FINAL

Review of Greenhouse Gas Emission Factors for Namibia

Report to the Ministry of Environment and Tourism, Namibia

by

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The review of the greenhouse gas emission factors used as part of the greenhouse gas emissions inventory and data collection systems is mainly based on the following reports:

- The Initial National Communication of Namibia
- Namibia's Country Study on Climate Change: Sources and sinks of greenhouse gases in Namibia

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Executive Summary

This report is a follow-up to Namibia's First National Communication (FNC) to the United Nations Framework Convention on Climate Change (UNFCCC). In the FNC, which was submitted in 2004, a number of areas of uncertainty requiring further work were identified. This study was undertaken to narrow those uncertainties and to make recommendations on the appropriate methods and values to use in future National Communications.

A number of minor areas of missing data have been addressed, such as for waste water treatment or the burning of agricultural wastes. These do not substantially change the emission estimates for Namibia. In the energy sector, it has been confirmed that the data used were accurate and that the appropriate data collection systems are in place.

In the agricultural sector, a new estimate of emissions from enteric fermentation is provided (243.8 Gg CH_4, up from 162 Gg CH_4 in the FNC). This is the result of having applied more detailed 'Tier 2' methods, rather than the 'Tier 1' methods previously used.

Recommendations are made regarding the most accurate and effective way of collecting data on the extent of vegetation wildfires ('veld fires'). The new estimate of the emission of methane from this source is very close to the previous one, and an error calculation is included.

The uptake of carbon dioxide as a result of bush encroachment in Namibia is confirmed to be large, and likely to be several times larger than the total CO_2-equivalent emissions from the country. Namibia is therefore a net sink of greenhouse gases. Further refinement of this figure will require a resurvey of bush encroachment monitoring plots in the future.

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Abbreviations, glossary and acronyms

AD	Activity Data
AS	Activated Sludge
BA	Burned Area
BDRF	Bi-directional Reflectance Distribution
C	carbon
CDM	Clean Development Mechanism
CH_4	methane, a greenhouse gas
cm	centimeter equals 0.01m
CO_2	carbon dioxide the principle anthropogenic greenhouse gas
CO_2-e	carbon dioxide equivalent based on the GWP's of CO_2, CH_4 and N_2O
COD	Chemical Oxygen Demand
CSIR	Council for Scientific and Industrial Research
CSIR	Council for Scientific and Industrial Research
DM	Dry Matter
EF	Emission Factor
FNC	First National Communication
G	**GRAM**
GBA	Global Burned Areas Initiative
Gg	gigagram or 1 kiloton (equals $1x10^9$ grams)
GHG	Greenhouse Gas
GIS	Geographical Information System
GWP	Global Warming Potentials (GWP of 1 for CO_2, 21 for CH_4 and 310 for N_2O are used)
ha	hectare (100x100m or 10 000m^2)
IPCC	**INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE**
JNC	Joint Research Center
kg	kilogram or one thousand grams
kl	kiloliter (equals one thousand liters)
km	kilometer (equals one thousands meters)
km^2	square kilometer (1x1km)
kt	kiloton or one thousand tons (equals $1x10^9$ grams)
LPG	Liquid Petroleum Gas
LSU	Life Stock Unit
LUCF	Land Use Change and Forestry
m	meter
m^2	square meter (1x1m)
m^3	cubic meters (1x1x1m) equals 1 000 liters
MAR	mean annual rainfall
MAWRD	Ministry of Agriculture, Water and Rural Development
MET	Ministry of Environment and Tourism
Mg	Megagram or 1 ton (equals $1x10^6$ grams
MIR	**MIDDLE INFRARED BAND**
mm	millimeter
MME	Ministry of Mines and Energy
MODIS	MODerate resolution Imaging Spectroradiometer
N	nitrogen

N_2	dinitrogen gas
N_2O	nitrous oxide, a greenhouse gas
NCCC	Namibia Climate Change Committee
NH_3	ammonia
NIR	Near Infrared band
NO_3	nitrate
NOAA AVHRR	National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer
O_2	oxygen
P_{grass}	Grass production
P_{leaf}	Tree leaf production
SAR	Second Assessment Report
t	ton (1 metric ton or one thousand kilograms equals $1x10^6$ grams)
TIR	Thermal Infrared bands
TKN	Total Kjeldahl Nitrogen
UNFCCC	United Nations Framework Convention on Climate Change
VIS	Visible channel (wavelengths. 0.5 - 0.9 micrometer).
Y_m	Fraction of energy intake converted to CH_4 (in energy terms)

Introduction

Namibia has signed and ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1995 and presented a First National Communication (FNC) to the UNFCCC in 2002. The 1994 greenhouse gas emissions inventory data were used as part of the FNC.

The Ministry of Environment and Tourism (MET) through the Namibia Climate Change Committee (NCCC) and based on the recommendations provided in the FNC, has as its intention to take concrete steps to:
a) Improve the accuracy of data collection
b) Reduce the high amount of uncertainty associated with the emission factors used, mainly in the LUCF and energy sectors

The purpose of this study is to review the emission factors used to compile the 1994 GHG inventory and to make proposals and/or recommendations for their incorporation into future national communications. The study was conducted by consultants from the CSIR in South Africa, working with Namibian experts.

The following specific tasks for individual IPCC sectors as listed in the GHG inventory are included as part of this study:

Energy sector
A review of the current data collection in the petroleum energy use sector as well as recommendations that will improve the estimation of the CO_2 emissions from the different source categories. This will involve the improvement of the sectoral-energy use and activity data.

Land Use Change and Forestry (LUCF) sector
- An estimation of the extent of the area covered and growth rates of different vegetation types as well as the amount of woody biomass removed in Namibia for:
  (a) direct energy consumption
  (b) charcoal production and
  (c) long-term storage products such as furniture.
- Collect and review data on the extent of savanna burning in Namibia. The National Botanical Research Institute in the MAWRD is currently quantifying the amount of area of savanna burning by making use of satellite imagery. These results as well as the biomass densities reported in the Department of Forestry's National Forest Inventory should be utilized as part of this study.
- Determine the level of emissions from the burning of cotton residues for pest control purposes.

Agricultural sector
- A review of the emission factors for the methane emissions from domestic livestock and recommendations for the ones applicable to conditions in Namibia.
- A review and quantification of the amount of manure deposited per manure management system.
- A review and quantification of the status of nitrous oxide emissions from the application of crop residue and sewage sludge to agricultural soils in Namibia.

- An estimation of the amount of nitrogen based fertilizer used in agriculture and the amount of nitrous oxide emissions from the use of synthetic fertilizer.

Waste sector

- A review of current data collection practices and recommendations on the data collection requirements for wastewater generated from:
  (a) domestic
  (b) commercial and industrial processes such as the fish processing, meat packing, brewing and tanning in terms of (i) the amounts treated (ii) the types of treatment systems used and (iii) organic contents of the different waste streams for inclusion in the second and subsequent national GHG inventories.

Review of greenhouse gas emission uncertainties

A rigorous statistical analysis of the uncertainty associated with the estimates of final carbon dioxide equivalent[1] (CO_2-e) emissions is not supported by the 1994 greenhouse gas emissions data. Uncertainty estimates reported in the First National Communications Report (FNCR) and in this study are based on expert opinion as well as subjectively defined uncertainty categories.

The uncertainty associated with the final carbon dioxide equivalent (CO_2-e) emissions from the relevant sources as well as the potential impact on the total national emissions is provided in Table 1. The IPCC sector that has the most significant impact on total national emissions is the LUCF sector in terms of absolute CO_2-e values and potential differences due to the magnitude of the uncertainty value. Individual sources may have a large uncertainty associated with their greenhouse gas emission estimates due to the lack of accurate activity data and/or emission factors but their potential impact on final greenhouse gas emission estimates on a national level are often small or insignificant (Table 1).

The most important greenhouse gas emission sources and/or sinks based on the magnitude of the uncertainties (i.e. the difference between upper and lower CO_2-e estimates provided in Table 1) and the individual relative contribution to the sum of the total differences (41 935 Gg/year) are ranked as follows:

- LUCF
  - Bush encroachment contributes more than 91%
- Agriculture
  - Burning of savannas contributes about 3.5%
  - Domestic livestock contributes about 2.8%
- Energy
  - Petrol and diesel consumption contributes about 1%
  - Fuelwood consumption contributes about 0.8%
- Rest (including international shipping, charcoal production and use, manure management, fertiliser consumption, burning of agricultural residues) contributes about 0.7%

[1] The CO_2-e emissions are based on emissions of carbon dioxide, methane and nitrous oxide using global warming potentials of 1, 21 and 310 respectively (from the IPCC SAR).

