Regional assessment of the

economics of land degradation related to bush encroachment in Otjozondjupa,

Namibia

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Contributing Authors

Catherine Birch and Angus Middleton.

Enquiries

Namibia Nature Foundation
76 – 78 Frans Indongo Street
Windhoek, Namibia
Tel: + 264 61 248345
Fax: +264 61 248344
Email: info@nnf.org.na

Table of contents

List of tables

List of charts

List of figures

List of acronyms

BAU	Business As Usual
CIAT	International Centre for Tropical Agriculture
CICES	Common International Classification of Ecosystem Services
ELD	Economics of Land Degradation
EPA	Environmental Protection Agency
FAO	UN Food and Agriculture Organisation
GIZ	Deutsche Gesellschaft für International Zusammenarbeit
IRLUP	Integrated Regional Land Use Planning
IUCN	International Union for Conservation of Nature
LDN	Land Degradation Neutrality
MA	Millenium Assessment
MAWF	Ministry of Agriculture, Water, and Forestry
MET	Ministry of Environment and Tourism
MLR	Ministry of Land Reform
NAU	Namibia Agricultural Union
N-BiG	Namibia Biomass industry Group
NCA	Namibia Charcoal Association
NIRP	National Integrated Resource Plan
NPV	Net Present Value
ResMob	Resource mobilisation for effective implementation of the updated biodiversity strategy in Namibia
SCC	Social Cost of Carbon
SEEA-EEA	UN System of Environmental Economic Accounting: Experimental Ecosystem Accounting
SOC	Soil Organic Carbon
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Valuation
UNCCD	United Nations Convention to Combat Desertification

Executive summary

Bush encroachment is "the invasion and/or thickening of aggressive undesired woody species resulting in an imbalance of the grass:bush ratio, a decrease in biodiversity, and a decrease in carrying capacity" (De Klerk 2004). It affects around 45 million hectares of Namibia's land area (SAIEA 2016). In Otjozondjupa, Namibia's fourth biggest region at more than 10.5 million hectares, bush encroachment reportedly affects the majority of the land area (Hengari 2016). Overgrazing is thought to be a key driver of bush encroachment, but the displacement of browsers by livestock, the suppression of high intensity fires due to cattle farming, rainfall and its variability, and increased atmospheric CO_2 concentrations are also contributors (Joubert and Zimmerman 2002).

Bush encroachment has negative impacts on some of Otjozondjupa's key ecosystem services, such as livestock production, groundwater recharge, and tourism, as well as biodiversity. This has given rise to calls for a comprehensive programme of de-bushing, to reduce bush encroachment and try to reverse some of these negative effects. De-bushing also offers economic opportunities for the utilisation of woody biomass via charcoal, firewood, and animal feed production, thermal power and electricity generation, and other products.

This report builds on the framework developed by the Namibia Nature Foundation (NNF) in the national assessment of the economics of land degradation related to bush encroachment (Birch et. al. 2016). Furthermore, it estimates the financial costs involved in unlocking the ecosystem service benefits and some of the wider economic impacts to build a business case for de-bushing.

This report delineates and assesses the state of bush encroachment in Otjozondjupa, identifies ecosystem services impacted by bush encroachment, and evaluates how flows and stocks of these services would likely change under a programme of de-bushing. The benefits and costs for key sectors and services, namely cattle production, groundwater recharge and supply, wildlife viewing, hunting and game products, carbon sequestration, and value addition industries are estimated. Furthermore, the wider economic benefits generated by additional jobs and income in these sectors are estimated. Cost-benefit analysis is then used to estimate the net benefit of de-bushing by sector and the overall net benefit, when compared with a business-as-usual (BAU) scenario of no de-bushing. This study follows the methodology of the Economics of Land Degradation (ELD) Initiative (ELD Initiative 2015).

The delineation of bush encroachment is based on new data collected by the LDN pilot project in 2016 and processed by CIAT. According to this data, bush encroachment is present across the majority of Otjozondjupa, affecting multiple ecosystems and land uses, but particularly commercial and communal agriculture and tourism (both consumptive and non-consumptive). This makes it a complex problem, as impacts can vary depending on the immediate environment (e.g. types of soil, other vegetation, wildlife), how the land is used (e.g. cattle farming, tourism), and how many people depend on the land. Furthermore, the appropriate method, range, and scope of de-bushing activities are also dependent on the local context.

To identify the ecosystem services affected by bush encroachment (and de-bushing), this report adopts the Common International Classification of Ecosystem Services (CICES) in order to remain

consistent with the draft Inventory of Ecosystem Services in Namibia (2015) and the UN System of Environmental-Economic Accounting (SEEA). The CICES classification recognises three broad categories of services: provisioning, regulation and maintenance, and cultural. Given data and research constraints, we are unable to quantify the likely impacts of de-bushing on the majority of services. However, there is reason to believe that many of these services would be positively affected by de-bushing, which suggests that there is upside risk to our estimates of net benefits (actual net benefit could be higher).

Some key assumptions underpin the estimation of benefits and costs for each sector and ecosystem service under a scenario of de-bushing. It is assumed that 60% of the bush-encroached area in Otjozondjupa could be targeted for de-bushing, and that 5% of the targeted area could be de-bushed per annum. We also assume that the density of the identified dominant encroacher species would be reduced by 90%, leaving non-encroacher species untouched. This would result in an overall reduction in bush density across the region of 38.5%. Another assumption made is that bush encroachment would remain constant without a widespread programme of de-bushing. In reality though, bush encroachment is thought to be increasing by around 3.18% per annum, which means that the negative impacts on ecosystem services are also likely to be increasing over time.

The impacts of de-bushing on key sectors and ecosystem services are then estimated, along with the direct costs of de-bushing operations and the wider economic impacts, using real prices (base year 2015). It is estimated that de-bushing could result in a net benefit for livestock production, groundwater recharge, wildlife viewing, and hunting and game products, as well as charcoal, firewood, and animal feed production, and power and electricity generation. Furthermore, wider economic (and social) benefits would arise from the additional jobs and household income. However, it would result in net costs for de-bushing operations, additional emissions from livestock, and loss of soil organic carbon.

