0	0	0	0	0	1628	-354
Makhado (LIM344)	-5074	6521	476	0	0	-9311	0	0	-78	-465
Mbizana (EC443)	-30	14	-1	0	0	672	0	0	3732	66
Emthanjeni (NC073)	-351	434	0	0	0	341	0	0	-83	73
Mohokare (FS163)	-8317	5953	240	0	0	17	0	0	3870	-75
Alfred Duma (KZN238)	-1426	2872	0	0	0	4826	0	0	-329	-43
Mnquma (EC122)	-15	0	0	0	-59	1215	0	0	420	-42
Nkomazi (MP324)	-3699	358	720	0	0	-10438	6852	10247	-1613	28
Walter Sisulu (EC145)	-15206	14809	-720	0	0	-9	0	0	715	-244
Elias Motsoaledi (LIM472)	-12265	5125	2064	0	0	1049	0	0	79	-18
Steve Tshwete (MP313)	-22964	7304	143	0	0	0	0	0	11	781
Greater Giyani (LIM331)	-1196	-344	-179	0	0	-4081	0	0	46	-140
Kannaland (WC041)	-6364	6418	338	-468	0	0	0	0	-26	10
Elundini (EC141)	-2110	2435	35	0	0	769	0	0	24747	-7
Emadlangeni (KZN253)	-7468	2552	-7	0	0	390	0	0	6101	-191
Mhlontlo (EC156)	16	0	1	0	0	598	0	0	498	-2
Swellendam (WC034)	-4889	6216	-343	-77	0	0	0	0	-1081	54
Mantsopa (FS196)	-7250	3095	0	0	0	229	0	0	252	-53
Msinga (KZN244)	-664	582	3	0	0	1061	0	5	-511	60
Dr Nkosazana Dlamini Zuma (KZN436)	-10712	13744	33	0	0	4368	0	0	17087	16
Umhlabuyalingana (KZN271)	-32	0	702	0	0	5889	0	0	6840	3
Lepele-Nkumpi (LIM355)	-2068	38	-1344	0	0	2028	0	0	158	-66
Mbhashe (EC121)	-68	0	489	0	0	1085	0	0	572	-49
Breede Valley (WC025)	-3523	701	902	-1378	0	0	0	0	-209	16
Ditsobotla (NW384)	-20942	8584	-2	0	0	-137	0	0	3584	-3094
Local Municipality of Madibeng (NW372)	-27653	19430	-34	0	0	-12	0	0	1402	2061
Thembisile (MP315)	-3547	396	0	0	0	989	0	0	416	-341
Joe Morolong (NC451)	-2162	-4	0	0	0	-284	0	0	25	843
Maluti a Phofung (FS194)	860	1939	17	0	0	62	0	0	1189	-244
Ramotshere Moiloa (NW385)	-19677	3074	-4	0	0	324	0	0	1431	-825
Ngquza Hill (EC153)	0	0	13	0	0	1621	0	0	159	-13
King Sabata Dalindyebo (EC157)	-82	52	0	0	0	730	0	0	104	5
Setsoto (FS191)	-6786	3257	-107	0	0	10	0	0	1008	-48
Okhahlamba (KZN235)	-10462	17005	-29	0	0	7703	0	0	-46	8
Ulundi (KZN266)	-690	-1	2	0	0	-97	0	0	-2114	-16
eThekwini (ETH)	-393	55	-94	0	0	2520	0	554	-1488	314
Hessequa (WC042)	-1181	6913	103	-112	0	0	0	0	-2218	133

Inkosi Langalibalele (KZN327)	-2793	3314	33	0	0	2434	0	0	3040	18
Thabazimbi (LIM361)	-35879	18204	-26	0	0	-54	0	0	92	508
Ventersdorp/Tlokwe (NW405)	-27166	11943	8	0	0	-17	0	0	1724	-984
Bergrivier (WC013)	-15977	13733	-1578	-642	0	19	0	0	-98	-266
Dr JS Moroka (MP316)	-1935	45	0	0	0	1981	0	0	38	-452
Bushbuckridge (MP325)	-218	0	209	0	0	1284	0	0	-12699	-145
Umzimkhulu (KZN435)	-217	149	16	0	0	1939	0	8	1666	54
Lekwa-Teemane (NW396)	-15548	2722	-163	0	0	0	0	0	483	-4528