Table 1. Summary of the uncertainty associated with the CO_2-e emissions reported in the 1994 GHGI

IPCC sector	Source	Uncertainty level[1]	Major source of uncertainty[2]	Uncertainty value used[3]	CO_2-e emission	Upper and lower limits based on uncertainty level[4]		Relative contribution to national CO_2-e emissions	Notes[5]
		L = Low M = Medium H = High VH = Very High				Lower limit	Upper limit		
				%	Gg/year	Gg/year	Gg/year	%	
Energy (reference approach)	Liquid fossil fuels	M	AD	15	1 437	1 221	1 652	~81%	The source of uncertainty the difference in actual data reported by different sources. It only refers to CO_2-e emissions. The overall contribution of this sector to total national CO_2 emissions will vary with about ±2% when considering the upper and lower estimates calculated.
	International bunkers (aviation and marine)	VH	AD	75	111	28	194	NA - Memo item	The uncertainty is a result of the lack of reliable data as data are not reported separately for national and international usage and needed to be estimated based on certain assumptions. International bunkers are not included in the national totals following IPCC Guidelines.
Energy: Liquid fuels (sectoral approach)	All sectors combined	M	AD	15	1 438	1 222	1 654	~25%	Lack of accurate data to calculate/report sectoral consumption of different energy types. Methane and nitrous oxide emissions from this sector are insignificant. The commercial and institutional sector is considered the most insignificant source in this category. The overall contribution of this sector to total national CO_2-e emissions (mainly CO_2) will vary with less than 3% when considering the upper and lower estimates calculated.
Energy: Biomass energy	Fuelwood	M	AD	15	1 054	896	1 212	NA - Memo item	Only CO_2 emissions. The consumption of wood by the residential sector is the single largest source of CO_2 emissions in the biomass sector (more than 90%). The impact on the total CO_2 emissions from biomass energy is less than 0.5%.
	Charcoal production	VH	AD, EF	75	68	17	119	NA - Memo item	Only CO_2 emissions. The amount of charcoal produced is based on a conversion efficiency of 20% from wood to charcoal. The EF reported in the literature (Lacaux, 1994) differs with about 66% from the EF used in the 1994 GHGI, i.e. 66% less.
	Charcoal consumption	M	EF, AD	15	13	11	15	NA - Memo item	Only CO_2 emissions
Agriculture	Domestic livestock: CH_4 from enteric fermentation	H	EF	25	2 352	1 764	2 940	~41%	Uncertainty value of 25% was used. The overall contribution of this sector to total national CO_2-e emissions will vary with about ±6% when considering the upper and lower estimates calculated.

IPCC sector	Source	Uncertainty level[1]	Major source of uncertainty[2]	Uncertainty value used[3]	CO_2-e emission	Upper and lower limits based on uncertainty level[4]		Relative contribution to national CO_2-e emissions	Notes[5]
		L = Low M = Medium H = High VH = Very High				Lower limit	Upper limit		
				%	Gg/year	Gg/year	Gg/year	%	
	Domestic livestock: CH_4 from manure	M	EF	15	63	54	72	~1%	The overall contribution of this sector to total national CO_2-e emissions will vary with about ±1% when considering the upper and lower estimates calculated.
	N_2O emissions from agricultural soils: Fertilisers	H	AD & EF	35	1	1	1	<<1%	Insignificant contribution.
	Field burning of agricultural residues	M	AD & EF	15	0	0	0	0%	Reported to be zero, or negligible.
	Prescribed burning of savannas	VH	AD & EF	75	989	247	1 731	~17%	The overall contribution of this sector to total national CO_2-e emissions will vary with about ±11% when considering the upper and lower estimates calculated.
LUCF		VH	AD	> 100	-6 373	-9 560	-47 798	NA as it is a sink and not a source of CO_2-e emissions	Mainly CO_2 considered in this sector. The estimate included in the FNC report is considered an underestimate and is most likely higher than reported. The lower limit uncertainty value is therefore not less than the reported value. The size of Namibia's total contribution to CO_2 emissions when considering the size of its sink can vary with as much as 70 % when only considering the lower limit estimate.
Waste	Wastewater	VH	AD & EF	-	-	-	-		Not included in FNC due to lack of data. Mainly CH_4 and to a lesser extent N_2O emissions.

1. A rigorous statistical analysis of the uncertainty is not supported by the available data used in the 1994 GHGI. Uncertainty estimates were made based on expert and subjective opinion.
2. The order of the uncertainty sources, i.e. AD and EF, reflects their relative importance in terms of contribution to the overall uncertainty associated with a specific source.
3. In cases where an uncertainty value was calculated or provided in the FNC or by experts, this value was used instead of the mid range value.
4. Upper and lower limit levels were calculated using mid range values for the quoted error ranges for the different uncertainty categories, i.e. 5% for "L"; 15% for "M"; 35% for "H" and 75% for "VH".
5. The impact on national CO_2-e emissions was calculated on an individual basis, i.e. assuming that only the specific source will change the final values.

Energy Sector

The purpose of this section is to provide recommendations on how to improve, if necessary the current petroleum usage data collection system. In the 1994 Greenhouse Gas Emissions Inventory, the major source of uncertainty is associated with the amount of yearly sectoral consumption of different petroleum products and the amount of bunker fuel used for international marine and aviation purposes (Table 1). A list of the people contacted to acquire information regarding the amount of petroleum products consumed on a yearly basis in Namibia is provided in Appendix A.

Background

Namibia imports all its liquid fuels that are marketed by five wholesalers licensed by the Ministry of Mines and Energy (MME) in Namibia. They are BP, Caltex, Engen, Shell and Total as reported by Von Jeney[2]. Imports are monitored by the MME while the Ministry of Trade and Industry issues the necessary import permits[3]. These wholesale companies report industry sales to retailers to Caltex in Cape Town [4] on a monthly cycle. The data is recorded in an electronic database. The data is reported per product and sales channel and has been in existence since before independence. Data is supplied on request to parties that have a specific reason for such a request. The same system has been and is in use in South Africa, except that the SA system is further disaggregated on a magisterial district basis.

This dataset excludes liquid petroleum gas (LPG) that is not exclusively in the domain of these five wholesalers, but includes bitumen (asphalt), grease and other lubricants. Their effect is small (1.25 to 2.5 % for LPG and 1.6% each for bitumen and lubricants).

The data as reported has been extracted from the database for 2003 and reformatted in the enclosed Appendix B. In order to obtain data per economic sector, this data had been recast in Appendix C. This is based on the grouping per Category Code as indicated in the right hand column and converted to mass units by means of the density factors[5] in row 2 of Appendix C. The following assumptions were made in this process:

- That all of the "International Marine Bunkers" is Heavy Fuel Oil that is utilised as international marine bunkers (5.1% of total).
- That all of "jet fuel" is international bunkers (2.2% of total).
- That the sales channel description (column 2 of Appendix B) indicates the sectoral use of the fuel, except that "Other resellers" and "Other commercial" is allocated to "Industry".
- That all of "Avgas' (aviation non-jet fuel) is used within Namibia (0.3% of total).

A number of resources have been identified that report on petroleum use. The results differ to a small extent but it is assumed that they are all based on the same source data with different approaches to interpreting the base data. Von Jeney[6] indicates extensive variability in petroleum use as a function of the selling price. It is assumed that that is mainly caused by the global oil price and the exchange rate. In his six-year study period total consumption varied

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[2] Von Jeney M, Namibia- Petroleum Downstream: New Developments, Issues and Opportunities, 7th Annual Africa Downstream 2000, Cape Town, July, page 12.

[3] Petroleum Downstream page of www.mme.gov.na/energy.

[4] Mbendi Profile: Namibia Oil and gas Industry- Overview on www.mbendi.co.za

[5] From Digest of SA Energy Statistics, 1998, page 65

[6] Op cit, page 6.

from a minimum of 581,433 kiloliters in 2002 to a maximum of 789,141 kiloliters in 1998. A comparison of the total consumption as reported by the different sources is given in Table 2, where bunkers have only specifically been identified in the last two cases.

Table 2. Comparison of the total petroleum product consumption data by different sources.

Source	Year	Consumption (kt)	Comment
Country energy data report, EIA[7]	2001	689	No bitumen and lubricants, LPG 2.5% of total
IEA data report[8]	2001	670	Ditto
Von Jeney (max)[2]	1998	629	No LPG and lubricants, bitumen 0.9% of total
Previous National UNFCC report[9]	1994	489	Includes bitumen (1.4%), lubricants and LPG (1.25%)
This report	2003	730	Excludes LPG

Conclusion

The industry database that is managed by Caltex in Cape Town contains almost all the data that is required to calculate GHG emissions. Marine and aviation bunkers can be separately identified. LPG data will have to be added and is reported in other publications, but the accuracy or origin could not be established. Extensive variation in total annual consumption takes place, and is assumed to be a function of the selling price. When this situation and different years as reported are taken into account there is a good correlation between the data gathered in this study against those of other reported studies.

In terms of the quality of the data, Ngishoongele[10] states, "We consider the data compiled by Caltex to be fairly representative and accurate".