Cost-benefit analysis is then used to estimate the potential net benefit of a programme of de-bushing, compared with the BAU scenario of no de-bushing, over a 25-year horizon. Annual costs and benefits are discounted by a real rate of 6% per annum. In the central case, the total net benefit is estimated at N$4.9 billion (2015 prices, discounted) over 25 years. Total cost is estimated at N$20.3 billion. Total benefit is estimated at N$25.1 billion and includes benefits for the wider economy of N$5.3 billion.

Scenario analysis indicates that the net benefit could range from -N$2.9 billion under a worst case scenario to N$10.6 billion under a best case scenario. The worst case scenario is significantly impacted by the use of the social cost of carbon to value the net change in carbon emissions/sequestration. It also assumes that meat prices would decline further, although it is thought that prices are currently bottomed out, and that de-bushing costs would be 20% higher. We believe that this worst case scenario is highly unlikely. The net benefit in the central case is also observed at varying discount rates. At a discount rate of 12%, the net benefit is estimated at N$1.3 billion, but this is an extremely high discount rate in the Namibian context. At a more realistic rate of 4%, the net benefit is estimated at N$7.3 billion.

De-bushing is treated as an isolated cost in the CBA but we look at a number of business cases to evaluate their industry net benefit and social net benefit when the sector-specific cost of de-bushing and economic multipliers are included. Of the value addition industries, animal feed, charcoal production, and electricity generation all have estimated positive industry and social net benefits. Although the social net benefit for charcoal production was estimated to be positive, the industry net benefit was estimated to be negative. More efficient technology, and therefore lower demand for biomass, would close this gap somewhat. In terms of farming, game farms were estimated to generate the largest net benefit under three different payment options for de-bushing the land, followed by mixed use farms, and cattle farms.

Overall, these results suggest that the net benefit of a comprehensive de-bushing programme in Otjozondjupa would be significantly positive and make a considerable contribution to Otjozondjupa and Namibia’s economy and social welfare. This model for Otjzondjupa could also be expanded to the other bush-encroached areas of Namibia. Furthermore, as we believe that many of the unquantified ecosystem services would be positively affected by de-bushing, it is reasonable to expect that there is upside risk to our estimates.

A comprehensive de-bushing programme deserves support from the private sector, which stands to reap returns in the long run, and the public sector, given the social, environmental, and wider economic benefits. In addition, it is in the interest of Namibians in Otjozondjupa and across the country, as well as the global community, to support an initiative that would also improve biodiversity and other unquantified ecosystem services. We also recommend further research focussing on the effects of de-bushing on ecosystem services that are currently unquantifiable or uncertain, the environmental impacts of de-bushing, and potential mitigation measures.

1 Introduction

1.1 Background

Bush encroachment in Namibia is a significant problem, affecting around 45 million hectares of land – more than half of the country's land area (SAIEA 2016). In Otjozondjupa, Namibia's fourth biggest region at more than 10.5 million hectares, bush encroachment reportedly affects the majority of the land area (Hengari 2016).

Bush encroachment has significant impacts on agricultural productivity, ecosystems, and their services. While the concerns over agricultural productivity are well recognised, the impacts on other ecosystem services are less well recognised but no less important. This importance is highlighted in the Namibian Government's Vision 2030, where Chapter 5 states:

> "The integrity of vital ecological processes, natural habitats and wild species throughout Namibia is maintained whilst significantly supporting national socio-economic development through sustainable low-impact, consumptive and non-consumptive uses, as well as providing diversity for rural and urban livelihoods."

The Harambee Prosperity Plan also states that "Debushing, as a strategy for increasing grazing land in order to improve productivity and create employment, will continue to be encouraged and supported."

This report builds on the framework developed by NNF in the *Assessment of the economics of land degradation related to bush encroachment in Namibia* (2016). Furthermore, it estimates the financial costs involved in unlocking the ecosystem service benefits and some of the wider economic impacts to build a business case for de-bushing.

1.2 Objectives

The key objectives of this study are:

- To establish a regional assessment of the economics of land degradation related to bush encroachment in Otjozondjupa with a specific focus on additional benefits from spin-off effects; and
- To contribute to the regional LDN pilot project and complement the IRLUP.

1.3 Structure

The report proceeds as follows:

- Section 2 provides a background to bush encroachment in Otjozondjupa and its effects;
- Section 3 presents the methodology used;
- Section 4 discusses the delineation and assessment of bush encroachment in Otjozondjupa;
- Section 5 identifies the ecosystem services impacted by bush encroachment;
- Sections 6 to 11 estimate the benefits and costs for various sectors impacted by de-bushing;
- Section 12 estimates the wider economic impacts of de-bushing;

- Section 13 details the cost-benefit analysis and its outcomes;
- Section 14 outlines some business cases;
- Section 15 provides policy recommendations; and
- Section 16 concludes.

