Towards the development of a GHG emissions baseline for the Agriculture, Forestry and Other Land Use (AFOLU) sector, South Africa

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Received: 14 September 2016 - **Reviewed:** 19 October 2016 - **Accepted:** 16 November 2016
http://dx.doi.org/10.17159/2410-972X/2016/v26n2a11

Abstract
South Africa is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and as such is required to report on Greenhouse gas (GHG) emissions from the Energy, Transport, Waste and the Agriculture, Forestry and Other Land Use (AFOLU) sectors every two years in national inventories. The AFOLU sector is unique in that it comprises both sources and sinks for GHGs. Emissions from the AFOLU sector are estimated to contribute a quarter of the total global greenhouse gas emissions. GHG emissions sources from agriculture include enteric fermentation; manure management; manure deposits on pastures, and soil fertilization. Emissions sources from Forestry and Other Land Use (FOLU) include anthropogenic land use activities such as: management of croplands, forests and grasslands and changes in land use cover (the conversion of one land use to another). South Africa has improved the quantification of AFOLU emissions and the understanding of the dynamic relationship between sinks and sources over the past decade through projects such as the 2010 GHG Inventory, the Mitigation Potential Analysis (MPA), and the National Terrestrial Carbon Sinks Assessment (NTCSA). These projects highlight key mitigation opportunities in South Africa and discuss their potentials. The problem remains that South Africa does not have an emissions baseline for the AFOLU sector against which the mitigation potentials can be measured. The AFOLU sector as a result is often excluded from future emission projections, giving an incomplete picture of South Africa's mitigation potential. The purpose of this project was to develop a robust GHG emissions baseline for the AFOLU sector which will enable South Africa to project emissions into the future and demonstrate its contribution towards the global goal of reducing emissions.

Keywords
AFOLU, GHG emissions, mitigation, projected baseline

Introduction
Anthropogenic activities have contributed 40% to the increase in carbon dioxide levels since 1750 and as a result have played a crucial role in shaping current and future climate. The Agriculture, Forestry and Other Land Use (AFOLU) sector plays a vital role in food security, sustainable development and climate change adaptation. The AFOLU sector is the only sector that acts as both a source (deforestation and peatland drainage) and sink (afforestation and management practices) of Greenhouse gases (GHGs), mainly CO_2. Non-CO_2 emissions (CH_4 and N_2O) primarily result from the agricultural sector through enteric fermentation, manure management, fertilizer application and biomass burning. Anthropogenic land use activities and changes in land cover can seriously affect these natural fluxes. Globally the AFOLU sector is responsible for almost a quarter (~10-12 $GtCO_2eq/yr$) of anthropogenic GHG emissions (Smith et al., 2014). South Africa's AFOLU sector is estimated to contribute around 7% of the total national GHG emissions (DEA, 2015).

Since South Africa is transitioning towards a low carbon economy mitigation options are being investigated. There are several supply and demand side options for mitigation in the AFOLU sector that have been identified. On the supply side emissions can be reduced from land use change, land and livestock management, and terrestrial carbon stocks can be enhanced by sequestration in soils and biomass. On the demand side emissions can be reduced through changing consumption patterns of natural resources (i.e. animal products and wood products). Over the past decade South Africa has improved the quantification of AFOLU emissions and the understanding of the dynamic relationship between sinks and sources through projects such as the 2010 GHG inventory (DEA, 2014a), the Mitigation Potential Analysis (MPA) (DEA, 2014b) and the NTCSA (DEA, 2015). These projects highlight the key mitigation opportunities in the country.

However, through these projects, a gap was identified in that South Africa does not have an emissions baseline (current or projected) for the AFOLU sector against which the mitigation potentials can be measured. This means that the AFOLU sector either gets underestimated or excluded from future emissions projections, which gives an incomplete picture of South Africa's mitigation potential. Baselines are routinely used for domestic policy planning. In recent years baselines have grown in importance as some countries (including South Africa) have used them to define their mitigation pledges in terms of emissions reductions.

A well-developed baseline, more specifically a projected baseline which shows future GHG emissions levels, will have the advantage of enabling Desired Emissions Reductions Outcomes (DEROs) and Carbon Budgets to be determined. In addition it will allow South Africa to demonstrate its contribution towards the global goal of reducing emissions from the AFOLU sector.