Recommendations

It is recommended that the database as is at present managed by Caltex in Cape Town be used to determine in country emissions from petroleum fuel use with the following provisos:

1. That all the fuel types as used in this report are included.
2. That the reported volumetric sales data is converted to mass data with locally published density factors, as used in this report.
3. That if this is considered necessary as it is a small component, suitable LPG data is gathered by means of a survey.
4. That if required, the assumptions that were made regarding LPG, lubricants and bunkers be verified.
5. Data for LPG will have to be gathered by means of a different process such as annual statistics supplied by the respective wholesalers (some of the present wholesalers and Afrox), a regular census or a sampling survey.

[7] Energy Information Administration, US-DOE, Country Energy Data Report, 2001. accessed by Internet, November 2004

[8] International Energy Agency, Oil in Namibia data report, 2001, accessed by Internet November 2004.

[9] Initial National Communication to the UNFCC, July 2002.

[10] Deputy Director: Energy, e-mail of 6 January 2005.

Agricultural Sector

Description

Since much of Namibia is arid, the agriculture sector is dominated by livestock husbandry, with a limited amount of crop agriculture in the north. The livestock show a rough progression from goats in the extreme south, through sheep in the area south of Windhoek, to cattle in the north. All are grazed on natural vegetation, with very limited fattening in feedlots at this stage.

The main crops in terms of area planted are maize and millet. The levels of fertilizer input are low, the soil organic matter is generally low, and the crop residues are grazed rather than burned.

Greenhouse gas emissions from crop agriculture in Namibia are relatively small, but for the sake of completeness, some outstanding data on emissions from fertilizer use and crop residue burning were required.

Cotton burning

Knowledgeable sources in the industry report that no cotton residue is burned in Namibia (Mr. Francois Wahl: Agro business Consultants, Grootfontein, Namibia). The mean annual area planted to cotton in Namibia in the period 1998 to 2002 is estimated to be 2 515 hectares, from the reported 5-year cotton yield of 18 867 tons and a mean per hectare harvest of 1.5 tons. In the year 2003, 1 594 ha of cotton was planted by commercial farmers and 521 ha by communal farmers, giving a total of 2 115 ha (RoN/Republic of Namibia. 2004. Agricultural Statistics Bulletin. Unpublished, Windhoek. Ministry of Agriculture Water and Rural Development).

Fertiliser use and sewage and crop residue applied to agricultural soils

Nitrous oxide emissions occur from the agricultural sector when nitrogen based fertilizers, sewage sludge and crop residue are applied to soils. The emissions from the use of nitrogen-based fertilisers are, however, negligible when applied on dry soils and at low rates as is the case in Namibia. Currently there is no centralized system for collecting and capturing fertiliser data in Namibia. By 2008 fertiliser users will, however, be required by EU EuroGAP regulations to register with MAWRD and the quantities of fertilisers that are imported will be monitored at the Namibian border.

Sewage sludge is in most cases not applied to agricultural soils. It is either used as a soil conditioner at most places or dumped at municipal dumping sites for burial, especially the sludge from industries that contain heavy metals and other toxic substances. The nitrogen content of sludge is generally not measured, compared to wastewater where it is measured on a regular basis for treatment and disposal purposes.

Crop residues mainly occur on irrigated farms. Almost all residues generated in Namibia are grazed or ploughed in, i.e. in most cases these are used for stock feed.

Emissions from livestock (enteric fermentation)

Problem statement

Livestock emit methane as a byproduct of their digestive systems. Methane from this source was estimated to constitute 66 % of the total Namibian CH_4 emissions. The amount emitted varies according to livestock type, body mass and diet. Since the livestock numbers in Namibia are relatively well-known from official censuses (see Table 3), the key uncertainty is the appropriate emission factors to use. The uncertainty associated with methane from livestock in the FNC was ± 25%, making this one of the biggest absolute uncertainties in the communication.

Table 3. Summary of the type and amount of livestock and their dietary requirements

Type	Number	Average live bodymass (kg)	Food consumption (tons) Daily	Food consumption (tons) Annually	Protein consumption (tons) Daily	Protein consumption (tons) Annually
Cattle						
Commercial	915 380					
Communal	1 420 14					
Total cattle	2 336 094	330	21 492	7 844 603	1 384	669 410
Sheep						
Karakul	222,832	50				
Dorper	1 931 566	65				
Other	801 056					
Total sheep	2 955 454	60	5 290	1 930 945	470	171 550
Goats						
Angora	4 544	60				
Boerbok	961 251	60				
Other	1 121 017	60				
Total Goats	2 086 812		3 756	1 371 035	350	127 750
Equids						
Donkeys	119 828	= 1 LSU	1 198	437 270	48	17 520
Horses	47 542	= 1 LSU	475	173 375	19	6 941
Pigs	46 932	130	221	80 665	28	10 220
Total			**32 432**	**11 837 893**	**2 299**	**839 141**

Sources:
Meat Board of Namibia
Directorate: Veterinary Services, Ministry of Agriculture, Water and Rural Development
Voeding Tabelle, Meissner
Agricultural Research Council. 1993. Pig production in South Africa. Bulletin 427.

The amount of manure produced has relevance to methane generated from manure disposal systems (virtually non-existent in Namibia) and for the use of manure as an agricultural fertilizer, where it can generate N_2O. The amount manure produced per year is provided in Table 4.

Table 4. Manure production in Namibia.

Manure production	Daily (tons)	Annually (tons)
Cattle (Intake*0.45)	9 671	3 529 915
Sheep (Intake*.40)	2 116	772 340
Goats (Intake*.45)	1 690	616 850
Donkeys (Intake*.45)	539	196 735
Horses (Intake*.45	214	78 110
Pigs (Intake*.3)	66	24 090
Total Manure	**14 296**	**5 218 040**

The emission factors for methane from enteric digestion can be calculated according to the Tier 2 method in the IPCC handbook (IPCC 1997) (Table 5). The key assumption is the factor Y_m, the fraction of energy intake that is converted to methane (in energy terms). The IPCC recommend 7% for cattle in Africa, due to the relatively poor forage quality there. This is a reasonable assumption for Namibia. In accordance with IPCC (1997), the Y_m for sheep and goats were assumed to be lower (6 and 4% respectively), due to the better quality forage they consume (see estimated protein values in table). The Y_m for equids (horses, donkeys and mules) was assumed to be 2.5%. The Y_m for pigs was assumed to be the developed country value (0.6%) rather than the developing country value (1.3%) since the majority of pigs in Namibia are kept under developed country conditions.

Table 5. Methane emission factors and estimates for Namibia.

Livestock type	Mean body mass	Namibian herd size	% protein in diet	Emission Factor	Total Emission
	kg		%	g CH_4/y/head	Gg CH_4/y
Cattle	330	2 336 094	8.5	77 931	182.1
Sheep	60	2 955 454	8.9	12 990	38.4
Goats	60	2 086 812	9.3	8 713	18.2
Equids	350	167 370	4.0	30 244	5.1
Pigs	130	46 932	12.7	3 417	0.2
Total					**243.8**

Recommendations

1. The Veterinary Services of the Ministry of Agriculture should be commended on the livestock statistics they collect, and reminded that they have other uses than within the Ministry. Therefore the information collected on livestock numbers and body mass should not be changed without prior consultation.
2. The methane emission factors in the above table should be used in future inventories, unless IPCC updates its recommendations for Tier 2 calculations.
3. The methane emissions from manure can be reported as zero, since effectively all Namibian livestock are free-ranging, and drop their manure in the grazing land, where it decomposes aerobically with minimal methane production.
4. A zero entry can be returned for the burning of agricultural residues.

Biomass burning

Problem statement

Wild fires emit methane and a small amount of nitrous oxide. The also emit CO_2, but because the vegetation regrows in the following years, the CO_2 emissions are assumed, in the medium term, to be zero. Because of the large extent of burned area in Namibia, the amounts emitted are large. In the FNC the CH_4 emission was estimated to be 47.10 Gg/y, with an uncertainty of $\pm$ 50%. There is uncertainty associated with all parts of the calculation: the area that burns; the amount of fuel consumed; and the gases given off per amount of fuel consumed.

Results

Estimation of burned area

Satellite derived data on burnt area (BA) extend is available for Southern Africa from three different sources; the Global Burned Areas Initiative (GBA) facilitated by the Joint Research

Center (JRC) of the European Commission (Grégoire *et al.*, 2003), the GLOBSCAR BA data, derived as part of a European Space Agency (ESA) programme (Eva and Lambin, 1998), and the BA fire product from the MODerate resolution Imaging Spectroradiometer (MODIS) (Roy *et al.*, 2002)[11]. Biomass burning is a function of biomass density, fraction of the biomass burned, burn efficiency and area burned (Seiler and Crutzen, 1980; Simon et al., 2004; Roy and Landmann, 2005, forthcoming). Biomass burning and data on the area burned is a key factor for bush encroachment studies and carbon stock exchange calculation between the biosphere and the atmosphere that is pyrogenic emissions profiles (Swap et al., 2002). Remote sensing can be used to calculate the area burned effectively, owing to the large spatial global coverage of satellite data and frequent observation passes (Simon *et al.*, 2004; Landmann, 2003). There are large differences and uncertainties in current burned area data sets from satellite remote sensing, and consequently these variances can introduce emission estimates with five fold differences (Roy *et al.*, 2002; Barbosa *et al.*, 1999).

