SOUTH AFRICAN NATIONAL TERRESTRIAL CARBON SINKS ASSESSMENT: SUPPLEMENTARY INFORMATION, INTERPRETATIONS AND SIMPLE DESCRIPTIONS

Dr. Graham von Maltitz, CSIR-NRE, GvMalt@csir.co.za

This document gives simple supplementary information to assist readers in understanding the issues around options for carbon sequestration and emissions from the LULUC sector. The full report from the South African National Terrestrial Carbon Sinks Assessment can be downloaded from the documents section of the carbon atlas web site or alternatively via www.environment.gov.za/documents/research. In addition a number of further data sources are referenced for those readers who require greater technical detail.

GLOSSARY OF TERMS

• Gross Primary Production (GPP) denotes the total amount of Carbon (C) fixed in the process of photosynthesis by plants in an ecosystem, such as a stand of trees. GPP is measured on photosynthetic tissues, principally leaves, on an hourly timescale and integrated to an annual amount. Global total GPP is about 120 Gt C yr-1.

• Net Primary Production (NPP) denotes the net production of organic matter by plants in an ecosystem. NPP is about half of GPP as plants respire the other half in building up and maintaining plant tissues. NPP can be measured as the increase in plant biomass on a daily or weekly timescale. For all terrestrial ecosystems combined, it is estimated to be about 60 Gt C yr-1.

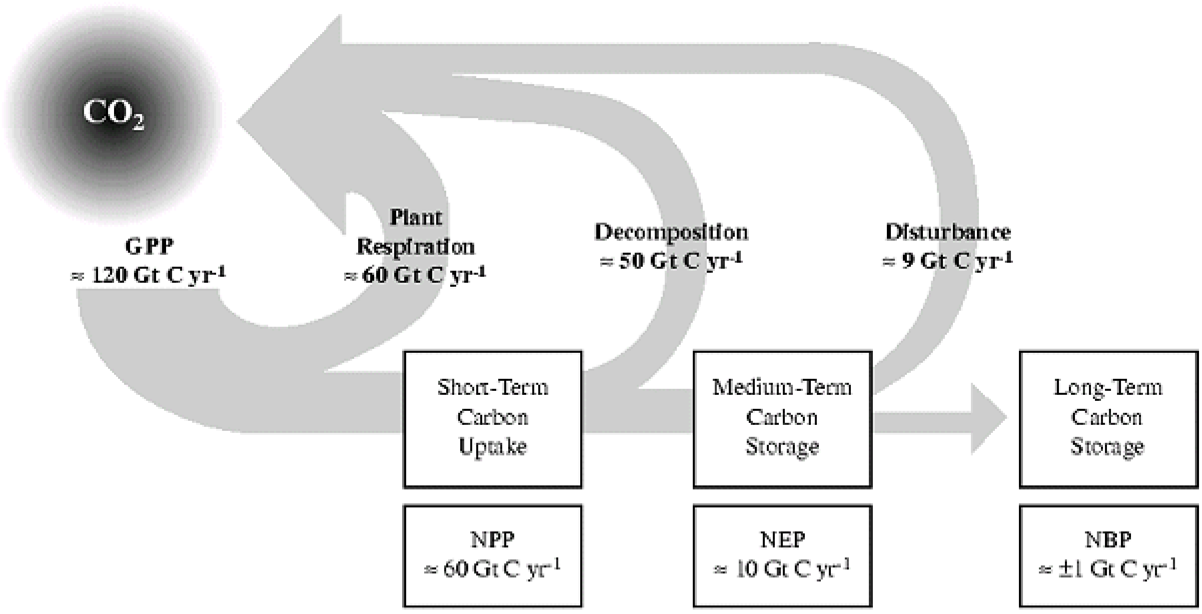

Figure 1. Global terrestrial carbon uptake. Plant (autotrophic) respiration releases CO_2 to the atmosphere, reducing GPP to NPP and resulting in short-term carbon uptake. Decomposition (heterotrophic respiration) of litter and soils in excess of that resulting from disturbance further releases CO_2 to the atmosphere, reducing NPP to NEP and resulting in medium-term carbon uptake. Disturbance from both natural and anthropogenic sources (e.g., harvest) leads to further release of CO_2 to the atmosphere by additional heterotrophic respiration and combustion-which, in turn, leads to long-term carbon storage (From http://www.ipcc.ch/ipccreports/sres/land_use adapted from Steffen et al., 1998).

• Net Ecosystem Production (NEP) denotes the net accumulation of organic matter or C by an ecosystem; NEP is the difference between the rate of production of living organic matter and the decomposition rate of dead organic matter (heterotrophic respiration). Heterotrophic respiration includes losses by herbivore and the decomposition of organic matter by organisms. Global NEP is estimated to be about 10 Gt C yr-1. NEP can be measured in two ways: one is to measure changes in C stocks in vegetation and soil over time, using an annual timescale; the other is to integrate hourly/daily fluxes of CO_2 into and out of vegetation and integrate up to the yearly timescale. NEP should be integrated up to a decadal (10 year) timescale.

• Net Biome Production denotes the net production of organic matter in a region containing a range of ecosystems (a biome) and includes, in addition to heterotrophic respiration, other processes leading to loss of living and dead organic matter (harvest, forest clearance, and fire, etc.) (Schulze and Heimann, 1998).