2 Bush encroachment in Otjozondjupa

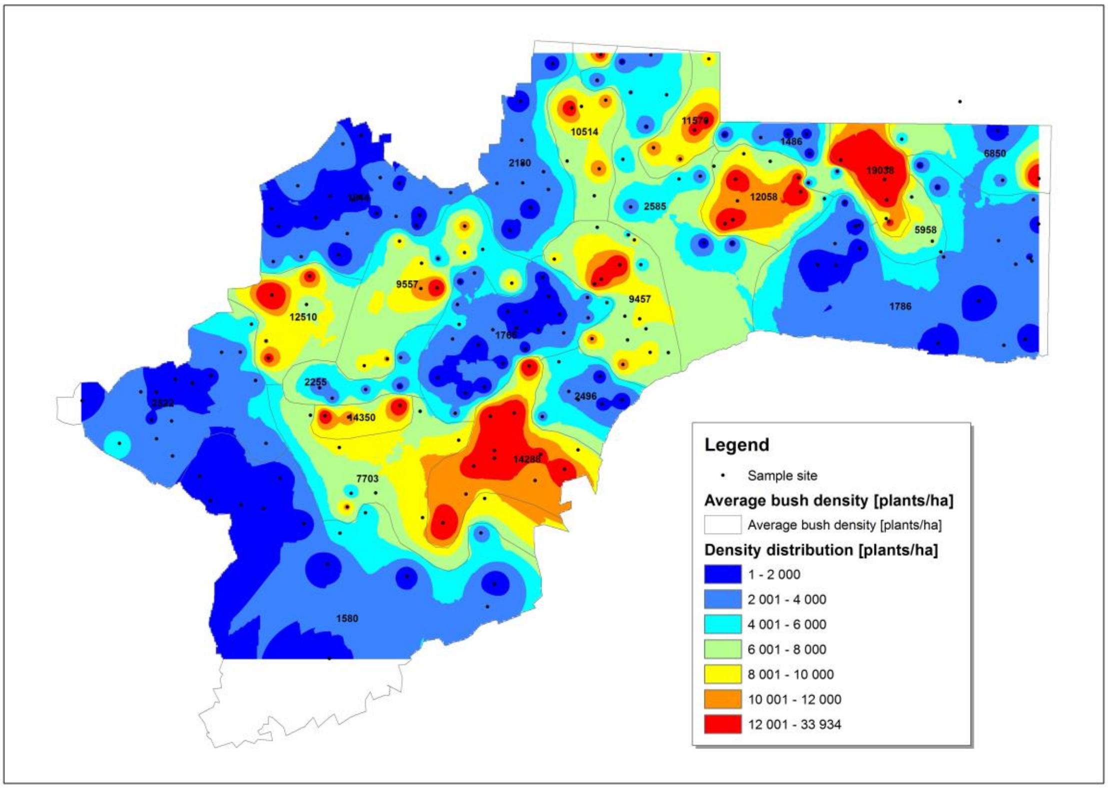
Bush encroachment is defined as “the invasion and/or thickening of aggressive undesired woody species resulting in an imbalance of the grass:bush ratio, a decrease in biodiversity, and a decrease in carrying capacity” (De Klerk 2004). It affects an estimated 45 million hectares of land in Namibia and is thought to affect the majority of Otjozondjupa’s 10.5 million hectares (SAIEA 2016, Hengari 2016).

The Land Degradation Neutrality (LDN) pilot project sampled almost 230 sites across Otjzondjupa in mid-2016, collecting data on soil and bush. It found that *Acacia mellifera* and *Terminalia cericea* are the dominant encroacher species in Otjozondjupa while Dichrostachys cinerea, Terminalia prunioides, and Acacia reficiens are more localised problems. The highest recorded density was over 25,000 bushes per hectare in the north-east of the region.

Hengari (2016) notes that livestock and game farming are major economic and job-creating industries in Otjozondjupa and that they are “constantly under threat from land degradation, especially by encroacher plant species”.

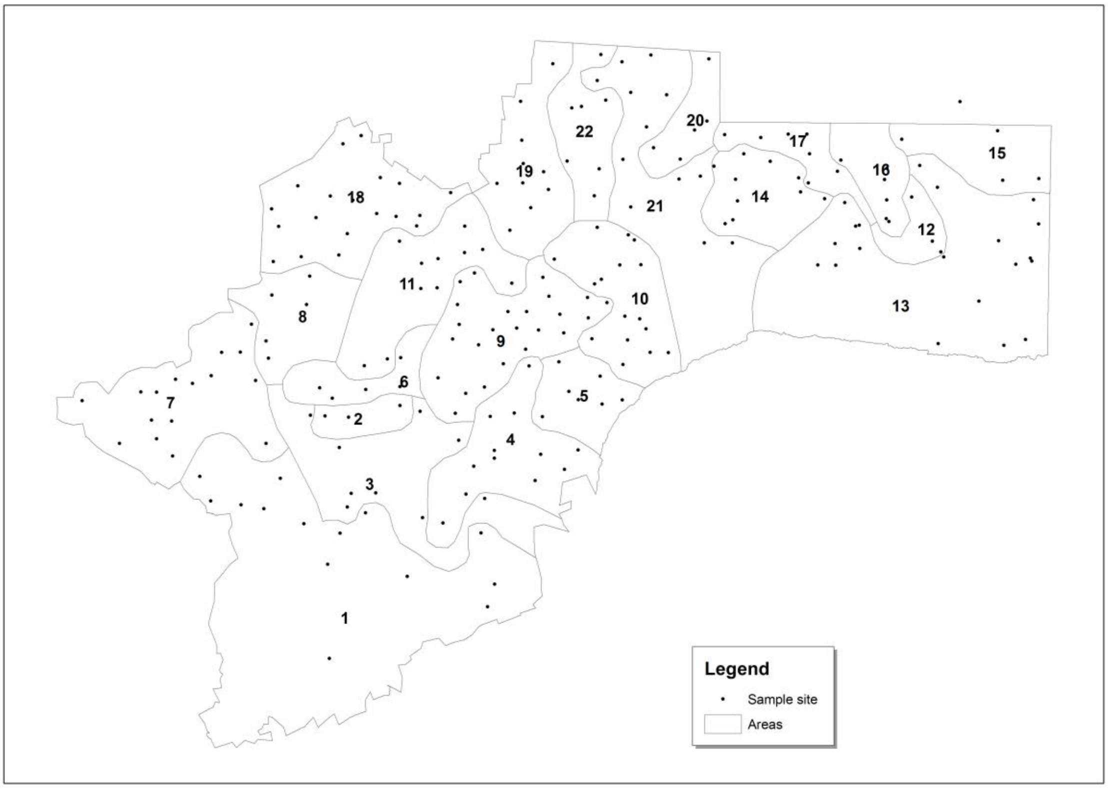
Figure 2.1 shows a heat map of density in Otjozondjupa using data collected by the Land Degradation Neutrality study in 2016 and processed by CIAT. Figure 2.2 shows how this data was grouped into 22 bush-encroached zones defined by location and average density.