Table 6 shows the differences between the three BA products available. The last two rows give the number of pixels that were detected using the algorithms and Landsat ETM+ imagery (and extend) for August 2001 at 1 km and also resampled to 500m resolution. The last column shows the corresponding number of pixels detected from Landsat data, but using another BA detection method (Landmann, 2003). This BA mask is derived as a comparative measure and because the resolution of Landsat is higher, *i.e.* at 30-meter pixel resolution, we can treat the Landsat BA estimates as the reference or truth data set.

The MODIS BA shows the best performance, as it is derived from 500-meter reflective data, extensively and systematically validated, and uses a multi-temporal change detection method, which implies that it will be more robust (Roy and Landmann, 2005, forthcoming) (see Table 6). The comparison of the MODIS BA estimate to the Landsat 'truth' BA estimate shows a 84% similarity in the area burned. The GBA and the Globscar estimates are very similar when compared to the Landsat reference data on BA, yet the GBA showed a limited ability to predict the perimeter of a burned area visible on the Landsat. Using visual comparisons, the GBA detected many 'unburned' and bright surfaces as burned areas and omitted other less charred surfaces within the fire scar. A visual comparison is illustrated in Figure 1, showing an exemplary fire near the south of the Landsat reference image. From Figure 1 it becomes apparent that the Globscar and the MODIS algorithms are similar in predicting the area burned. The GBA fire scar (A in Figure 1) shows large areas within the fire being unmapped (errors of omission) and other areas being mapped as burned outside of the fire perimeter.

All three BA products cover the southern African sub-continent well since the source satellite data has a large footprint at high to moderate resolutions.

[11] Globscar: http://shark1.esrin.esa.it/ionia/FIRE/BS/ATSR/
GBA: http://www-gvm.jrc.it/fire/gba2000/
MODIS BA: http://modis-fire.gsfc.nasa.gov/

Table 6. Comparison between the GLOBSCAR, the GBA and the MODIS BA algorithms using variables of data set validation, pixel resolution spectral waveband region, overpass frequency and area burned.

	GLOBSCAR	GBA	MODIS BA
Validation	Using Landsat TM, country vector data on BA, unsystematic	(1) using Landsat TM systematic, (2) using country statistics on BA	Systematic validation using field mapped Landsat ETM BA
Resolution (equals final BA product resolution)	1 km	1 km	500 m
Spectral region	VIS, NIR, MIR, TIR	VIS, NIR, MIR	VIS, NIR, 2 MIR
Temporal resolution	3-5 days	3-5 days	4 daily overpass
BA algorithm description	Contextual, reflective & thermal thresholding, single date data	Albedo, vegetation & moisture ratios, multi-temporal, thresholding	BRDF[1] z-score prediction method, multi-temporal.
# of pixels burned at 1km resolution (km^2) detected[2,3]	1 100	1 575	1 546
# of pixels burned at 500m resolution detected[2]	4 400	6 300	6 173

1. Bi-directional Reflectance Distribution, which is a model to correct the satellite reflectance for sun effects and satellite viewing geometry
2. For an observation area of 185km by 190km in northern Namibia and corresponding to two Landsat imagery (path, 180, row 073) captured on the 6th of August 2001 and on the 22nd of August 2001
3. 1312 burned pixels detected using the concurrent 30-meter Landsat derived BA map (1 km resolution).

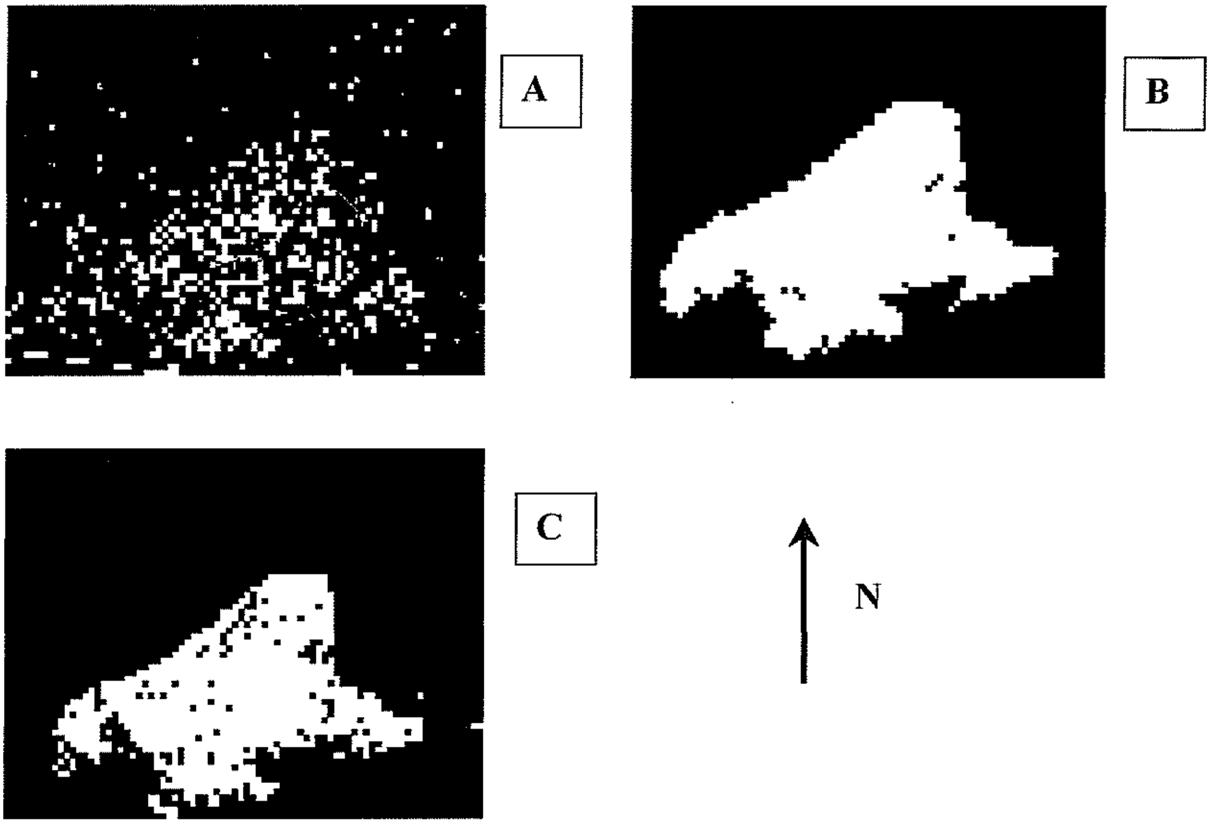

Figure 1. Burned area detection in northern Namibia in late 2001, using the GBA simulated algorithm in A, the MODIS BA algorithm in B, and the Globscar algorithm in C. The white pixels show the area mapped as burnt. Landsat data resampled to 500-meter and 1km resolution is used to simulate the BA algorithms.

Fire frequencies per vegetation type

A SPATIAL MAP OF VEGETATION BIOMES OF NAMIBIA (FIGURE 2) WAS OVERLAYED OVER THE 500-METER MODIS BA ESTIMATES FOR THE PERIOD OF AUGUST 2001. BURNT AREA CLUSTERS AS MULTI-POINTS CREATED IN A GEOGRAPHICAL INFORMATION SYSTEM (GIS) WERE MOST FREQUENT WITHIN THE NORTH-EASTERN KALAHARI WOODLANDS VEGETATION TYPE. THE DWARF SHRUB SAVANNA, DESERT BIOMES AND PANS SHOW THE LEAST BURNING IN AUGUST 2001 (TABLE 7)

Table 7. Vegetation types in Namibia and number of multi-points from a GIS that are burned areas

Vegetation type	# of BA multi-points
Caprivi Floodplains	2418
Caprivi mopane woodland	7636
Central desert	79
Central Kalahari	71
Central-western escarpment and inselbergs	2 884
Cuvelai drainage	90
Desert/dwarf shrub transition	47
Dwarf shrub savanna	0
Dwarf shrub savanna	300
Dwarf shrub/southern Kalahari transition	0
Eastern drainage	5 229
Etosha grass and dwarf shrubland	383
Highland shrubland	1 611
Karas dwarf shrubland	223
Karstveld	3 189
Mopane shrubland	643
North-eastern Kalahari woodlands	30 607
Northern desert	49
Northern Kalahari	1 400
North-western escarpment and inselbergs	63
Okavango valley	44
Omatako drainage	2 244
Pans	3
Riverine woodlands and islands	150
Southern desert	138
Southern Kalahari	86
Succulent steppe	123
Thornbush shrubland	1 475
Western highlands	3 507
Western Kalahari	3 062

Recommendations

From the above assessment we recommend to use the MODIS BA product for future fire BA monitoring and emissions modeling. Vegetation type areas such as deserts and pans can be excluded from the fire-monitoring tool by applying a vegetation biome mask within the algorithm.