Methods

There is currently limited information and guidance available for setting national GHG baselines with significant variability in the approaches and assumptions used by countries globally. In general the methods employed are specific to countries' goals and targets (Clapp and Prag, 2012). A baseline scenario is defined as the future GHG emission levels in the absence of future, additional mitigation actions. It can also be referred to as the 'business-as-usual' scenario. Baseline scenarios can serve different purposes and therefore can be established at different levels of aggregation (e.g. project-specific, multi-project, sectoral, regional and national) so as to accommodate the various requirements of the specific applications.

It was decided for this study to use the last year of the National GHG inventory as the base year of emissions projections. Activity data and emission calculations used in the projections were extracted from the 2010 inventory (DEA, 2014a). Projections were set to decadal intervals up until 2050. The baseline was calculated in two parts; where emissions projections were made for the Agricultural sector and Land (FOLU) sector separately, these two baselines were then combined for a total AFOLU baseline.

The emissions calculations for Agriculture were based on the expanded AFOLU sector categories as they are in the national GHG inventory (2010), which incorporates the following agricultural components:

- Livestock enteric fermentation (CH_4),
- Livestock manure management (CH_4 and N_2O),
- Liming (CO_2),
- Urea application (CO_2),
- Direct N_2O emissions from managed soils,
- Indirect N_2O emissions from managed soils,
- Indirect N_2O emissions from manure management.

The emissions calculations for Land were based on emissions (CO_2, CH_4 and N_2O) from land-use conversion which takes into consideration changes in biomass carbon, dead organic matter carbon and soil carbon (gain-loss method). The land-use conversion categories used were those from the National GHG inventory 2010 which include:

- Forest land,
- Cropland,
- Grasslands,
- Wetlands,
- Settlements,
- Other land, and
- Emissions from biomass burning.

The methodology for calculating the GHG emissions is drawn from equations stipulated in IPCC 2006 guidelines (IPCC, 2006). A series of spreadsheet-based emission models were developed from these equations. Tier 1 and Tier 2 equations were used depending on the sub-category and the amount of data available. The detailed method of the emissions calculations and activity data are described in the project report (DEA, 2016). There are numerous approaches for making projections, one of them being a modelling approach which makes projections of future values of a variable based on a function that integrates the impacts of multiple drivers on that variable. A modelled approach was considered, however, this approach is very data intensive and requires the use of models which have already been tested or calibrated for the South African system. In the AFOLU sector there are numerous variables driving change and limited data to support them. There are also gaps in activity data which complicates scenario setting.

In the Agricultural sector the Bureau for Food and Agricultural Policy (BFAP) has developed a model to project changes in agricultural commodities. The model is an economic recursive, partial equilibrium model which incorporates economic, technological, environmental, political and social factors (BFAP, 2015). It was therefore decided for this study to build on the outputs of the BFAP modelling process, for the purpose of extrapolating activity data, as it is a model which has been previously used and calibrated for South African conditions making it more robust. The model outputs of the BFAP model, however, only cover commercial livestock numbers. In order to project subsistence livestock population numbers historical data was used obtained from Agricultural Abstracts (DAFF, 2012), LACTO (2015), Meissner et al. (2013) and FAO Statistics reports. A regression was fitted to the historical population data and a logarithmic transformation completed to obtain an average rate of change which was then applied to decadal intervals up to 2050 in order to project livestock numbers into the future. In addition, game farming numbers were added to the baseline. Population numbers were based on data from Wildlife ranching SA, Pers. Comm, Cloete (2015) and Du Toit et al. (2013).

The BFAP model only projects numbers up until 2024. In order to project livestock numbers up to 2050 the rate of change between 2010 and 2024 was then extrapolated and applied to decadal intervals up until 2050. The assumptions used in setting the Agricultural baseline are presented in Appendix A – Table 1. A detailed description of the assumptions and uncertainties are described in DEA (2016).