Maquassi Hills (NW404)	-22373	2576	17	0	0	0	0	0	1121	-861
eDumbe (KZN261)	-2066	1333	34	0	0	1529	0	0	17571	-72
Umzumbe (KZN213)	-47	27	4	0	0	4677	0	870	-580	1
Govan Mbeki (MP307)	-10775	1726	-12	0	0	0	0	0	827	625
Dihlabeng (FS192)	-3321	3574	185	0	0	0	0	0	1737	-154
Matatiele (EC441)	-9300	3616	-10	0	0	2234	0	0	1203	-97
Nyandeni (EC155)	12	0	0	0	0	415	0	0	284	16
Engcobo (EC137)	2	0	0	0	0	538	0	0	-550	47
Umvoti (KZN245)	-3130	2192	86	0	0	-364	0	-1303	5942	16
Mafikeng (NW383)	-4071	975	-2	0	0	-3499	0	0	395	-1107
Umzimvubu (EC442)	0	0	0	0	0	881	0	0	1207	-3
Newcastle (KZN252)	-1700	1446	20	0	0	478	0	0	3979	-151
Musina (LIM341)	-2043	1086	941	0	0	6095	0	0	163	-758
uPhongolo (KZN262)	-1213	105	323	0	0	1918	3212	393	155	12
Nqutu (KZN242)	-18	1	0	0	0	2439	0	0	-643	-12
Phumelela (FS195)	-1158	6720	47	0	0	0	0	0	4831	-353
Sundays River Valley (EC106)	-6657	2729	4022	0	0	0	0	0	-551	-121
Kgetlengrivier (NW374)	-11317	3281	0	0	0	-240	0	0	438	-99
Ephraim Mogale (LIM471)	-9445	5402	479	0	0	1845	0	0	52	-293
Ngqushwa (EC126)	59	79	-149	0	-3290	2673	0	0	298	-60
Intsika Yethu (EC135)	-558	357	0	0	0	1361	0	0	57	-18
Maruleng (LIM335)	-2524	712	1742	0	0	1902	0	0	363	-198
Oudtshoorn (WC045)	-15357	12138	-31	-59	0	0	0	0	-23	63
Ratlou (NW381)	-15005	995	0	0	0	-1704	0	0	252	586
Umdoni (KZN212)	-26	30	13	0	0	927	0	1414	-193	8
City of Matlosana (NW403)	-12017	2314	-1	0	0	0	0	0	1121	111
Tsantsabane (NC085)	-14	47	0	0	0	0	0	0	-49	1281
Ray Nkonyeni (KZN216)	-83	46	2845	0	0	4121	0	-398	-1172	119
Endumeni (KZN241)	-4666	3732	0	0	0	536	0	0	-175	-140
City of Johannesburg (JHB)	-7252	706	20	0	0	143	0	0	-3685	693
Greater Kokstad (KZN433)	-6138	8133	14	0	0	97	0	0	3709	-16
Ubuhlebezwe (KZN434)	-3348	2949	113	0	0	3636	12	746	2487	20
Greater Letaba (LIM332)	-812	13	238	0	0	-6254	0	0	-760	-50
Jozini (KZN272)	-3889	482	13	0	-1372	5869	1378	4508	-41	39

Ntabankulu (EC444)	0	0	0	0	0	360	0	0	-72	-3
Moretele (NW371)	-1885	15	0	0	0	-3595	0	0	96	-94
Victor Khanye (MP311)	-15010	6268	2	0	0	0	0	0	414	4346
Tokologo (FS182)	-53955	31212	125	0	0	0	0	0	2556	-1374
City of Cape Town (CPT)	203	1144	330	-1238	0	0	0	0	-2973	486
Sakhisizwe (EC138)	-1225	770	0	0	0	541	0	0	4540	-32
Nongoma (KZN265)	-189	0	7	0	0	-1869	54	-12	42	4
Naledi (NW392)	-19662	2966	2	0	0	-10	0	0	1036	-3425
Thaba Chweu (MP321)	-5449	4789	2060	0	0	66	0	0	-20013	168
Dannhauser (KZN254)	-2963	2340	1	0	0	3123	0	0	1335	-149
Dipaleseng (MP306)	-4687	3330	0	0	0	0	0	0	484	-163
Nkandla (KZN286)	-38	0	1	0	0	1275	0	26	-1108	-4