The GLOBSCAR algorithm (Eva and Lambin, 1998) can be applied effectively as a fast tool to map BA, since it is easy to model and simulate, shows the second highest accuracy from

Table 6 and Figure 1, relies on single data and less complex to model than the MODIS BA method.

Calculation of fuel load

Considerable work has been done in southern Africa on measuring and estimating fuel loads in southern Africa. The work done by the Etosha Ecological Research Centre has contributed to this knowledge. The estimates of fuel load for African savannas in IPCC (1997) are far too high (see Scholes *et al* 1996, Hely *et al* 2004).

The procedure followed here to calculate mean fuel loads for each vegetation type in Namibia is a modification of Scholes (1996). It assumes that three main fuel types are involved: dry standing grass, fallen leaf litter from trees, and twigs fallen from trees. For grass fuels, the grass production (P_{grass}, g/m^2/year, which is numerically equal to tons/km^2/year) in the absence of trees is estimated using one of two equations, based on Scholes (2003). For loamy soils,

$$P_{grass} = 0.41 \text{ Annual Rainfall} + 12,$$

and for sandy soils,

$$P_{grass} = 0.061 \text{ Annual Rainfall} + 129$$

where Annual Rainfall (mm) can be for a particular year, or the mean for a number of years. This grass production is reduced in the presence of tree cover. A simple reduction factor is suggested (1-treecover %/100), which somewhat overestimates the grass fuel at high tree cover, but is a fair estimate at the typical tree cover levels found in Namibia (20-30%). The tree cover percentage is available at 500m resolution for all of Namibia from the MODIS tree cover product. This source is preferred to the tree cover ranges in the vegetation map of Namibia, which are for potential, rather than actual vegetation.

From this production, the amount consumed by herbivores must be subtracted. This was based on the recommended stocking rates in Namibia (expressed as Large Stock Units/km^2, where 6 Small Stock Units equals one LSU). One LSU consumes 3.650 tons (Mg) of forage per year.

For leaf fuel, a simple model was assumed. Savanna tree canopies have a mean leaf area index for the canopy-covered area of 3, with little variation (Scholes *et al* 2004), and a specific leaf mass of 167 g/m^2. Since the vast majority of savanna trees are deciduous, the annual tree leaf production (P_{tree}, g/m^2 or tons/km^2) is given by

$$P_{leaf} = (1\text{-tree cover}\%/100) \times 3 \times 167$$

Shea *et al* (1996) showed that over a wide range of African savannas, twig litter is an additional 78 $\pm$17 % of leaf litter.

The fuel accumulates year to year, losing about 40% of its mass during the wet season due to decomposition. Therefore, if fires occur once every three years (the most frequent *average* return time in Namibia), the accumulated fuel load is the annual production (minus grazing for the grasses) multiplied by 1+0.6+0.36, i.e. approximately double the annual net production.

The amount of the fuel exposed to the fire that is actually consumed is known as the combustion fraction. It varies from 98±2% for grass, 90 ±3% for leaf litter, to 35±6% for twigs.

All these considerations have been incorporated in the estimates of the mean amount of actual fuel consumed per unit of burned area in each vegetation type in Namibia (tons/km^2) (Table 8).

Table 8. Summary of fuel loads and total area burned.

The fraction of the landscape burned as determined by an advanced burn scar mapping algorithm applied to MODIS data for the year 2003. This was a fairly average fire year in Namibia. The fundamental resolution of the data is 500 m x 500 m. The burn scar product has been developed annually since 2001. The product also indicates the day of the year on which the fire occurred. Data courtesy of Dr David Roy, University of Maryland. Independent data, collected in Namibia using the NOAA AVHRR sensor, suggest that the fraction of Namibia as a whole that burns each year varies between 6 and 13% (John Mendelsohn, RAISON, personal communication). The AVHRR sensor will tend to slightly overestimate due to its somewhat larger ground resolution (1 km2).

eg code	Vegetation type	Area	MAR	Tree and shrub cover %		Soil	Grazing	Burned Area Fraction	Fuel Load				Fuel consumed
									Grass	Leaf	Twigs	Actual	
(Figure 2)		km^2	mm	Vegmap	Modis	type	LSU/km^2	%	t/km^2				Mg/y
1	Central desert	32096	59	0	0	loam	1.2	0%	64	0	0	62	3
2	Northern desert	20893	56	38	0	loam	1.2	0%	61	2	2	62	0
3	Southern desert	47304	62	0	0	sand	1.2	0%	256	3	2	254	4
4	Succulent steppe	20265	50	0	4	sand	1.2	0%	245	40	31	287	6
5	Pans	5454	400	0	0	clay	4.1	0%	322	0	0	316	12
6	North-western escarpment and Inselbergs	13014	115	6	0	loam	1.8	0%	105	0	0	103	0
7	Desert/dwarf shrub transition	25014	120	0	1	sand	2.4	0%	252	10	8	259	0
8	Dwarf shrub savanna	65687	166	30	3	loam	2.8	0%	135	30	23	167	64
9	Dwarf shrub/southern Kalahari transition	10471	156	4	1	sand	2.8	0%	254	10	8	260	0
10	Etosha grass and dwarf shrubland	2255	370	2	7	sand	5.0	3%	245	70	54	322	230
11	Karas dwarf shrubland	66308	132	3	1	loam	1.8	0%	118	10	8	127	11
12	Central-western escarpment and inselbergs	18474	130	1	1	loam	1.8	0%	116	10	8	126	59
13	Central Kalahari	60945	370	32	11	sand	2.5	1%	252	110	85	375	1464
14	Cuvelai drainage	14833	434	44	13	loam	3.0	12%	309	129	101	454	8034
15	Highland shrubland	23801	331	36	20	loam	4.0	1%	207	199	155	437	548
16	Karstveld	43534	428	81	56	loam	5.0	1%	128	558	435	780	2138
17	Mopane shrubland	6809	391	56	9	sand	4.0	2%	249	90	70	349	434
18	Southern Kalahari	57890	218	4	0	sand	2.5	0%	265	4	3	265	0
19	Thornbush shrubland	42495	393	76	33	loam	4.5	0%	198	331	258	582	100
20	Western Kalahari	16030	368	76	11	sand	4.1	3%	240	110	85	363	1933
21	Western highlands	70631	231	24	14	loam	2.8	1%	163	139	109	323	1530
22	Caprivi Floodplains	3823	609	1	60	loam	8.3	19%	149	598	466	847	6101
23	Caprivi mopane woodland	4626	595	76	96	loam	8.3	32%	-40	956	746	1082	16093

eg code (Figure 2)	Vegetation type	Area km²	MAR mm	Tree and shrub cover % Vegmap	Tree and shrub cover % Modis	Soil type	Grazing LSU/km²	Burned Area Fraction %	Grass t/km²	Fuel Load Leaf t/km²	Fuel Load Twigs t/km²	Actual t/km²	Fuel consumed Mg/y
24	Eastern drainage	8833	512	56	33	sand	8.0	36%	156	329	256	539	17292
25	North-eastern Kalahari woodlands	74056	115	19	37	sand	2.0	24%	157	369	287	586	103706
26	Northern Kalahari	66541	426	32	12	sand	5.0	9%	236	120	93	372	22956
27	Okavango valley	1504	556	56	0	loam	8.0	3%	422	0	0	413	190
28	Omatako drainage	1820	505	19	18	loam	8.0	19%	301	179	140	505	1702
29	Riverine woodlands and islands	347	593	100	91	loam	0.0	13%	46	906	707	1108	518

Estimation of emission factors
During the past decade a great deal of research work has been conducted in southern Africa (including in Namibia) on wildfire emission factors. A good summary can be found in Sinha *et al* (2004). A summary of applicable emission factors is provided in Table 9.

Table 9. Summary of applicable EFs

	Fuel consumed	EmissionFactors (kg/Mg)		Emissions (Gg/y)	
	Mg	CH_4	N_2O	CH_4	N_2O
Mean	31 413 608	1.7	0.064	53.4	2.0
SE		0.098	0.013		

Emissions from fires in Namibia
Combining the area burned, the fuel consumed per area and the emission per unit fuel consumed gives an estimate of 53.4 Gg CH_4/year and 2.0 Gg N_2O/year for Namibia.

The estimated error associated with the burned area is $\pm$21% (relative to the burned area, which is less than 20% of the total area, so the absolute error is $\pm$ 5%). There are two components to this uncertainty: one is interannual variability in burned area, which is high (in excess of 30%) since it is related to interannual variability of rainfall. Drought years have substantially less area burned than wet years, because the fuel load is too low to carry many fires. If the burned area fraction is estimated for a series of years, as recommended, this source of variation is reduced by 1/sqrt(number of years), i.e. for five years its is approximately halved. The second is the technical error associated with different ways of estimating burned area. The MODIS burned area map recommended here is thought, by expert opinion, to have a relative error of about $\pm$ 15% as well. Since these two sources of error are believed to be independent, the overall relative error of burned area is sqrt(15^2 + 15^2) = 21% .