For the land sector 2013/2014 land cover change data (DEA, 2015) recently produced for the GHG inventory was the basis for the projections. The original maps had 72 classes but for the purpose of determining emissions these classes were condensed to 17 classes. Furthermore, the land change mapping between 1990 and 2013/14 was only done on the 17 land classes. Most of the remaining classes were related to land use, many of which fall within the settlement or mine categories. Emissions were determined based on these classes, but then these were further condensed to the 6 main IPCC classes for reporting purposes.

The base maps used to determine change were the 1990 and 2013/14 land cover maps recently developed by GeoTerra Image for the DEA (GTI, 2015) from Landsat 8 imagery. As a starting point, annual rates of land cover change were calculated from these maps, and then additional data provided information to restrict or validate the change rates. The rate of change in the transformed landscapes (plantations, settlements, mines, cultivated lands, as well as the smaller indigenous forest category) were investigated in more detail by obtaining data from literature and expert opinions. This information was used to restrict the rates of change for these categories. Natural vegetation classes were then added and the area normalized to provincial areas which lead to smaller rates of change than those originally projected between the 1990 and 2014 land cover change maps. This was more appropriate as baselines should be conservative. These provincial changes were then compared to overall national land change for consistency. The assumptions used in developing the Land baseline are listed in Appendix A – Table 2. The detailed description of the assumptions and uncertainties are presented in DEA (2016).

Results

Agriculture

The agricultural baseline emissions show an increase from 50 568 $GgCO_2eq$ in 2010 to 69 621 $GgCO_2eq$ in 2050 (Table 1). This is a 37.7% increase. The livestock populations have the largest influence over emissions in this sector (60%) as they contribute to enteric fermentation, manure management and indirect N_2O emissions from manure management. Enteric fermentation and manure management contribute 55.4% and 3% respectively to the total agriculture baseline. The relative contribution from enteric fermentation doesn't increase, whereas it increases by 0.8% from manure management. According to the baseline livestock numbers increase by 38.7% between 2010 and 2050 as feedlot cattle, pigs, poultry and game populations are predicted to increase (BFAP, 2015, SA Feedlot Association, 2013). The contribution from game to enteric fermentation increases from 48.1 $GgCO_2eq$ (3.9% of total enteric fermentation emissions) in 2010 to 190 $GgCO_2eq$ (11.3%) in 2050.

Emissions from aggregated and non-CO_2 emission sources are projected to increase by 36.4% between 2010 and 2050. Direct N_2O emissions from managed soils are the largest contributor to this category, contributing 30.3% in 2010. This declines to a contribution of 27.0% in 2050, as the contribution from fertilizer application increases (Table 1). Enteric fermentation is the largest contributor, accounting for roughly 56% of the agricultural emissions. Enteric fermentation shows an increase of 37% between 2010 and 2050. The largest increase (424%) comes from emissions from urea application; however the urea consumption data is highly variable and comes with high uncertainties. Indirect N_2O emissions from manure management increase by 123% between 2010 and 2050.

***Table 1**: Baseline emissions ($GgCO_2eq$) for the Agricultural Sector*

	2010	2020	2030	2040	2050
Total for agriculture	**50 568.01**	**54 282.82**	**60 852.48**	**66 201.91**	**69 621.35**
Livestock	**29 708.32**	**32 256.49**	**36 353.45**	**39 516.62**	**41 177.52**
Enteric fermentation	28 139.89	30 457.99	34 187.25	37 103.13	38 550.78
Manure management	1 568.44	1 798.50	2 166.20	2 413.49	2 626.74
Aggregated and non-CO_2 emission sources	**20 859.69**	**22 026.32**	**24 499.04**	**26 685.29**	**28 443.83**
Liming	585.54	577.13	594.85	640.87	718.76
Urea application	478.69	724.41	1 096.26	1 658.97	2 510.54
Direct N_2O emissions from managed soils	15 097.01	15 749.39	17 218.19	18 316.03	18 813.55
Indirect N_2O emissions from managed soils	4 212.69	4 332.67	4 759.90	5 104.78	5 317.29
Indirect N_2O emissions from manure management	485.76	642.73	829.84	964.64	1 083.70

***Table 2**: Baseline emissions ($GgCO_2eq$) for the Land Sector*

	Total Land	Land	Biomass burning
2014	-21104.5	-22 920.7	1818.47
2020	-25 860.4	-27 663.2	1805.02
2030	-31 390.6	-33 169.9	1781.55
2040	-32 223.2	-33 977.9	1756.86
2050	-30 683.2	-32 407.6	1726.61