Figure 2.1: Bush density in Otjozondjupa



Source: Katharina Dierkes, CIAT 2016

Figure 2.2: Bush encroached zones delineated by average bush density in Otjozondjupa



Source: Katharina Dierkes, CIAT 2016

Error! Not a valid bookmark self-reference. summarises the average bush density by height, the area, and the dominant species in each zone.

Table 2.1: Bush encroached zones in Otjozondjupa

Bush encroached zone	Dominant species	Area (ha)	Average density (bushes/ha)			
			Bush height			Total
			<1.5m	>1.5m, no main stem	>1.5m, main stem	
1	A. mellifera	1 856 773	888	586	107	**1 580**
2	A. mellifera	109 282	5 925	7 858	567	**14 350**
3	A. mellifera	620 177	3 711	3 817	175	**7 703**
4	A. mellifera	474 894	8 710	5 302	275	**14 288**
5	T. cericea	228 993	1 757	543	196	**2 496**
6	A. mellifera, D. cinerea	176 140	1 310	730	215	**2 255**
7	A. mellifera	680 335	1 916	491	116	**2 522**
8	T. prunioides	312 849	6 040	5 820	650	**12 510**
9	A. mellifera, T. cericea	548 916	1 002	476	286	**1 765**
10	A. mellifera, T. cericea	432 499	5 831	2 847	779	**9 457**
11	A. mellifera, T. prunioides	509 133	5 277	3 705	575	**9 557**
12	A. mellifera, T. cericea	110 477	4 200	1 583	175	**5 958**
13	T. cericea	1 258 116	1 223	456	108	**1 786**
14	T. cericea, A. mellifera	298 047	8 908	2 735	415	**12 058**
15	T. cericea, A. mellifera	271 529	5 306	1 244	300	**6 850**
16	T. cericea	185 472	12 917	5 654	467	**19 038**
17	T. cericea	175 155	875	546	64	**1 486**
18	D. cinerea, A. mellifera	600 779	1 234	489	121	**1 844**
19	A. mellifera	424 024	1 513	355	313	**2 180**
20	T. cericea	171 348	7 740	3 195	635	**11 570**
21	A. mellifera, T. cericea	799 614	1 890	542	154	**2 585**
22	A. mellifera	276 172	6 325	3 186	1 004	**10 514**

Source: LDN, CIAT

There are many interlinked factors contributing to bush encroachment, but overgrazing is thought to be one of the key drivers (Joubert and Zimmermann 2002). Overgrazing causes a decrease in the root base of grasses, reducing their competitiveness with regard to water and nutrient uptake and weakening their suppressive effect over emerging bushes. The additional water and nutrients left in the soil are then taken up by bushes, fuelling their growth at the expense of grass growth and recovery.

This can also happen when periods of drought, which reduce the grassy layer, are followed by periods of high rainfall. This creates very favourable conditions for woody plants to establish themselves in large numbers.

However, the relationship is complex and, depending on the area and nature of encroachment, other factors include:

- The displacement of browsers, such as kudu, by cattle or other grazing livestock, which puts extra pressure on the grassy component and relieves pressure on the woody plants which flourish
- Increased CO_2 concentrations in the atmosphere may also be encouraging the growth of woody species over grasses
- Rainfall – greater rainfall is associated with higher densities of bush
- The suppression of high-intensity fires, due to cattle farming, which would otherwise kill the seedlings and saplings of woody species (Joubert and Zimmermann 2002).

Whatever the underlying causes, the phenomenon of bush encroachment certainly impacts on ecosystem services and biodiversity, as discussed in Section 5. The national assessment found that de-bushing could benefit services such as livestock production, tourism, charcoal and firewood production, electricity generation, and, most particularly, groundwater. This supports the argument for an extensive programme of de-bushing, to reduce bush encroachment and try to reverse some of its negative impacts.

We define “de-bushing” as the *thinning* of encroacher bushes, by mechanical, manual, or chemical means, to reduce bush density and return the landscape towards the historically “natural” balance between bushes, trees, and grasses. De-bushing is not intended to mean the removal of all bushes or clearing of land (see 3.3.1).

The direct, environmental, and social costs are discussed and, where possible, quantified in Section **Error! Reference source not found.**. However, de-bushing is also likely to have some negative effects and resultant environmental costs. Mechanical means of de-bushing, such as bulldozing, can disrupt the soil and non-encroacher vegetation while chemical means, such as aerial arboricides, have the potential to poison non-target vegetation and water sources. As bushes are a carbon sink, de-bushing will decrease the amount of carbon sequestered in the soil as well as in the woody component. Furthermore, if cattle stocks are increased in response to de-bushing, this too would increase greenhouse gas emissions.

3 Methodology

The methodology used in this report broadly follows the 6+1 step approach of the Economics of Land Degradation (ELD) Initiative, which establishes a common methodological approach for conducting a robust cost-benefit analysis to inform decision-making processes. Some changes have been adopted in response to known data availability and other environmental economic approaches being promoted in Namibia (see

Figure 3.1). These variations from the general ELD approach should not impact the validity of the final product and if anything should further enhance the outcomes as being consistent with and relevant to the other environmental economics processes underway in Namibia.