SOUTH AFRICAN BIOMES

South Africa boasts 5 dominant natural vegetation biomes namely the savanna (32.5%), grassland (27.9%), nama-karoo (19.5%), fynbos (6.6%) and succulent karoo (6.5%) (figure 2). Other biomes include Albany thicket (2.2%), Indian Ocean coastal belt (1.1%), desert (0.5%) and forest (0.3%). The objective of the National Carbon Sinks Atlas is to present the distribution of carbon stocks in these biomes and to allow for downloading of this information by a range of stakeholders.

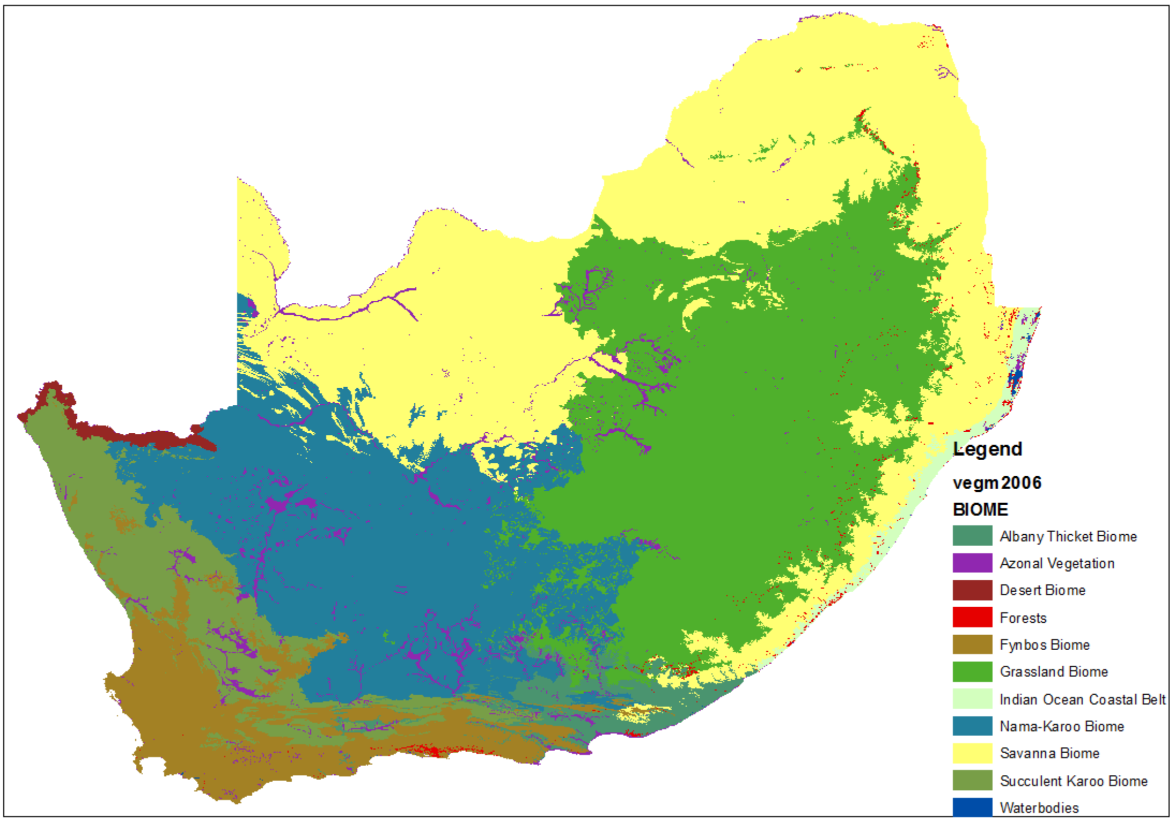

Figure 2. The biomes of South Africa

THE POTENTIAL FUTURE EFFECTS OF CLIMATE CHANGE ON EMISSIONS FROM THE LAND USE SECTOR

The temperature in the interior of South Africa appears to be rising at rates greater than the international average, possibly as much as twice the global average. Rates of temperature increases in coastal areas is slightly slower than in the interior, more in line with global averages. In both cases there is a high degree of consensus that the future will be hotter than the present (Engelbrecht et al 2015). The final extent of temperature rises is strongly dependent on the worlds ability to reduce carbon emission in the future, however a $2^{o}C$ global average rise in temperature by the end of the century seems likely, with far higher temperature rises not impossible. The fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) demonstrated that average global temperatures have on average increased by 0.85 degrees Celsius over the last 100 years.

Predictions of changes in rainfall are less certain, with likely impacts also being more location specific than temperature rises. The actual predictions of future rainfall varying greatly between different future CO_2 predictions and the global circulation models used (DEA 2013 a,b and South African Risk and Vulnerability Atlas) . It is likely thought that much of the wetter eastern half of the country might get a slight increase in precipitation, whilst the already dry west may well become dryer. It is also speculated that rainfall may become more concentrated in fewer, but heavier rainfall events(DEA 2013 a, b)).