Ekurhuleni (EKU)	-15004	1822	107	0	0	574	0	0	-3317	-801
Big Five Hlabisa (KZN276)	-3431	0	-2393	0	-2281	-1281	283	372	2240	13
Buffalo City (BUF)	1758	75	-877	0	-3467	1450	0	0	566	-120
Swartland (WC015)	-7069	3451	749	-3212	0	0	0	0	211	-19
Mpofana (KZN223)	-7708	8815	26	0	0	-164	0	0	2497	2
uMlalazi (KZN284)	-442	24	-443	0	0	-3046	0	15421	-2279	329
Moqhaka (FS201)	-19443	4188	68	0	0	0	0	0	4865	235
Thembelihle (NC076)	-1787	7818	135	0	0	0	0	0	-18	-469
Ndlambe (EC105)	-2666	650	-5557	0	5000	-165	0	0	1398	29
City of Mbombela (MP326)	-13820	92	10973	0	0	-2073	372	706	-19056	-82
Ba-Phalaborwa (LIM334)	-1011	226	-79	0	0	2374	0	0	-30	-1202
Mamusa (NW393)	-16942	791	1	0	0	0	0	0	697	1
Port St Johns (EC154)	0	0	23	0	0	694	0	0	-181	24
Amahlathi (EC124)	-1280	543	-664	0	0	202	0	0	3262	-40
Renosterberg (NC075)	-483	1245	0	0	0	0	0	0	-56	21
Cape Agulhas (WC033)	-601	481	1	-7	0	0	0	0	-2068	67
Tswelopele (FS183)	-29900	24457	206	0	0	0	0	0	1910	-53
Siyancuma (NC078)	-4568	11518	80	-31	0	0	0	0	66	-925
Drakenstein (WC023)	4549	1006	776	-4670	0	24	0	0	-425	-32
uMuziwabantu (KZN214)	-396	65	16	0	0	3569	0	1581	-28	13
uMngeni (KZN222)	-7199	6917	92	0	0	8	0	-136	1919	16
Ga-Segonyana (NC452)	159	84	0	0	0	0	0	0	54	-52
Saldanha Bay (WC014)	-8942	1080	27	1	0	19	0	0	-127	331
Matjhabeng (FS184)	-22423	8703	2	0	0	0	0	0	2471	14
Gamagara (NC453)	-33	-67	0	0	0	0	0	0	-16	1373
Mossel Bay (WC043)	-3546	4381	171	-34	0	0	0	0	-1051	51
Mkhambathini (KZN226)	-242	186	31	0	0	456	0	2657	-1757	70
Makana (EC104)	-395	701	-1534	0	389	-201	0	0	751	-161
Richmond (KZN227)	-839	816	-154	0	0	226	28	2141	55	7
Mogale City (GT481)	-1778	1919	246	0	0	53	0	0	204	226

Greater Taung (NW394)	-5507	1185	20	0	0	-178	0	0	510	-468
Impendle (KZN224)	-1541	1231	-5	0	0	403	0	0	3551	4
Nketoana (FS193)	-12392	9642	23	0	0	0	0	0	1981	-171
Overstrand (WC032)	-762	481	-94	-420	0	0	0	0	-1272	24
Masilonyana (FS181)	-14960	5754	-6	0	0	3	0	0	2677	-26
uMhlathuze (KZN282)	-1082	221	267	0	0	-1186	1337	2376	-5365	575
The Msunduzi (KZN225)	139	44	-11	0	0	48	0	-87	-1070	48
Mafube (FS205)	-8728	9513	1	0	0	0	0	0	153	-238
uMshwathi (KZN221)	-1181	410	34	0	0	3304	203	3662	-4480	32
Mthonjaneni (KZN285)	-252	0	43	0	0	1767	0	-602	1439	-5
Midvaal (GT422)	-4047	3355	16	0	0	14	0	0	-1190	94
Lesedi (GT423)	-5251	1206	0	0	0	-13	0	0	-73	-83
Great Kei (EC123)	-220	406	13	0	-2181	36	0	0	625	-21
Tswaing (NW382)	-16177	5888	1	0	0	-143	0	0	2294	98
Nelson Mandela Bay (NMA)	-2154	672	-162	0	0	0	0	0	-171	-1758