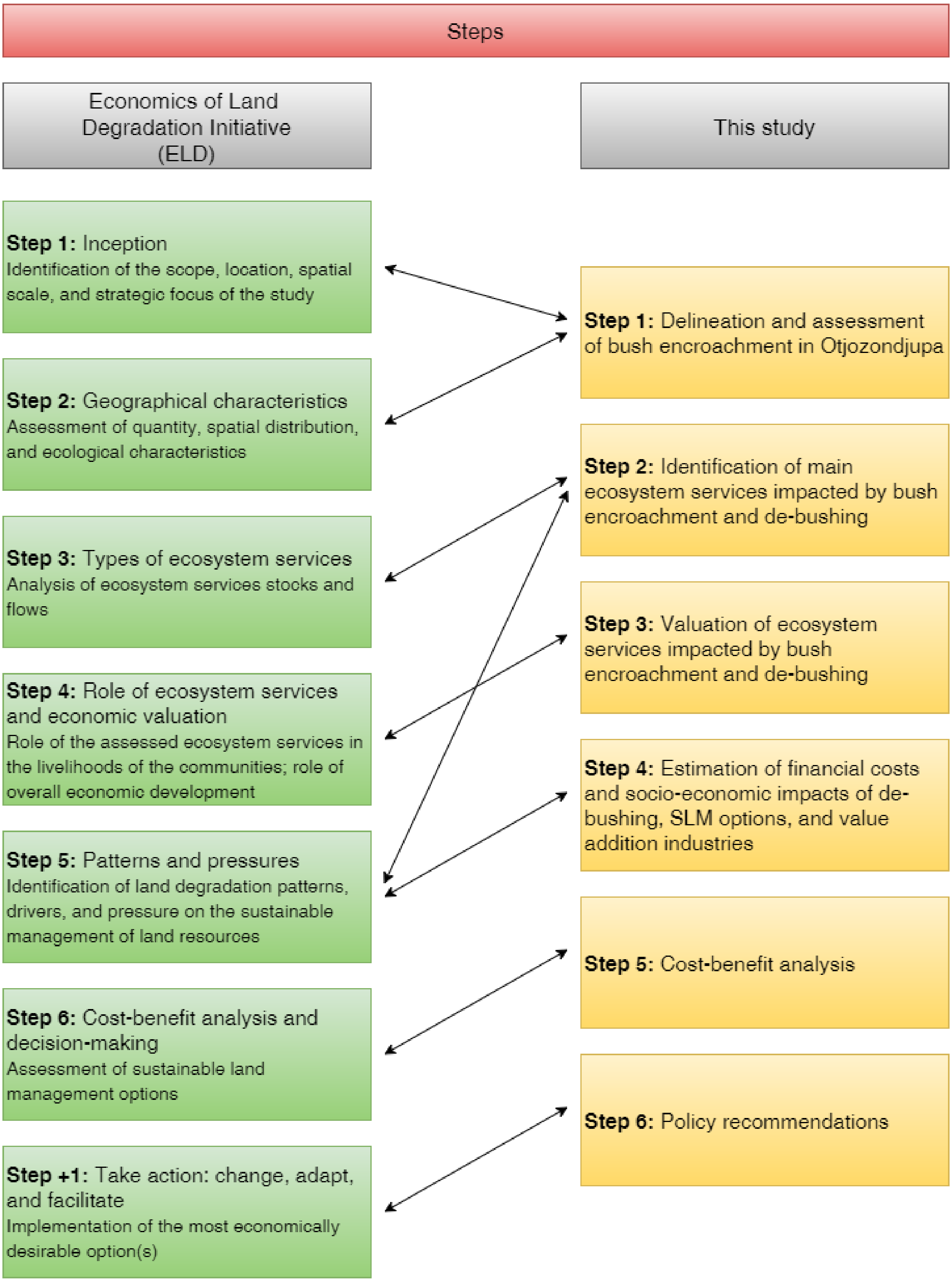
Limitations on the available data have prevented the analysis and valuation of several ecosystem services affected by bush encroachment and de-bushing. This report builds on the framework developed for the national assessment which highlights gaps and limitations that could be addressed through further work. This includes further natural resource economics work undertaken by the Ministry of Environment and Tourism (MET), with the Resource Mobilisation (ResMob) project, the ongoing work by the Ministry of Land Reform (MLR) in developing Integrated Regional Land-use Plans (IRLUP), the Land Degradation Neutrality (LDN) championed by the Sustainable Land Management Committee, and, of course, this project.

3.1 Delineation and assessment of bush encroachment in Otjozondjupa

This step effectively combines steps 1 and 2 of the ELD approach (see Section 4).

As bush encroachment only affects certain areas of Namibia, bush-encroached zones were mapped out in relation to ecological, social, utilisation, and political parameters, using GIS software. This spatial visualisation allowed for an analysis of existing data to determine the extent and symptoms of bush encroachment in relation to these key parameters.

Figure 3.1: Methodology for the ELD Initiative and this study



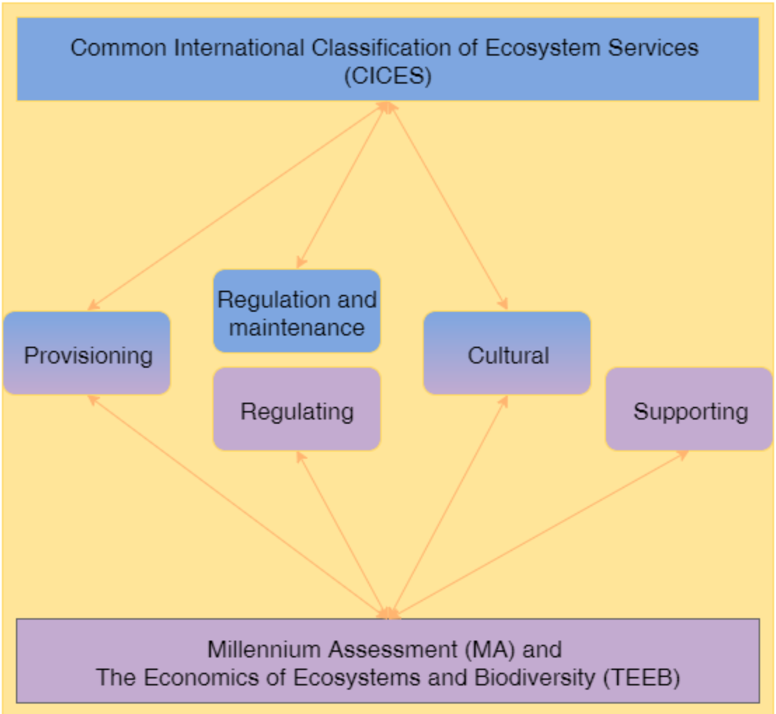
Source: NNF, ELD Initiative 2015

3.2 Identification of ecosystem services impacted by bush encroachment and de-bushing

This step effectively combines steps 3 and 5 of the ELD approach (see Section 5).