These climatic changes are likely to have profound impacts on the carbon stocks and emissions from the LULUC sector. Some of the likely impacts are:

1) Raised temperatures are likely to result in greater oxidation of soil carbon, potentially reducing the amount of soil stored organic carbon. This might be offset in areas with higher plant NPP, but in areas with constant or declining NPP these impacts may be quite large.
2) A changing climate will impact on NPP. Plants tend to produce more biomass in hot wet areas. However, increased temperature, without increased rainfall will create a greater water stress on plants. This will, to some extent, be offset by the fertilizer effect of increased global CO_2. Plants have an optimum temperature for maximum photosynthesis. This optimum temperature is slightly higher for C_4 and CAM plants, compared to C_3 plants. At temperatures above this optimum, photosynthesis rates decline. There are interactions between atmospheric CO_2 and optimum growth temperatures, with raised CO_2 potentially raising optimum temperatures (Yamori and Hikosaka 2012, Sage and Kunien 2007).
3) Increased CO_2 levels reduce the amount leaf stomata have to be open to take up CO_2. Since plants 'lose" water through the stomata when they are open, plants can therefore reduce their transpiration for the same amount of carbon uptake. This means that plants can be slightly more drought hardy, or put differently, can grow more given the same amount of rainfall, the so-called CO_2 fertilization effect. C_3 plants benefit (all trees and most other plants excluding tropical grasses) more from this CO_2 fertilization effect than C_4 plants (tropical grasses) (Kgope et al 2010, Bond and Midgley 2012).
4) There is a possibility of shifts in biomes. In particular, it seems very probable that the savanna biome will move into the grassland biome. This will increase aboveground biomass, but may decrease soil carbon stocks (DEA 2013c).

5) There is a possibility of tree densification (i.e. bush encroachment). The CO_2 fertilizer effect may well give trees a competitive edge over grass, and it is likely that the savanna biome might increase in tree density, in some places becoming forest (Kgope et al 2010, Bond and Midgley 2012).
6) Fire regimes might change. Hot weather increases the likelihood and intensity of fires. However, increased tree density may limit fires, as fires are rare in areas with greater than 60% tree cover.

Understanding the interactions between the above factors is complex. For instance increased fires may decrease woody expansion whilst CO_2 fertilization is promoting it. The report (NTCSA 2015) give current best estimates on biome level impacts from climate change.

A modelling approach using the Century Model was used to consider possible carbon change impacts at a few select locations. It was found that total carbon responses to changing climate was very situation specific and that depending on the situation, climate change could either increase or decrease the carbon stock (NTCSA 2015).

Climate change will also impact on agricultural crop production. Again the CO_2 fertilization effect will be important, but agricultural areas that have both an increase in temperature and a decrease in rainfall may well become too dry for cropping in the future. It is therefore likely that some historically cropped areas may become abandoned, whilst other areas may become suitable for cropping. Abandoned crop areas can take exceptionally long periods of time to recover soil carbon stocks to those comparable with the surrounding natural vegetation. Of course the extent of recovery in carbon stocks would be determined by land management regimes that would be introduced as part of rehabilitation/restoration (Birru TC. 2002). Furthermore these areas are very susceptible to invasive alien plant establishment.

DEFINING CARBON SINKS AND FLUXES IN ACCORDANCE WITH 2006 IPCC GUIDELINES

The IPCC is an independent scientific body linked to the United Nations Framework Convention on Climate Change (UNFCCC). The IPCC provides sets of guidelines as to how carbon dioxide (CO_2) and other greenhouse gasses (GHG) emissions should be measured, reported and verified (MRV). They provide three tiers of measurement approaches, tier one being a simple default method, with tier two and three being more complex based on better levels of national data (See IPCC guidelines http://www.ipcc-tfi.iges.or.jp/public/2006gl/vol4.html and http://www.ipcc.ch/ipccreports/sres/land_use).

When countries report on their GHG emissions to the UNFCCC, one of the sectors they report on is land use and land use change (LULUC). It is this sector for which this carbon atlas is designed as a supporting tool. All vegetation consists largely of carbon, with oven-dry wood typically being about 48% carbon bases on weight. When vegetation is burned or de-composes, most of this carbon is converted into CO_2, with 3.66g of CO_2 produced per gram of carbon burnt. Some of the vegetation carbon is not burnt or oxidised, and becomes soil organic carbon. Any change in the amount of vegetation on a piece of land therefore reflects either an uptake or emission of CO_2. The total amount of carbon on a unit of land is the sum of the carbon stored in above ground plant material, the below ground plant material (roots), the litter layer on the soil surface, the carbon in animals and other living organisms including soil microbes, and the soil organic carbon (Figure 3).