Theewaterskloof (WC031)	-1004	3786	-464	-818	0	61	0	0	-3637	18
KwaDukuza (KZN292)	-339	0	15	0	0	-540	58	2211	-510	76
George (WC044)	-15632	9147	161	34	0	0	0	0	-4989	-29
Kouga (EC108)	-14981	13341	391	0	0	28	0	0	-1436	-3
Kou-Kamma (EC109)	-13517	14109	870	0	0	55	0	0	-3068	-21
Emfuleni (GT421)	-3634	504	-116	0	0	-13	0	0	-488	-258
Greater Tzaneen (LIM333)	-1920	470	-620	0	0	-4794	0	0	-4899	-149
Merafong City (GT484)	-9628	1080	-2	0	0	0	0	0	625	-363
Bela-Bela (LIM366)	-24698	4799	35	0	0	-10	0	0	125	-2209
New (LIM345)	78	254	-52	0	0	-17885	0	0	-21	-41
Sol Plaatjie (NC091)	-1081	3660	12	0	0	0	0	0	11	-1501
Magareng (NC093)	-4777	6791	412	0	0	20	0	0	15	-751
Rand West City (GT485)	-12717	3312	181	0	0	-1	0	0	358	-532
Metsimaholo (FS204)	-4246	2428	0	0	0	0	0	0	-163	1969
Mfolozi (KZN281)	-298	0	-32	0	0	-1695	103	1557	152	902
Maphumulo (KZN294)	27	0	0	0	0	1234	0	44	-1294	3
Letsemeng (FS161)	-31156	33176	248	0	0	1	0	0	1242	-401
Ndwedwe (KZN293)	-257	0	36	0	0	4875	0	1118	-931	7
Raymond Mhlaba (EC129)	-1433	373	-868	0	0	-67	0	0	243	-60
Mandeni (KZN291)	-225	0	3	0	0	4718	11	2707	-2478	18
Kopanong (FS162)	-6549	7764	-21	0	0	0	0	0	2789	43
Prince Albert (WC052)	-1633	1393	134	-57	0	0	0	0	21	38
Nala (FS185)	-10222	6496	3	0	0	0	0	0	851	-25
Bitou (WC047)	-467	945	32	57	0	0	0	0	-1502	11
Phokwane (NC094)	-18760	16657	2183	0	0	204	0	0	116	-4
Ngwathe (FS203)	-6059	1623	-2	0	0	0	0	0	2922	14
Kgatelopele (NC086)	31	110	0	0	0	0	0	0	-20	-324
Stellenbosch (WC024)	2692	773	584	-4043	0	0	0	0	-4185	-18
Dikgatlong (NC092)	-5024	4575	0	0	0	0	0	0	77	-3714

Knysna (WC048)	-2799	3084	12	0	0	0	0	0	-7935	-6
Thulamela (LIM343)	-423	-82	-137	0	0	-16507	0	0	-260	18
Mtubatuba (KZN275)	-68	0	100	0	0	-6191	163	2875	-11939	668
Umsobomvu (NC072)	-1597	1582	0	0	0	0	0	0	135	-94
KhÃƒÂ¢i-Ma (NC067)	-132	237	305	-228	0	0	0	0	5	993
Inxuba Yethemba (EC131)	-14285	20279	-1530	0	0	140	0	0	421	-239
Siyathemba (NC077)	-918	4546	14	-70	0	0	0	0	32	-1362
Dawid Kruiper (NC087)	42	173	76	80	0	0	0	0	-12	-312
!Kheis (NC084)	-15	51	189	-229	0	0	0	0	2	110
Karoo Hoogland (NC066)	-1433	831	-8	0	0	0	0	0	35	347
Emalahleni (MP312)	-93050	351	-5	0	0	42461	0	0	-4226	-14298
Blue Crane Rout/ie (EC102)	-8572	12965	68	0	0	0	0	0	151	-178
Kareeberg (NC074)	-668	289	0	0	0	0	0	0	-14	118
Ubuntu (NC071)	-1565	904	-126	0	0	0	0	0	-38	-50
Beaufort West (WC053)	-3280	2604	94	4	0	0	0	0	155	45
Dr Beyers Naude (EC101)	-6513	4793	0	0	0	2	0	0	44	-34
TOTAL	-1 449 231	790 013	-8 909	-19 748	-7 262	71 495	14 067	55 834	139 182	5 524