***Table 3**: Combined Land and Agriculture Baseline Emissions*

Years	Total AFOLU	Livestock	Aggregate sources and non-CO_2 emissions sources	Land
2014	30 949.4	30727.59	21326.34	-22 920.7
2020	28 442.4	32256.49	22026.32	-27 663.2
2030	29 461.9	36353.45	24499.04	-33 169.9
2040	33 978.7	39516.62	26685.29	-33 977.9
2050	38 938.2	41177.52	28443.83	-32 407.6

Land

At the national level the land projections don't show large changes in land area, but the largest changes are around the decrease in grassland, and increase in forest land and bare ground. Since forest land plays such a focal point in carbon estimations this increasing forest land leads to increased carbon sinks.

The estimated national baseline for the land sector shows an increased sink between 2014 and 2040 (21 104 GgCO_2eq to 32 223 GgCO_2eq), after which the sink slows and becomes stable (Table 2). The increasing sink is mainly due to the predicted increase in forestland, but is also combined with the decrease in wood removal from woodlands in the period until 2030. Keeping fuel wood removal constant (i.e. assuming no reduction in wood removals due to electrification) produces a more constant sink (varying less than 3 000 GgCO_2eq between 2014 and 2050), but it still shows a slight increase in the sink to 2030 after which it declines to 2050. If the thicket area is increased by 1% then the sink increases by 17% by 2050, which shows the importance of understanding whether the thicket area is increasing, decreasing or remaining constant. Moving towards 2050, there is also a predicted increase in bare ground and this leads to a loss of carbon (both biomass and soil) causing the overall land carbon sink to stabilize.

Combining the land and the agriculture baseline creates a baseline which shows an 8.2% decline between 2014 and 2020, after which it increases by 37% to 38 938 GgCO_2eq in 2050 (Table 3 and Figure 1). The increasing land sink contributes to the slight decline in the early years while the increasing agricultural emissions combined with the stabilizing carbon sink leads to the increase between 2030 and 2050. Land sequesters almost as much as the aggregated non-CO_2 emission emit and so the baseline is very similar in magnitude to the enteric fermentation value.

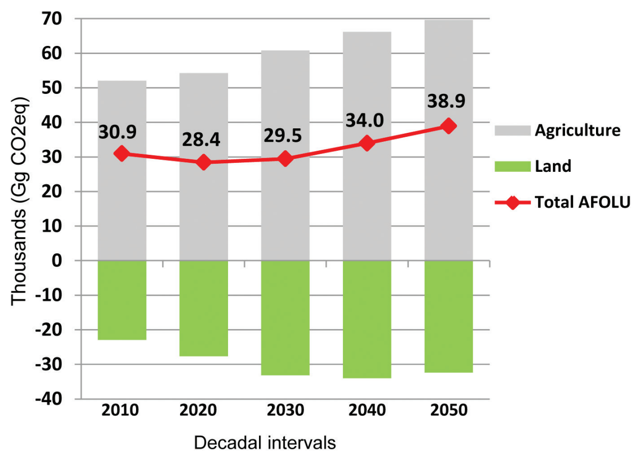

Figure 1: *Combined AFOLU Baseline emissions*

Discussion

It is not unexpected that enteric fermentation is the largest contributor of emissions, accounting for roughly 56% of the agricultural emissions. These results are consistent with the current GHG inventory trends (DEA, 2014a). Urea application had the highest increase according to the projections. The reason being that urea consumption is determined from import and export data, and it is assumed that all urea is being applied to the field. This data thus presents a high degree of uncertainty. It is therefore, recommended that more detailed data be collected for urea consumption. One limitation of this model is that not all fertilizer types are included, and this can be another aspect which could be improved in the future. Manure management emissions increased in the projections due to future increasing feedlot cattle, piggeries and poultry.