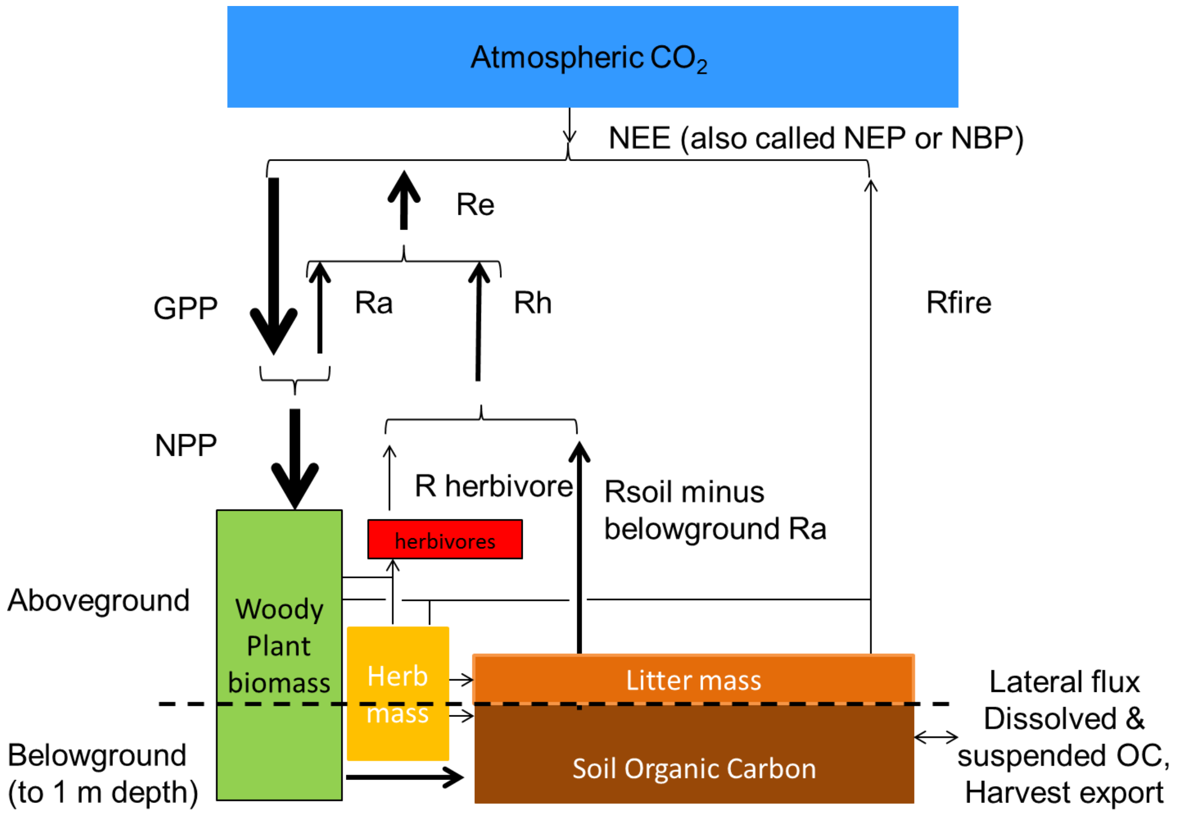

Figure 3. Components of a generalised terrestrial carbon cycle. The size of the boxes and the arrows, which represent stocks and fluxes respectively, is roughly indicative of their relative size. The herbivore stock is relatively small (<10^{12}gC nationally). Net Primary Production (NPP) is net amount of Carbon sequestered by plant, whilst respiration releases CO2 into the atmosphere.
GPP = gross primary production
NPP = net primary production
Re = ecosystem respiration
Ra = plant respiration
Rh = heterotrophic respiration (respiration by all organisms other than plants)
RSoil = respiration from soil (excluding belowground plant respiration)
RFire = fire flux
NEP Net ecosystem production / net ecosystem exchange /net biome production
GPP = gross primary production

Most land use change, or land degradation, results in a net loss of vegetation and soil carbon to the atmosphere (CO_2 emissions). There are a few situations where land use change results in a net sequestration of carbon, for instance converting dryland agriculture to irrigated agriculture or the establishment of forestry plantations. Reclamation activities and switching from conventional to organic agriculture, non-till agriculture or climate smart agriculture practices may also help sequester and maintain carbon stocks. When recording national carbon stocks it is important to take into account carbon lost (or gained) through land use change. The IPCC lists six land-use classes: forest land; cropland; grassland; wetlands; settlement and other lands as the sectors for consideration. This definition is problematic for South Africa where biomes such as the fynbos, karoo and succulent thickets do not fit well into any of the IPCC classes. Further, though it is assumed that dense savanna is included as forest, and less dense savanna is included as grassland, it is not clear where this differentiation occurs (the FAO definition of forest as areas with greater than 10% tree cover or the broad forest definition in the Marrakesh Accord).

The tier 1 IPCC guidelines use simple equations based on the change in land between a specified small set of land use types. The IPCC methodology places a huge emphasis on movement into or out of forests. Given the nature of South African biomes, the relatively limited importance of forests in South Africa and the variation in biomass stocks within biomes, this tier 1 methodology will give a poor representation of South African LULUC biomass stocks and fluxes.

The approach in the carbon atlas has been to conduct a countrywide land use carbon assessment based on all vegetation types, and not simply limited to the IPCC guideline definitions. This in effect is a tier 2 methodology, developed specifically for South Africa. A map of biomes is provided in the Carbon Atlas for reference on the unique South African biomes. In the South African context the following land use changes are the most important for considering carbon impacts are:

1) Any natural vegetation being changed to dryland crop agriculture. This can result in a 40 to 60% loss of soil carbon (Du Toit 1992, Du Toit et al 1994, Du Preez 2011). This is typically a far higher loss than the above ground loss of carbon, though this may also be important, especially if land was previously savanna or forest.
2) Change from any natural vegetation to plantation forestry. This may increase above and below ground biomass carbon stocks. Impacts on soil carbon stocks can vary and be either positive or negative.
3) Any change to irrigation crop agriculture. Impacts on total carbon will depend on crop and agricultural practices and could be positive or negative.
4) Any degradation of natural vegetation. This will lead to both aboveground plant biomass loss as well as reductions in soil carbon.
5) Any loss of cropland or natural vegetation to urban expansion. This will typically reduce both biomass carbon stocks as well as soil carbon stocks.

The carbon atlas has two sets of above ground woody biomass data. A relatively course estimate covering the entire country and a new updated and more spatially accurate database that currently is only available for the lowveld areas of the country. This updated dataset has a number of advantages over the initial data, and is likely to be more accurate when considering woody biomass for any specific location. In addition it is produced at a far higher spatial resolution.

ASSESSING THE EFFECTS OF LAND-USE CHANGES AND LAND COVER CHANGES ON GHG EMISSIONS OF THE AFOLU SECTOR

Land use change typically results in changes in the above ground, below ground, litter and soil carbon pools. In general, any reduction in the amount of standing vegetation biomass, will also result in a reduction in the equilibrium soil biomass over time. In the case of crop agriculture the combined impact of reduces vegetation cover, together with the impacts of soil disturbance, through ploughing, results in substantive loss of soil carbon. No-till agricultural practices and other conservation farming practices can reduce this degree of soil carbon loss, or help to sequester soil carbon in fields where the carbon is already lost.