A literature review was conducted and expert knowledge used to understand the key types of ecosystem services affected by bush encroachment and assess the positive and negative impacts of bush encroachment and de-bushing across a range of these ecosystem services. This report adopts the Common International Classification of Ecosystem Services (CICES) classification (see Appendix I) in order to remain consistent with the draft Inventory of Ecosystem Services in Namibia (2015) and also the UN System of Environmental-Economic Accounting: Experimental Ecosystem Accounting (SEEA-EEA, 2014), which is being promoted by the MET-GIZ ResMob project in Namibia. The CICES classification recognises three categories of services: provisioning, regulation and maintenance, and cultural. This differs from the ELD Initiative which uses the Millennium Assessment (MA) and The Economics of Ecosystems and Biodiversity (TEEB) approach of recognising four categories of services: provisioning, regulating, cultural, and supporting.

Figure 3.2: Classification of ecosystem services – CICES, MA, and TEEB



Source: Pauline Lindeque

3.3 Valuation of ecosystem services impacted by bush encroachment and de-bushing

This step is effectively step 4 of the ELD approach (see Sections 6 to 11).

Where possible, the key ecosystem services affected by bush encroachment and de-bushing were quantified and valued. Monetary values were generated for livestock production, groundwater recharge, carbon sequestration, wildlife viewing, trophy hunting and game products, as well as a number of uses of the biomass for energy. However, many impacted ecosystem services were unable to be valued due to a lack of data and research.

Table 5.1, Table 5.2, and Table 5.3 present our assessments of the likely direction of change in ecosystem service values due to de-bushing. We believe that a large number of ecosystem services would benefit from de-bushing, which suggests that there is upside risk to our estimated net benefit.

The valuation framework focussed on market values, as most of the valued services were provisioning services. An avoided cost approach was taken for groundwater recharge and for biomass power for industry. Changes in carbon sequestered were valued using an estimate for the offset value in Namibia (in the absence of a market) as well as the Social Cost of Carbon (SCC). Option values were used to estimate the value of the increase in the stocks of game and cattle.

3.3.1 Key assumptions

Below are listed some key assumptions for this study, which are consistently held throughout the analysis.

- **60% (more than 6.3 million hectares) of the identified bush-encroached land to be de-bushed.**

- **90% of encroacher bushes to be de-bushed, leaving 10% of the current density. Non-encroacher species to be left untouched.**

  A rule of thumb for estimating optimal bush density is:

  > "The number of tree equivalents per hectare should not exceed twice the long-term average rainfall (mm). A tree equivalent (TE) is defined as a tree (shrub) of 1.5 m in height. Thus, a 3-m shrub would represent 2 TE, a 4.5-m shrub 3 TE, etc. Land should, therefore, never be completely cleared." (de Klerk 2004, Smit 2004)

  As the data on bush encroachment used in this study reports density in bushes per hectare as either less than 1.5m or more than 1.5m with or without main stem, we were unable to apply this relationship and instead relied on other relevant literature and anecdotal evidence. Instead we took N-BiG's recommendation of reducing the density of encroacher species by 90%, leaving 10% according to environmental management practices. This would result in an overall reduction of 38.5% of the current bush density. A 38.5% reduction is in line with Smit et. al.'s (2015) suggestion that only 30-35% of total available biomass should be harvested.

- **5% of the targeted bush-encroached land to be de-bushed per annum**
  This would be equivalent to around 316,000ha being de-bushed per annum. The initial round of de-bushing (i.e. disregarding any follow up or aftercare) would therefore be carried out over a period of 20 years, with the effects being captured over one 25 year period.

3.4 Estimation of financial costs and socioeconomic impacts of de-bushing, SLM options, and value addition industries

This step is effectively step 5 of the ELD approach (see Sections 6 to 12).

3.4.1 Direct costs of de-bushing

N-BiG provided their expertise with regard to de-bushing operations. They used the data from the LDN project to determine the appropriate type of de-bushing for each bush-encroached zone (large-scale mechanical, small-to-medium-scale mechanical, semi-mechanical and manual, and arboricides) and estimate the capacity, capex, and opex for each operation. They also provided estimates of the harvested biomass based on species, size, and density.

3.4.2 Investment, operating, and maintenance costs

These costs were largely obtained from reports (published and unpublished) from the NAU, NCA, WSP (2012), from personal communication with cattle and game farmers, animal feed producers, NamWater, N-BiG, and from material produced for the GIZ/MAWF Support to De-bushing project.

3.4.3 Socioeconomic impacts

Labour costs form part of the operating costs for each sector. The additions to household income (and jobs) were calculated and then an economic formula used to estimate the wider impacts on the Namibian economy (see Section 12).

3.5 Cost Benefit Analysis

This step is effectively step 6 of the ELD approach (see Section 13).

This is where the costs and benefits for each sector were weighed against each other to determine the overall net benefit of a comprehensive de-bushing programme. The benefits of increased stocks of cattle and game and the wider economic benefits of additional employment and household income were also included here.

Further assumptions and decisions had to be made for the cost-benefit analysis.

3.5.1 Time horizon

A time horizon of 25 years was chosen. This captures the 20 years spent on the initial de-bushing (i.e. without follow ups or aftercare) and allows time for ecosystem services, such as livestock production and groundwater recharge, to reach their new potential.