The estimated error associated with the fuel load has the same two main components: interannual variation (about 30%, or about 14% for a five-year run), and model uncertainty (about 20%). This gives a root mean square error of about 24%.
The errors associated with the emission factors are well known, and shown in the table. In relative terms they are 7.6% for CH_4 and 20% for N_2O.

Since the burned area, fuel load and emission factor errors are probably independent; the overall root mean square error for their product is 33%.

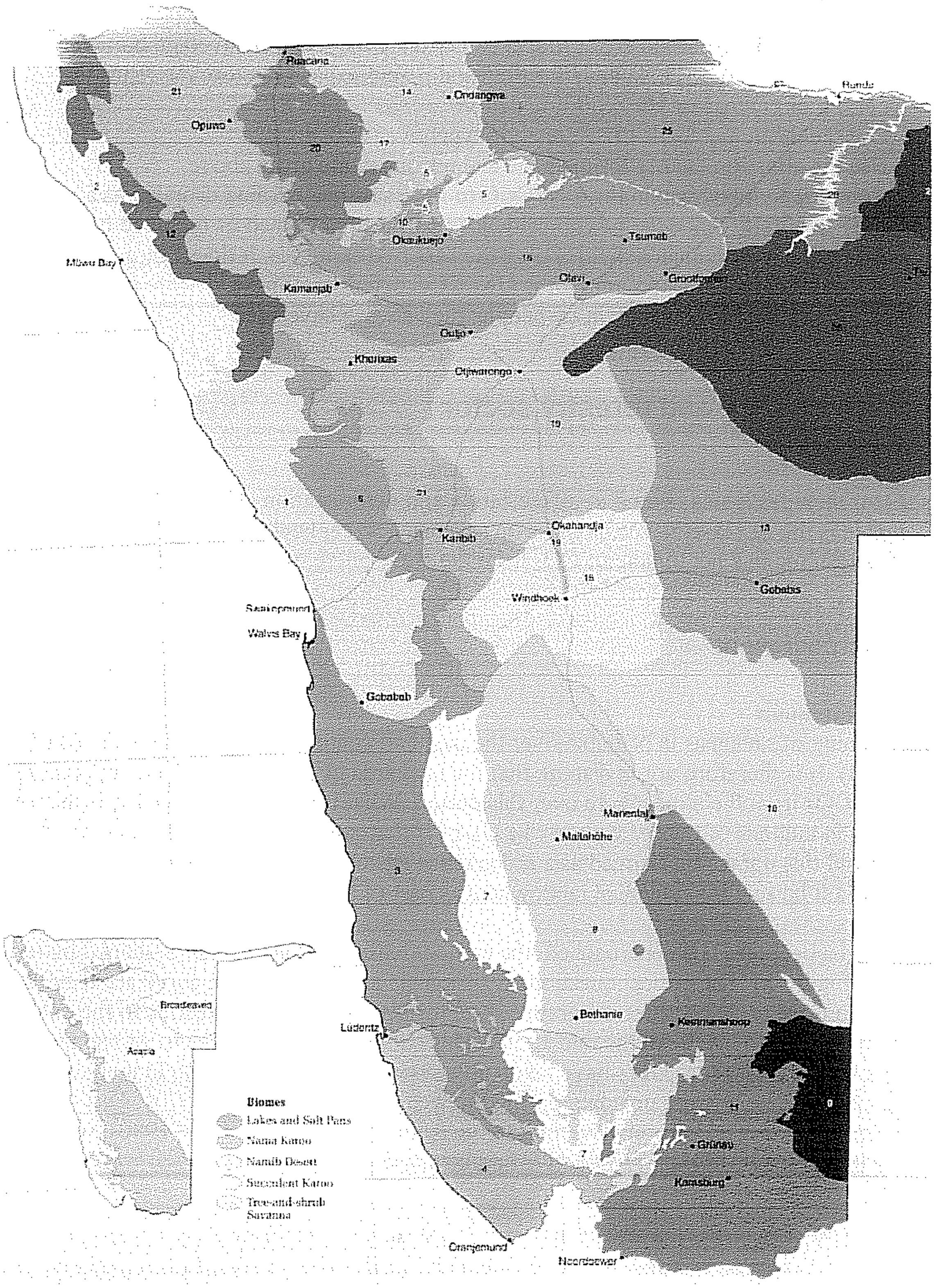

Figure 2. Vegetation map of Namibia used as the basis of the calculations in this report. Source: Mendelsohn (2002) (See Table 8 for description of numeric codes used).

Recommendations

1. Use the MODIS burned area product to calculate the five-year average burned area per vegetation type in Namibia for the window immediately before the reporting period, or centred on the reporting period.
2. Use the mean fuel loads per vegetation type given above.
3. Use the emission factors for methane and nitrous oxide given above.
4. Continue to lobby within the UNFCCC to have savanna burning dropped as a reporting item. Since there is no evidence that the area burned or fuel load have changed due to human activities over the past two centuries, it does not qualify as an 'anthropogenic emission' under the UNFCCC definition. This is despite the fact that the fires are predominantly lit by people; they always have been.

Land use change and forestry sector

Description

This sector includes issues related to afforestation and deforestation. The key 'forestry' issue for Namibia is the increase in tree biomass on savanna grazing land (bush encroachment), which has resulted in a net uptake of CO_2 from the atmosphere over the past 50 years.

Bush encroachment

Problem statement

The thickening of savannas in Namibia over the past half century is well documented (de Klerk 2004). It is therefore not in dispute that the land area of Namibia has taken up a large amount of CO_2 from the atmosphere over this period. What is unknown is a) what is the total magnitude, in millions of tons of carbon (Tg C), b) is that uptake still occurring and at what rate, c) could this uptake be claimed as a greenhouse gas offset in the national communication and d) could it be sold by individual landowners as part of a CDM scheme?

When an area becomes bush encroached, the carbon density increases in an S-shaped pattern over time (Figure 3). The critical questions for Namibia are where on the curve are they? In practice, there are probably three separate curves for Namibia. The first relates to the cohort of trees that began to invade in the mid 1950s. This curve is probably close to its maximum point: in other words, those areas have taken up carbon, but are probably no longer doing so. The second curve is for trees invading during the wet period of the early 1970s. They may still be actively taking up carbon. The third curve is for trees invading in the 1980s, which are probably in the middle of their most active uptake phase.

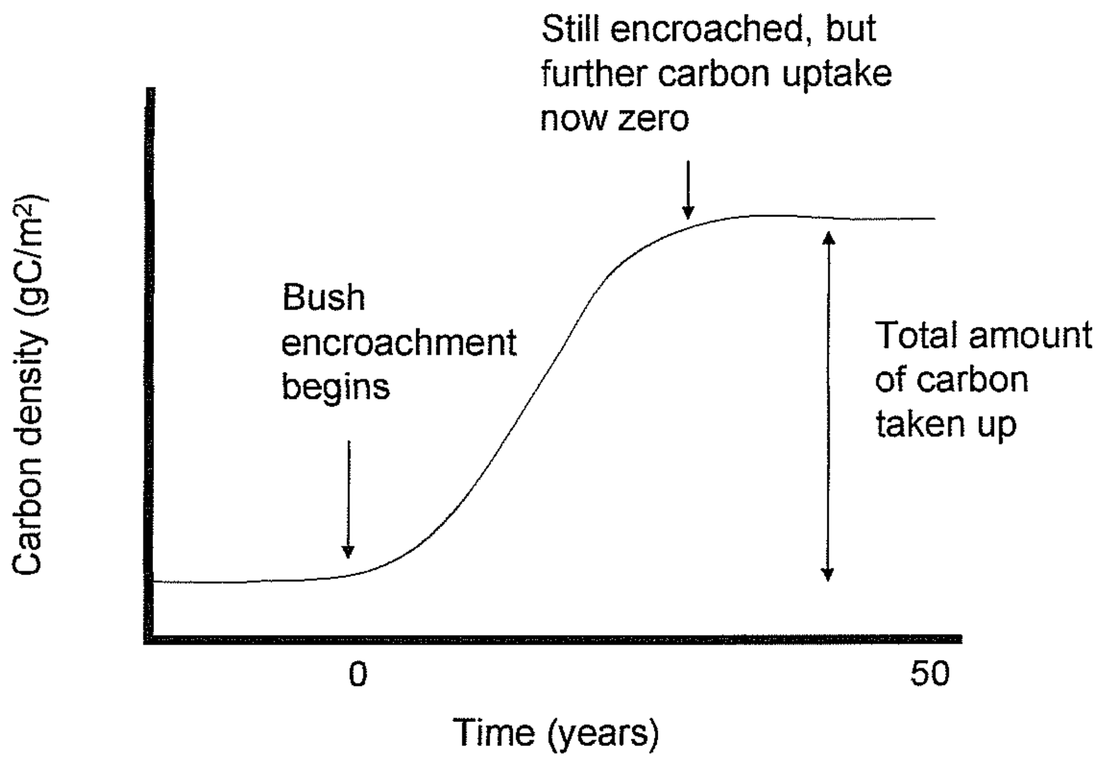

Figure 3. A schematic diagram of the process of carbon uptake during bush encroachment. The carbon accumulates in both the trees and in the soil.