Based on the relatively limited available data, the following soil carbon losses from different land use changes were assumed.

F_{lu} = 0.5 for dryland crops
F_{lu} = 0.8 for irrigated crops
F_{lu} = 0.8 for Horticulture tree crops
F_{lu} = 0.6 for sugar cane
F_{lu} = 0.5 for dryland crops

Where F_{lu} is a Land use factor reflecting the proportion of soil carbon retained in a given land use. Box 1 gives the EU guidelines on determanig soil organic carbon in agriculture. For the carbon atlas F_{mg} and F_i

Box 1. EU methodology (EU 2010) for calculating soil organic carbon in agriculture

$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_{I}$

where:

SOC = soil organic carbon (measured as mass of carbon per hectare);

SOC_{ST} = standard soil organic carbon in the 0-30 centimetre topsoil layer (measured as mass of carbon per hectare);

F_{LU} = land use factor reflecting the difference in soil organic carbon associated with the type of land use compared to the standard soil organic carbon;

F_{MG} = management factor reflecting the difference in soil organic carbon associated with the principle management practice compared to the standard soil organic carbon;

F_{I} = input factor reflecting the difference in soil organic carbon associated with different levels of carbon input to soil compared to the standard soil organic carbon.

For biomass carbon in the agricultural sector the following was assumed:

AGB_{crop} was computed as a function of the at-harvest aboveground biomass ($AGB_{harvest}$) and the year-round residue mass left in stalks ($AGB_{residue}$). Crop duration is the average period between planting and harvest for that crop, in days.

$AGB_{crop} = AGB_{harvest}$*0.5* crop duration/365+ $AGB_{residue}$

The Harvest index (HI) was used to determine $AGB_{harvest}$ per hectare

$AGB_{harvest}$ = Y (t/ha) / HI

Where:
Y = yield * (1 – fraction moisture)

Yield (in gC/m^2) was quantified at municipal level for each crop group and used the 2002 agricultural senses data (STATS SA 2002) to determine the proportional distribution of crop types and local yields. The carbon fraction was assumed the be 0.47 (EU 2010) for all agricultural vegetation. We had no error information on this term so had to assume no error. Fraction moisture was estimated for each crop type from the literature.

$AGB_{residual} = (AGB_{harvest} - Y) * R_{AGB}$

Where R_{AGB} is the residual aboveground biomass expressed as a proportion of the non-yield biomass

$BGB_{crop} = 0.2\ AGB_{crop}$

except for root crops, where BGB_{crop} is the root DM yield.

Table 1. Calibration factors used for agricultural crops

Crop group	**HI**[1]	**Moisture**	**Below ground fraction**[2]	**Carbon fraction**	**Residual fraction AGB R_{AGB}**	**Residual fraction BGB R_{BGB}**	**Crop duration**[3]
Summer cereals [4]	0.5	0.13	0.2	0.47	0.2 (dry) 0.1 (irr)	0.8 (dry) 0.6 (irr)	0.66
Winter cereals[5]	0.4	0.11	0.2	0.47	0.2 (dry) 0.1 (irr)	0.8 (dry) 0.6 (irr)	0.5
Oil seeds	0.39	0.15	0.2	0.47	0.2 (dry) 0.1 (irr)	0.8 (dry) 0.6 (irr)	0.66
Legumes	0.85	0.15	0.2	0.47	0.2 (dry) 0.1 (irr)	0.8 (dry) 0.6 (irr)	0.5
Fodder crops	1	0.5	0.2	0.47	0.2 (dry) 0.0 (irr)	0.2 (dry) 0.0 (irr)	1
Sugar cane	1	0.2	0.2	0.47	0.1 (dry) 0.1 (irr)	1 (dry) 1 (irr)	1
Other crops	1	0.5	0.2	0.47	0.2 (dry) 0.0 (irr)	0.2 (dry) 0.0 (irr)	1
Vegetables	1	0.5	0.2	0.47	0.0 (irr)	0.6 (irr)	0.83

[1] HI = Harvest Index: the ratio of harvested yield to total aboveground biomass
[2]as proportion of AGB
[3]as proportion of year
[4]based on Maize which accounts for over 94% of this group
[5]based on wheat which accounts for over 85% of this group

For tree crops the following was assumed

For tree crops two categories of trees where used. Grape vines and all other trees (see table 2). An area and tree category weighted average was derived per municipality. It was assumed that tree biomass is the same in all locations. Below ground biomass was assumed as a proportion of above ground biomass. A non-tree biomass of 1 t/ha was assumed for other (non-tree) biomass in the orchard.

Table 2. Calibration factor for tree crops

	t/ha above ground (dry)	Belowground fraction	Residual biomass (non tree) t/ha
Vines	14	0.4	1

Other trees	38	0.4	1

For urban areas the following was assumed:

$AGB_{urban} = FAPAR_{annual\ mean} * 5000$ [gC/m^2] (Based on an IPCC 2006 value for closed urban forests. The multiplier can be adjusted to match estimates for the urban areas which have been surveyed, eg Johannesburg and eThikweni.)

$BGB_{urban} = 0.5\ AGB_{urban}$ (assumes a mix of trees and herbaceous)

$SOC_{urban} = 0.8\ SOC_{0\text{-}1000}$ (from AFSIS)

$AGL_{urban} = 0$. This could be used to reflect an estimate of carbon as timber in buildings and their furniture, plus the carbon in landfills from the National Communication.