Mitigation options for the agriculture sector are not often highlighted in terms of the AFOLU sector as they are seen to have limited potential. This does not, however, mean that these options shouldn't be considered, especially since enteric fermentation is a key category in South Africa's GHG inventory. In terms of enteric fermentation there are two options for reducing emissions; namely, increase rumen efficiency and increase livestock productivity. In terms of manure management the mitigation option of biodigesters would assist in reducing these emissions. The draft Mitigation and Adaptation Strategy of DAFF (DAFF 2015a) highlights that it is harder to reduce emissions in agriculture than it is to increase sequestration, hence the importance of land cover and land use activities.

The land baseline suggests that if forest land is increased through afforestation and thicket restoration, then the carbon sink would increase. It also indicates that if soil erosion and degradation is prevented, the future decrease in the sink would be alleviated, highlighting the importance of mitigation actions suggested in the NTCSA (DEA, 2015).

The baseline is an indication of what the expected emissions are going to be based on a business-as-usual scenario. The inventory provides information on what the actual emissions are. Both are developed based on current knowledge, and under the current reporting regime the inventory is updated every two years. However, there are still many unknown factors in the AFOLU sector, with uncertainties still being determined, therefore there are continuous improvements being made to the AFOLU sector inventory. Since the baseline is dependent on the inventory, it is suggested that the baseline be updated again in the near future, so as to incorporate any new information in this sector. The biggest unknown factor is land cover change and this is extremely difficult to predict into the future. Since land cover change drives the land sector baseline it would be necessary to update the baseline when new land change maps become available.

Conclusion

This was the first attempt at creating a baseline for the AFOLU sector in South Africa. It was a challenging task given the variability and uncertainty of the available data. Therefore the results of this study cannot be seen as the actual final baseline but rather the first step in the movement towards one in the near future. The process of developing the baseline provided many lessons. Several recommendations are listed below which would help improve the baseline in the future:

- There is a need to develop consistency in national data sets. This relates to the variability in the data sources and differences in mapping classifications, and applies both to the agricultural and land sector data.

- There are enormous challenges in predicting land cover and land use change. The method used in this study relies on historical change data and expert opinion. Land change maps can provide varied outputs depending on when in the year or in which year they were created. South Africa needs to detect change on a more regular basis, using a consistent methodology, in order to be able to have improved forward projections.

- More detailed degradation data needs to be incorporated to improve estimates. There are many different types of degradation and determining the extent of degradation is still debated. For the baseline development the rate of degradation as well as the extent is required.

- More detailed cropland data needs to be incorporated (pivot and non-pivot categories).

- Detailed livestock population estimates in the subsistence sector are still required.

- Research on nitrogen emissions is needed in order to improve the emission factors used, currently IPCC default emission factors are being used in many of the categories.

- A register of biodigesters and their fuel sources is required. The information on biodigesters is scattered, therefore, it would be useful to have a central register of this information to assist in estimating and predicting emission savings in terms of the AFOLU sector.

- A better understanding of fuelwood consumption. There is a lack of information at a national scale as to whether fuelwood removal is declining or not. It would be important to develop an understanding of the amount of fuelwood consumed at a national scale and to investigate how this is changing over time in order to improve estimates.

Acknowledgements

This project was a Department of Environmental Affairs study, funding for which was made available by the British High Commission. Thanks are given to the project steering committee and all project stakeholders for their expert input and data supply.

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Appendix A

***Table 1**: The assumptions used in projecting the agricultural emissions*

Agricultural baseline assumptions	
Enteric fermentation	Livestock diet remains as it is
	Current Emission factor kept constant
	Herd composition kept at current ratios
	Average Emission Factor used, so no cattle species detail required
Manure management	Livestock diet remains the same
	Emission Factor kept constant
	Manure management systems continue as currently being used
	No biodigestor usage
Managed soils	Fertilizer consumption continues at current rate
	Fraction of livestock / game population in fields remains the same
	Amount of manure used for feed, fuel and construction remains constant
	Ratio of crop residues retained remain at current levels
	Emission Factors kept constant
Urea application	Rate of lime consumption continues at current level
	Rate of urea consumption continues at current level
	Emission Factor kept constant

***Table 2**: The assumptions used in projecting the emissions from Land*

Land baseline assumptions
Thickets continue to degrade at current rate
No increase in plantations
Grasslands continue to decline at current rates
Degradation continues to increase at current rates
Tillage practices continue as they currently are
No biochar application (soil carbon reference levels remain as they are)