3.5.2 Prices

Real prices in Namibian dollars (base year 2015) were used. Prices were generally held constant (in real terms) across the entire time horizon. The exception was the Social Cost of Carbon (SCC), which escalated each year, as it has been forecasted by the US government.

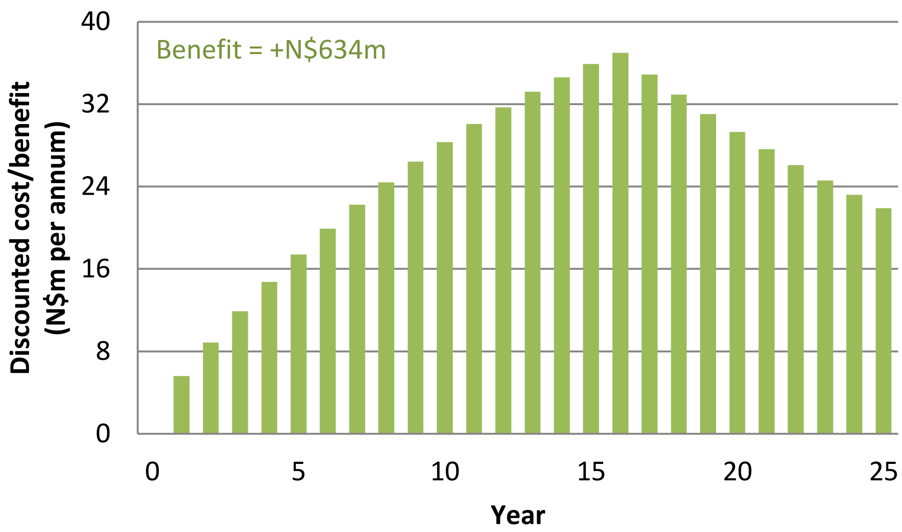
3.5.3 Discount rate

The costs and benefits calculated must be discounted because it is generally accepted that their values in the future are worth less than the same amount today. This reflects the opportunity cost of resources (i.e. money could be invested today to reap a return in the future) and people's time preference (the general preference is to consume resources sooner rather than later) (Boardman et. al., 2014).

As real prices were used in the calculations, a real discount rate had to be used (rather than a nominal rate). In the central case, a real discount rate of 6% per annum was used. This was based on the real discount rate used in the Wildlife Resource Accounts of Namibia, 2004 (2009).

Chart 3.1 (same as Chart 11.4) illustrates the effect of discounting. Although additional firewood production plateaus at around 53,500 tonnes per annum from Year 16 until Year 25, the annual benefits decline over the same period. This is because the same real monetary benefits are valued less the further into the future they are.

Chart 3.1: Benefit of increased firewood production



Example
If you were offered $100 today or $100 in one year's time, which would you take?
If you took the $100 today and invested it in the bank at an interest rate of 10%, in one year's time you would have $110. So the **present value** of $110 in one year's time is $100.
This is why we need to discount future values – so that we can compare intertemporal costs and benefits.

3.5.4 Sensitivity analysis

Sensitivity analysis involves changing key assumptions and variables to ascertain how they would affect the final outcome (see Section 13). One of the most important variables to undergo sensitivity analysis is the discount rate, as the choice of rate can be quite subjective and it can significantly impact the final outcome. In this case, net benefits tend to decrease as the discount rate rises because the benefits of de-bushing tend to be weighted towards the middle and end of the time horizon and are consequently more heavily discounted.

3.6 Key limitations

We assume that bush encroachment would remain constant in a BAU case, but it is actually projected to be increasing by around 3.18% per annum[1]. This means there is upside to the positive impacts on ecosystem services and value addition industries, which rely on supply of biomass, but it also means that there is upside to the cost of de-bushing operations.

One of the key limitations of this study is the deficiency of data and knowledge on how ecosystem services are affected by bush encroachment and de-bushing. For example, the uncertainty regarding the impact on groundwater recharge rates is of particular concern as an increase in the sustainable supply of groundwater would be very beneficial for Namibia. As such, further research in this area would undoubtedly improve the accuracy of these estimates.

Furthermore, data on ecosystem service values, particularly in the Namibian context, is lacking, preventing many impacted services from being valued. Even a benefit transfer approach, drawing estimates from other studies, was constrained as there is very little research in the public domain on this subject.

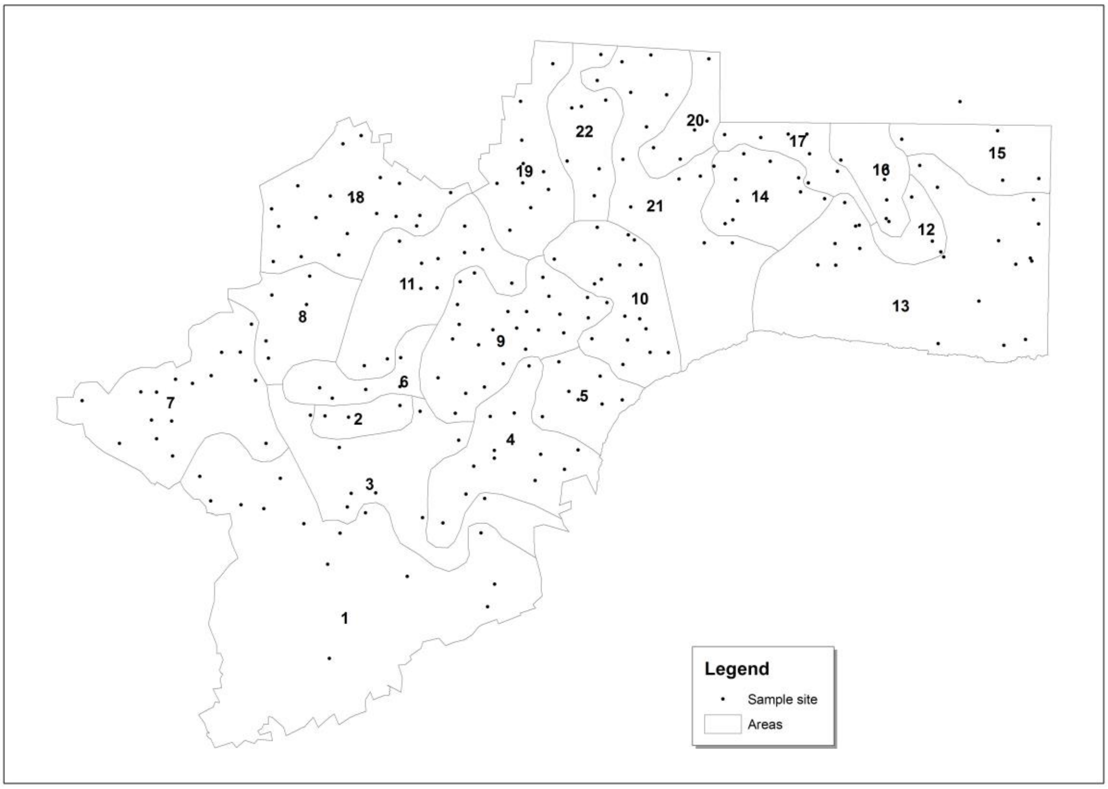
Specific data constraints, assumptions, and limitations and risks for each sector/ecosystem service are detailed in Sections 6 to 12.