IMPACTS OF FIRES ON GHG EMISSIONS

Fire is a natural part of the savanna, grassland and fynbos biomes as well as in grassy areas of the indian ocean coastal belt biome of South Africa, but are rare or non-existent in the remaining biomes. In fact for those biomes where fire is common, removing fire will have devastating consequences to the biodiversity of the biome, and may well fundamentally change the structure of the biome. For instance moist grasslands may change to forest with the absence of fire. Almost all fynbos species are in some way adapted to fire, and many would become extinct without fire. The return period between fires is, however, different for different biomes, and different rainfalls within a biome. For moist grasslands and savannas fire return periods are every two to three years, whilst at the dry end of savannas or grasslands, fire return periods may be closer to 15 to 20 years. For fynbos a 15 to 20 year fire cycle is probably the natural cycle, but way more frequent fires occur due to humans.

For practical purposes, fires can be regarded as CO_2 neutral. The CO_2 emitted in the fire is taken up in the vegetation that grows back after the fire. This assumes that over the long term the vegetation has a relatively constant biomass.

Modifying fire regimes can result in some changes to the land sector carbon stocks and fluxes. Fire could, therefore, be used as a way of reducing emissions. The following factors need to be considered:

1) Changing the frequency so that fires are less frequent can lead to a higher accumulation of above and below ground biomass. In extreme cases it could lead to a fire prone habitat becoming fire resistant (grassland changing to forest, woodland changing to closed canopy forest). However, reducing the frequency of fires can also result in a situation that when fires do occur they are exceptionally severe, causing extreme damage to the natural vegetation and threatening lives and property.
2) Fires may play an important role in the build-up of soil organic matter.
3) Changing the seasonality of fires can change the nature of emissions. Though most emissions are of CO_2, a small proportion of emissions are other compounds with a higher

global warming potential than CO_2 such as methane and nitrous oxide. Hot clean burning fires have less non-CO_2 emissions than slow smouldering fires.

4) Black carbon emissions have a strong impact on heat absorption and there is evidence that this can retard the formation of rain clouds, especially in areas of convectional rain such as in the interior of South Africa.
5) Climate change is predicted to change fire regimes as the landscape will be hotter and possibly dryer. It is very possible that high intensity fires may become more common. This enhanced fire regime may well offset any attempts to reduce fire frequency as a strategy for sequestering carbon.

Although changing fire regimes has not been recognised as a major mitigating option for South Africa (DEA 2014, NTCSA 2015) , in Australia the Carbon Farming Initiative is recommending changing the seasonal timing of grass fires as a mechanism to reduce emissions.

Burning of agricultural crop residue also adds to fire derived emissions. In Europe and Russia, this is considered a key source of the black carbon which is a cause of arctic ice melting. In southern Africa this impact is less and largely masked by natural fires. However, conservation agriculture techniques and using crop residue for animal fodder can reduce the fires, though given the complex emissions from livestock this may not reduce net emissions. Reducing burning in the sugarcane sector by not burning cane prior to harvesting can have positive benefits, especially if this increases the bagasse volume that can be used for power generation and hence offset coal based power production.

KEY FACTORS/DRIVERS OF THE OBSERVED TRENDS IN EMISSIONS AND REMOVALS OF THE AGRICULTURE, FORESTRY AND OTHER LAND USE (AFOLU) SECTOR

South Africa has a relatively constant agricultural sector with a relatively slow rate of land use change. However, the trend is a slow decrease in natural vegetation with an increase in degraded and transformed areas. Based on the NCSA (2015) there is a slow loss from most natural biomes other than grasslands between 2001 and 2020, with the biggest growth area being semi-commercial and subsistence agriculture. Areas of bare soil (degraded areas) also appear to be increasing. Sugarcane, commercial dryland and centre-pivot irrigation areas are also expanding. It must be emphasised that percentage changes in land use differ between different land cover products, with the NLC (2015) product giving slightly different trends. However, the fact that slightly different methodologies are used between different land cover assessment means there is always some uncertainty around the magnitude of detected changes.

There is some evidence that commercial plantation forestry might expand slightly (by about 10%) in the future, but the long term trend was expansion until 1998. With a slow decline in area until 2006, and then the area remaining relatively constant (figure 4) (forestry SA statistics). Lack of suitable areas for forestry, and lack of available water licences in most catchments means that the potential for future forestry expansion is limited.