Results

Namibia has established bush encroachment monitoring plots in the affected areas, mostly in the central region. A sample of tree basal area data from these plots is shown in Figure 4. Note that many of the plots are either near, or above, the line showing the maximum long-term stable basal area in savannas. Secondly, the relationship between rainfall and basal area in the Namibia sample is

$$BA = 0.028(\pm 0.014) * MAR + 5.07(\pm 5.45)$$

whereas the relation for South Africa is

$$BA = 0.0246(\pm 0.007)*MAR - 3.90(\pm 5.42)$$

Thus the Namibia plots have, on average, nearly 9 m^2/ha of basal area more woody vegetation than the South African plots. This represents a difference of about 35 t DM/ha, given the relation BA (m^2/ha) = 1.5873 Mass (t/ha) $^{0.6008}$, and the current mean Namibian basal area of 16 m^2/ha. Since 45% of the biomass is carbon, the change in carbon density due to increased tree biomass is 15.75 t C/ha, or 1575 g/m^2 (which equals 1575 tons/km^2). This does not include any increase in soil organic matter or belowground carbon, for which data are not available.

The region over which this increase applies is vegetation types 6,13,15,16,19,21,25 and 26. This represents a combined area of 393943 km^2, or 47.8% of Namibia. The amount of carbon taken up over the past fifty years by this mechanism is therefore approximately 620 million tons (620 x 10^{12}g C, or 620 Tg C). Averaged over the 50-year period, this translates to 12.4 Tg C/y, which is equivalent to 45.4 Tg CO_2/y. For comparison, an estimate of 6.373 Tg CO_2 was given for uptake due to this mechanism in the FNC.

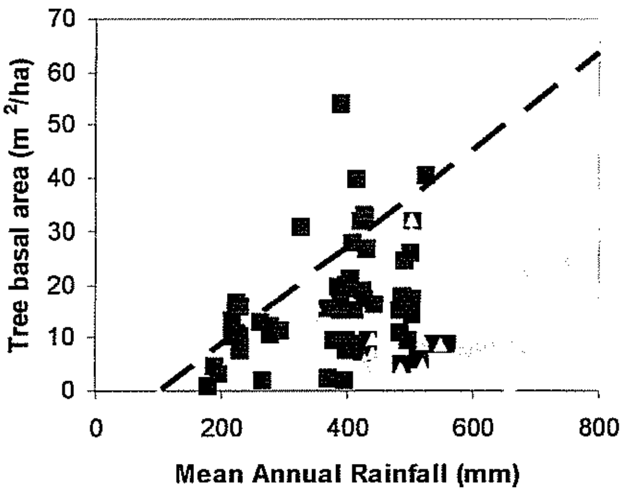

Figure 4. The basal area of woody plants in 56 randomly-selected bush monitoring plots in central Namibia (block squares) in relation to the mean annual rainfall at those locations. Also shown are data from 51 plots in South Africa (grey triangles, Shackleton 1998), and a line representing the upper envelope of basal area in savannas all around the world.

The fact that many of the sites are close to, or even above the maximum stable basal area line in Figure 4 suggests that for these central districts, many of the encroached savannas are nearing the top part of the 'S' curve illustrated in Figure 3. In other words, the current carbon uptake rate will be less than the 50-year average given above (the FNC estimate of 6 Tg C/year is therefore not unreasonable, but may be on the low side). Furthermore, the fact that the *mean* line for Namibia still lies only about a third of the way to the upper maximum suggests that substantially more encroachment is possible on sites presently unencroached or only partly encroached: the average basal area could rise to 25 t/ha. Without a re-measurement of the monitoring plots, a more definitive statement regarding the current carbon uptake rate is not possible.

This carbon uptake can, and must, be entered on future national communications by Namibia to the UNFCCC. It is very likely that Namibia is overall a net sink for greenhouse gases as a result. While there is a scientific speculation that some of this increase in tree biomass may be related to rising CO_2, and therefore not be eligible as a human-caused uptake of greenhouse gases, the balance of scientific opinion remains that most of it is due to ranching practices put in place by European settlers during the twentieth century: notable high fixed stocking rates and the combating of fires. It therefore does qualify as a landuse practice that led to a net carbon uptake.

It is our opinion that the uptake to date is probably *not* eligible for CDM carbon sales by private individuals, corporations or communities. This is because they fail two CDM criteria: firstly, they are not 'additional', because they happen completely accidentally, and without any intention to combat climate change; and secondly, they are arguably unsustainable because of the impact that the increased bush density has on grazing potential, biodiversity and livelihoods.

Data on the amount of wood harvested for domestic and commercial purposes as well as the amount of wood products that can be considered for long term storage purposes are provided in Appendix D.

Recommendations

1. Repeat the survey of the bush encroachment monitoring plots within a decade of the initial survey. At the same time, soil samples for the 0-30 cm range should be collected for carbon analysis.

Waste Sector

Description

The organic matter content of waste streams (municipal solid waste, industrial, domestic and farming liquid wastes) generates CH_4 if it decomposes under anaerobic conditions, which is usually the case. Nitrous oxide (N_2O) may be generated during both nitrification and denitrification of the nitrogen present in the wastewater, usually in the form of urea, ammonia, and proteins. These compounds are converted to nitrate via nitrification, an aerobic process (in the presence of oxygen) converting ammonia-nitrogen into nitrate (NO_3). Denitrification occurs under anaerobic conditions (in the absence of oxygen), and involves the biological conversion of nitrate into dinitrogen gas (N_2). Nitrous oxide (N2O) can be an intermediate product of both processes, but is more often associated with denitrification.

Activity data on the amount of different wastewater streams treated and their organic contents were incomplete when the 1994 GHG Inventory was compiled. This factor contributed the most to the uncertainty levels associated with the final methane and nitrous oxide emission estimates from the treatment of wastewater (Table 1).

The purpose of this section is to review and make recommendations on the data collection requirements for wastewater generated from:

1) Domestic sources
2) Commercial and industrial processes such as the fish processing, meat packing, brewing and tanning industries in terms of:
    a) the amounts treated
    b) the types of treatment systems used; and
    c) the organic contents of the different waste streams for possible inclusion in the second and subsequent national GHG inventories.

Results

The volumes of wastewater treated for the different wastewater streams (domestic and industrial) per year are needed to calculate the total CH_4 and N_2O emissions. This data are not readily available on a national level for all the different treatment plants. Swakopmund reported an average amount of about 60 000 m^3 to be treated on an annual basis.

Most of the wastewater (domestic and industrial) generated in Namibia is treated at municipal plants. Some companies do pre-treatment but data are not readily available.

The MAWRD takes raw wastewater and final effluent samples on a yearly basis or after every other year at each plant. Some of the water quality data are captured in electronic and the rest in hard copy formats.

The main types of wastewater treatment systems used in Namibia include:

- Oxidation ponds
- Activated sludge
- Biological filtration
- Septic tanks (on a small scale)

Anaerobic conditions that lead to emissions of CH_4 occur during most of the treatment processes used in Namibia.

No methane is currently captured at any of the treatment plants in Namibia (Laura Namene, MAWRD, personal communication).

Nitrous oxide emissions from human sewage have not been included in the 1994 GHG Inventory. It was not possible to calculate the total amount of nitrogen emitted as N_2O from the treatment of wastewater as not all the plants reported total volumes treated and/or nitrogen content of the sewage treated. Only data on the total amount of nitrogen load for Windhoek were available at the time of the study. The total nitrogen amount treated in 2004 in Windhoek was estimated at about 665 780 kg N.

Windhoek's two domestic sewage treatment plants employ activated sludge (AS) biological nitrogen removal methods to achieve TKN reduction through 3 basic processes:

1) Absorption of organically bound nitrogen into new bacterial cell mass (sludge) that is retained within the works
2) Nitrification: Conversion of Ammonia to Nitrate (NH_3 to NO_3) using O_2
3) De-nitrification: Subsequent conversion of Nitrate to dinitrogen gas (NO_3 to N_2) that escapes to the atmosphere

THE NITROGEN CONTENT OF THE SEWAGE TREATED IN LÜDERITZ AND WINDHOEK IS ON THE LOWER END OF RANGES QUOTED IN THE IPCC GUIDELINES. IN THE ABSENCE OF DATA ON THE AMOUNT OF N_2O EMISSIONS FROM HUMAN SEWAGE, A VALUE OF 0.002 KG N_2O-N/KG SEWAGE-N (THE LOWER VALUE OF THE IPCC RANGE OF 0.002 TO 0.12) WAS USED TO CALCULATE AN EMISSION OF ABOUT 0.002 KT N_2O EMISSIONS FOR WINDHOEK FOR 1994. THE UNCERTAINTY ASSOCIATED WITH THIS EMISSION FACTOR VALUE IS ESTIMATED TO BE "MEDIUM' I.E. ABOUT 10-20% ERROR. ABOUT 54% OF ALL (RURAL, URBAN AND SEMI-URBAN) NAMIBIANS HAVE NO TOILETS AND USE THE BUSH AND ABOUT 34.4% HAVE FLUSH TOILETS, ALTHOUGH NO DATA ARE AVAILABLE ON THE TYPE OF TREATMENT SYSTEMS USED. ABOUT 70% OF PEOPLE LIVING IN URBAN AREAS HAVE FLUSH TOILETS COMPARED TO LESS THAN 10% IN THE RURAL AREAS. ABOUT 11% OF ALL PEOPLE USE PIT LATRINES.