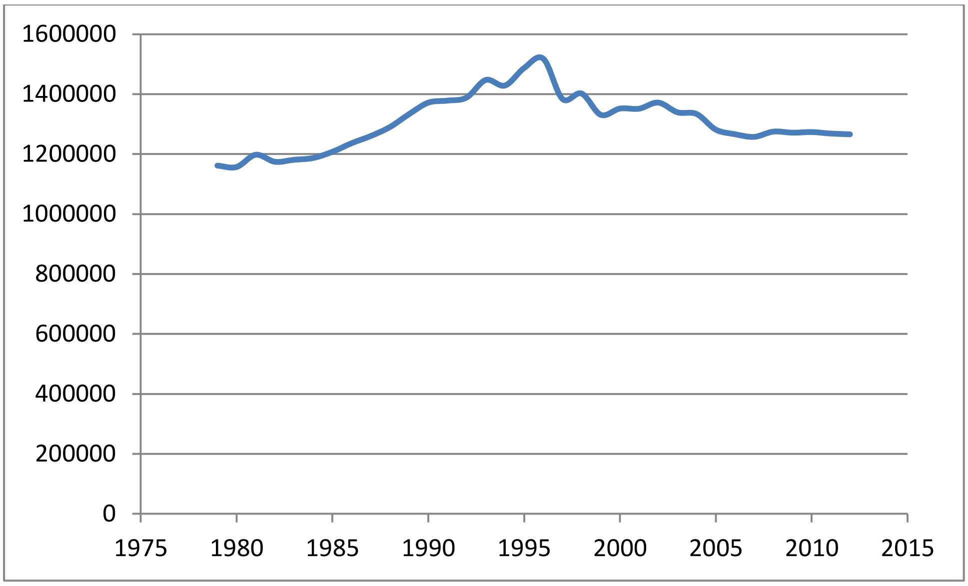

Figure 4: Trends in the area of commercial forestry

There is also evidence that climate change is having impacts on the distribution of biomes, with the savanna biome intruding into the grassland biome (DEA 2013c). There is also mounting evidence that global CO_2 levels are having a direct impact on tree densities within the savanna (Bond and Midgley 2012).

If biofuel production ever takes off as a major fuel source in South Africa then this could potentially result in an increase of agricultural land, at the expense of natural vegetation.

Alien plant invasion has resulted in thousands of hectares of land being infested with woody alien plants. This has often resulted in a net sequestration of carbon, but with significant modifications in ecosystem structure and function and the provision of ecosystem goods and services.

BARRIERS AND OPPORTUNITIES FOR ENHANCING THE SEQUESTRATION POTENTIAL IN NATURAL AND MANAGED TERRESTRIAL ECOSYSTEMS

Two recent reports have considered sequestration opportunities in the LULUC sector. These are the National Terrestrial Carbon Sinks Assessment (NTCSA 2015) and the South Africa's Greenhouse Gas (GHG) Mitigation Potential Analysis (DEA 2014). The following key mitigations options from the LULUC sector have been identified as having potential for South Africa (figures quoted are from NTCSA 2015):

Manure management. The use of bio-digesters to convert manure into biogas that can be used to generate electricity will then reduce emissions from coal generated electricity. This particular intervention is seen as potentially having the biggest mitigation potential and could result in a reduction of 4370 ktCO_2e per year.

Restoration of degraded land. Restoring the thicket biome with predominantly spekboom appears to have the potential to sequester a large amount of carbon, an estimated 2200 ktCO_2e per year. Restoring degraded coastal and scarp forest, and broadleaf woodlands are estimated to be able to contribute 67 and 1452 ktCO_2e per year. Restoring grasslands could potentially sequester 6921 ktCO_2e per year.

Increasing the amount of commercial forestry. The potential to expand commercial forestry is limited by climate and water licences. However, there is still a small potential, particularly for small scale forester which is estimated to potentially contribute 660 ktCO_2e per year.

Invasive alien plants. Clearing of IAP will in most cases result in the emission of CO_2. However if the plants are used for power generation then this will offset coal power and be a net uptake of carbon. An estimated 2388 ktCO_2e per year could be achieved through this.

Biochar. Biochar, a form of charcoal produced from wood that is ploughed into agricultural fields. Biochar is often produced as a by-product of pyrolysis, where the pyrolysis gas is used for other purposes such as power generation. Though the practice is still a bit contentious, in some circumstances it results in the near permanent sequestration of the carbon, as well as improving soil properties for plant growth. Biochar can reduce the amount of fertilizer and water needed for crop growth, and can enhance yields.

Reduced tillage techniques. Reduced tillage can assist in building up soil carbon. The rates of carbon build up are, however, quite slow and the benefits of reduced tillage are currently poorly researched for South Africa. If implemented over about 20% of agricultural lands an estimated 1266 ktCO_2e per year of reduced emissions could be achieved.

Urban tree planting. Growing trees in the urban environment can contribute to sequestration, though the area compared to the natural environment is quite small.

REDD+ through planning and regulation. This measure has potential, but could not be quantified due to a lack of data.

Other techniques which might have benefit, but which are not currently seen as important options include: reduced deforestation and degradation, reduced enteric fermentation (i.e. methane from livestock), improved fertilizer use practices, growing of biofuels, managing of fires to change emission or increase standing biomass, biomass burning for energy production (such as sugar cane bagasse – though IPCC terms this might be accounted for in the energy rather than LULUC sector).

The main barrier to implementing the above is the cost of the implementation. In some instances a co-product may help reduce the cost. I.e. restoring thicket vegetation not only sequesters carbon, but also improved the carrying capacity of game animals and improves biodiversity conservation. Biogas digesters provide an alternative electricity source. The NTCSA (2015) found that costing mitigation options was difficult because of too many uncertainties. However they found that restoration options tended to be an order of magnitude cheaper per tCO_2e than energy based options. Restoration was in the range of R54 to R112 per tCO_2 whilst biomass energy options where in the region of R1000.

BARRIERS AND OPPORTUNITIES FOR INCENTIVES TO REDUCE GHG EMISSIONS IN AGRICULTURAL AND FORESTRY LANDSCAPES.

The introduction of a carbon tax is being muted as an incentive to sequester carbon. In addition, carbon markets for sequestered carbon can provide a strong positive incentive. Unfortunately the early carbon markets set up under the CDM mechanism were very volatile giving no strong investor confidence for long term carbon projects. Voluntary carbon market prices also fell sharply from their high of $7.30 per tonne in 2008 to $3.80 per tonne in 2014. Despite this a number of voluntary markets have now developed and are starting to mature.