Recommendations

1. Data are available for individual towns but are not stored centrally. National data on wastewater amounts, amounts of wastewater treated with different treatment systems, organic contents and especially the nitrogen content should be collected or made available centrally, i.e. at the relevant national department (MAWRD) responsible for water data collection and

management. A list of people that can be contacted in different towns regarding wastewater data is provided in Appendix E.

2. No locally applicable N_2O emission factor for human sewage in Namibia is available. It is therefore recommended that an emission factor of 2 g N_2O per person per year[12] is used in the absence of data on the amounts of sewage treated at different treatment plants in the country as well as the nitrogen content. Ideally an emission factor based on the amounts of wastewater treated and not the total population size should be applied, especially in the case of Namibia where a large portion of the population does not have access to a flush toilet. If data do become available on the amounts of sewage treated per type of treatment system and the nitrogen content of the sewage, the IPCC default emission factor of 0.01 kg N_2O-N/kg sewage-N produced, needs to be adjusted to reflect local conditions. An emission factor of close to 0.002 kg N_2O-N/kg sewage-N produced is recommended.

3. The amount of N_2O emissions from human sewage is influenced by seasonal and diurnal fluctuations. Ideally, wastewater amounts and contents should be collected and reported on a monthly basis for a period of time to determine the magnitude of these fluctuations on the emissions. Once this is established and emission factors and emission values are calculated, yearly data can be used in the future.

[12] Values ranging between 3.2 and 7 g N_2O per person per year are reported in the USA GHG inventory.

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APPENDIX A: CONTACTS IN THE ENERGY SECTOR

- Mr C McClelland, Director, SA Petroleum Industries Association, Cape Town.
- Mr H Schmidt, Secretariat of Petroleum Wholesalers, Windhoek.
- Mr P de Plessis, Centre for Research Information Action in Africa, Southern African Development and Consulting, who developed the initial GHGI in 1989/99.
- Dr C Cooper, Director of the SA National Committee of the World Energy Council who was responsible for the development of the SADC Energy Yearbook 2002, that includes a statistical summary.
- Mr A P Peens, Data Base Manager, Caltex, Cape Town.
- Mr I Ngishoongele, Deputy Director at the MME.

APPENDIX B: LIQUID FUEL USE FOR NAMIBIA, 2003 (LITRES)[13]

Category code	Description	Diesel	Mogas	IK	Furnace oil	Avgas	Jet fuel	Int'l marine bunkers	Total sector	% of total
10	SERVICE STATIONS	65,669,484	248,225,946	787,762					**314,683,192**	**36.0%**
15	OTHER RESELLERS	27,036,504	27,309,622	2,015,953					**56,362,079**	**6.4%**
20	FARMERS	9,559,398	1,412,878	110,692					**11,082,968**	**1.3%**
25	CO-OPS	26,333,886	4,744,331	682,359					**31,760,576**	**3.6%**
30	OTHER COMMERCIAL	79,669,012	3,764,806	1,151,580	4,877,584	2,604,520	19,528,591	*42,018,133*	**153,614,226**	**17.6%**
50	CENTRAL GOVT	16,613,284	11,620,337	56,219	3,988,129				**32,277,969**	**3.7%**
55	LOCAL GOVT	2,379,686	1,228,753	1,760					**3,610,199**	**0.4%**
60	TRANSNAMIB	10,960,412	98,337	4,020					**11,062,769**	**1.3%**
70	MINING	52,649,195	3,232,848	92,949	346,500				**56,321,492**	**6.4%**
75	CONSTRUCTION	13,125,355	220,542	283,680	75,000			168,210	**13,872,787**	**1.6%**
80	BUSES	613,014	253,820	15,660					**882,494**	**0.1%**
85	ROAD TRUCKS	28,740,049	1,616,083	237,546				290,846	**30,884,524**	**3.5%**
90	FISHING	149,608,459	161,827	14,499	6,123,416			2,238,700	**158,146,901**	**18.1%**
	Total	**482,957,738**	**303,890,130**	**5,454,679**	**15,410,629**	**2,604,520**	**19,528,591**	**44,715,889**	**874,562,176**	**100.0%**
	% of total	**55.2%**	**34.7%**	**0.6%**	**1.8%**	**0.3%**	**2.2%**	**5.1%**	**100.0%**	

Note: IK- Illuminating kerosene, bitumen and lubricant sales data has not been indicated.

[13] Data base data obtained from Caltex, Cape Town, November 2004.

APPENDIX C: SECTORAL LIQUID FUEL USE IN NAMIBIA, 2003 (TON)

Consumption, tonne	Diesel	Mogas	IK	Furnace oil	Avgas	Jet fuel	Bitumen/ Asphalt	Lubricants	Total	% of total	Data from Category
Density (kg/litre)	0.839	0.723	0.788	0.984	0.788	0.788	1	1	n/a	n/a	n/a
Industry	89,526	22,467	2,496	4,800				3416	**122,704**	16.8%	15, 30
Mining	44,173	2,337	73	341					**46,924**	6.4%	70
Commercial, constructio	26,947	9,449	269	3,998			11513		**52,177**	7.1%	50,55,75
Transport	88,920	180,890	823	0	2,052			7897	**280,583**	38.4%	10,60,80,85
Agriculture	30,114	4,452	625	0					**35,191**	4.8%	20
Fishing	125,521	117	11	6,025				628	**132,303**	18.1%	90
International bunkers	0	0	0	44,716		15,389			**60,104**	8.2%	Intl bunkers, Jet Fuel
Total	**405,202**	**219,713**	**4,298**	**59,880**	**2,052**	**15,389**	**11,513**	**11,941**	**729,987**	**100.0%**	
% of total	55.5%	30.1%	0.6%	8.2%	0.3%	2.1%	1.6%	1.6%	100.0%		

Note: Bitumen and grease are reported in kg, other lubricants in litre. The density of the latter has been assumed to be unity.

APPENDIX D: DATA ON CHANGES IN BIOMASS STOCKS DUE TO DOMESTIC AND COMMERCIAL WOOD CONSUMPTION AND LONG TERM STORAGE PRODUCTS.

Year	Fuelwood used (t)	Firewood exported(t)[d]	Charcoal produced (t)[b]	Long-term storage (t)
1996	635000[c1]			
1997				440[c2] 625[c3] 347 000[c4] + buildings + crafts
1998		52 492.21	43 294.58	694 000[e]
1999		56 892.6	35 281.3	
2000		56 094.32	35 998	
2001	296 015[a]	50 431	47 083	
2002		50 430	49 917	
2003		43 331	38 048	

a) = 811 t/day x 365 - unpublished data from RAISON, based on 2001 Population and Housing Census; same document also mentions 270 000 t/a

b) Charcoal produced = charcoal exported, with domestic consumption unknown but estimated around 300t/a [H Visage Dir. of Forestry pers comm.] Ongopolo Smelter at Tsumeb reported using 60t charcoal a month – unknown if this is included in DoF data

c1) Klaeboe and Omwami 1997

c2) ibid. Carving

c3) ibid. Mopane roots

c4) ibid. This is the demand for poles, not actual quantity of poles used.

d) Visagie DoF pers comm. Unpublished DoF permit data from Windhoek, Grootfontein and Otjiwarongo offices

e) John Mendelsohn personal communication. after Carter Hearts – wood for fencing poles and construction

APPENDIX E: CONTACTS IN THE WASTE WATER TREATMENT SECTOR

Town	Name
Swakopmund	Günther Hülsmann Deputy Town Engineer – Planning
Walvis Bay	Andre Burger City Engineer
Tsumeb	FW Becker
Grootfontein	Mr Kariko City Engineer/ Martin le Roux
Keetmanshoop	Mr Dax
Luderitz	Arnold Kollmann City Engineer
Gobabis	Town Engineer Rudolf Oosthuizen
Karibib	Robert
Khorixas	Mr Gawiseb
Okahandja	Vincent Sazida
Okakarara	VD Maherero
Omaruru	Jurgen Richer
Outapi	Mr Malakia (artisan)
Ondangwa	Mr Kanjibi
Ongwediva	Damien Iwumbu
Katima Mulilo	John Kambimbi