Carbon markets in the LULUC sector are complicated. Changes in carbon stocks tend to be slow and both hard and costly to monitor. Monitoring of soil carbon is especially problematic though new approaches are developing. Further, there is often a high risk factor. For instance, an accidental fire could result in a loss of carbon that has taken years to accumulate. The issue of permanence is therefore an important barrier to many land based carbon schemes. This is not a problem from energy schemes such as biogas production or biomass burning for energy as the carbon benefits are measured against the offset carbon from coal powered energy production and as such are permanent. Another major constraint is the high transactional costs related to pre- and post-validation and verification.

Cost effective monitoring, reporting and verification mechanisms is an important barrier. This can be slow and costly, reducing any true profit from the carbon project.

Some options have well established mechanisms and can potentially be implemented in the short term. These include biomass energy, anaerobic biomass digestion and commercial afforestation. Less well understood medium term options include sub-tropical thicket forest, and grassland restoration. Options such as biochar and reduced tillage as well as avoided deforestation (REDD) are less well understood, require greater research and as such are considered as medium to long term options (NTCSA 2015).

Long term financing incentives as well as the capacity within government and provincial government to support project implementation is currently lacking. From a policy perspective, most national policy is broadly in support of the proposed mitigation measures, and many mitigation measures have a broad set of benefits that go beyond carbon storage. For instance all the restoration options will increase productivity and biodiversity within their biome. Options for energy generation are handicapped by cost factors and the current energy production regulations.

Furthermore, the CDM mechanism is undergoing a reform under the UNFCCC. However, how this will develop and seek to influence the future design, functioning and architecture of the mechanism is unclear.

REFERENCES

Bond, W.J. and Midgley, G.F. 1012. Carbon dioxide and the uneasy interactions of trees and savannah grasses. Philos Trans R Soc Lond B Biol Sci. 367(1588): 601–612.

Birru TC. 2002. Organic matter restoration by conversion of cultivated land to perennial pasture on three agro-ecosystems in the Free State. MSc dissertation, Bloemfontein, University of the Free State, 2002.

DEA (Department of Environmental Affairs). 2013a. Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa. Summary for Policy-Makers. Pretoria, South Africa. http://www.sanbi.org/sites/default/files/documents/documents/ltassummary-policy-makers2013high-res.pdf

DEA (Department of Environmental Affairs). 2013b. Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa. Climate Trends and Scenarios for South Africa. Pretoria, South Africa. https://www.environment.gov.za/sites/default/files/docs/climate_trends_bookV3.pdf

DEA (Department of Environmental Affairs). 2013c. Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa. Climate Change Implications for the Biodiversity Sector in South Africa. Pretoria, South Africa. https://www.environment.gov.za/sites/default/files/docs/biodiversity_BookV4.pdf

Department of Environmental Affairs, 2014 South Africa's Greenhouse Gas (GHG) Mitigation Potential Analysis, Pretoria, South Africa.

Du Preez CC, Van Huyssteen CW, Mnkeni PNS. 2011. Land use and soil organic matter in South Africa 2: A review on the influence of arable crop production. S Afr J Sci.;107(5/6), Art. #358, 8 pages. doi:10.4102/sajs. v107i5/6.358

Du Toit ME, Du Preez CC, Hensley M, Bennie ATP. 1994.Effect of cultivation on the organic matter content of selected dryland soils in South Africa. S Afr J Plant Soil. 11:71–79. Afrikaans.

Du Toit ME.1992. Effect of cultivation on the organic carbon and total nitrogen in selected dryland soils. MSc Agric dissertation, Bloemfontein, University of the Free State, 1992. Afrikaans

Engelbrecht F., Adegoke J., Bopape M-J., Naidoo M., Garland R., Thatcher M., McGregor J., Katzfey J., Werner M., Ichoku C. and Gatebe C., 2015. Projections of rapidly rising surface temperatures over Africa. Env. Res. Letters. *In press.*

Kgope B. S., Bond W. J., Midgley G. F. 2010. Growth responses of African savanna trees implicate atmospheric [CO2] as a driver of past and current changes in savanna tree cover. Aust. Ecol. 35, 451–463 (doi:10.1111/j.1442-9993.2009.02046.x)10.1111/j.1442-9993.2009.02046.x

National terrestrial carbon sinks assessment (NTCSA) 2015. Department of Environmental Affairs. Pretoria. South Africa.

Sage R.F and Kubin D.S. 2007. The temperature response of C3 and C4 photosynthesis. Plant, Cell and Environment. #): 1086-1106

Schulze, E-D. and M. Heimann, 1998: Carbon and water exchange of terrestrial systems. In: Asian Change in the Context of Global Change [Galloway, J.N. and J. Melillo (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 145-161.

Steffen, W., I. Noble, J. Canadell, M. Apps, E.-D. Schulze, P.G. Jarvis, D. Baldocchi, P. Ciais, W. Cramer, J. Ehleringer, G. Farquhar, C.B. Field, A. Ghazi, R. Gifford, M. Heimann, R. Houghton, P. Kabat, C. Körner, E. Lambin, S. Linder, H.A. Mooney, D. Murdiyarso, W.M. Post, C. Prentice, M.R. Raupach, D.S. Schimel, A. Shvidenko, and R. Valentini, 1998: The terrestrial carbon cycle: Implications for the Kyoto protocol. Science, 280, 1393-1394.

Yamori, W and Hikosaka, K. 2013. Temperature response of photosynthesis in C3, C4, and CAM plants: temperature acclimation and temperature adaptation. Photosynth Res.119(1-2):101-17