[1] N-BiG, pers. comm.

4 Delineation and assessment of bush encroachment in Otjozondjupa

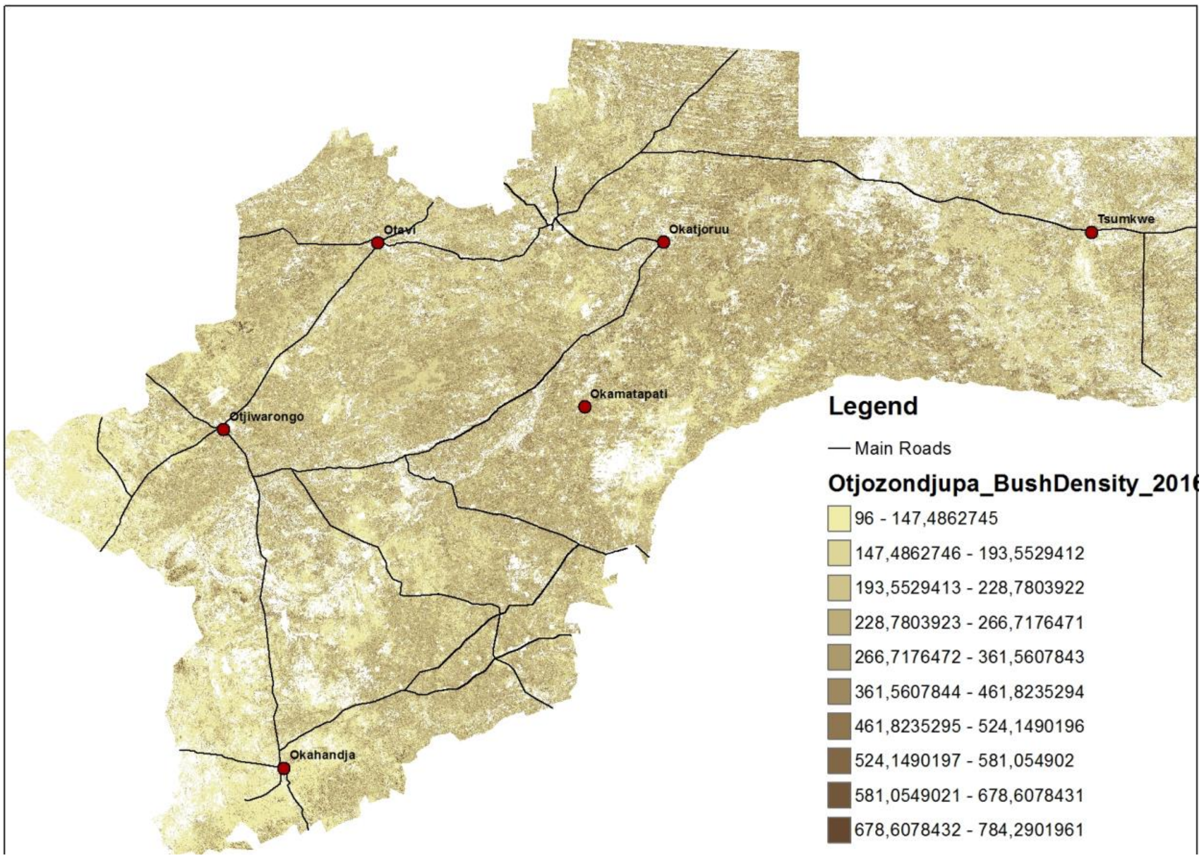
Bush encroachment affects the majority of Otjozondjupa, impacting multiple ecosystems and land uses across the region. This makes it a complex problem, as impacts can vary depending on the surrounding environment (e.g. types of soil, other vegetation, wildlife), how the land is and could be used (e.g. cattle farming, tourism), and how many people depend on the land.

Figure 4.1: Bush encroachment in Otjozondjupa



Source: Katharina Dierkes, CIAT 2016

Figure 4.2: Bush density in Otjozondjupa



Source: CIAT 2016

Table 4.1: Bush encroached zones in Otjozondjupa

Bush encroached zone	Dominant species	Area (ha)	Average density (bushes/ha)			
			Bush height			Total
			<1.5m	>1.5m, no main stem	>1.5m, main stem	
1	A. mellifera	1 856 773	888	586	107	**1 580**
2	A. mellifera	109 282	5 925	7 858	567	**14 350**
3	A. mellifera	620 177	3 711	3 817	175	**7 703**
4	A. mellifera	474 894	8 710	5 302	275	**14 288**
5	T. cericea	228 993	1 757	543	196	**2 496**
6	A. mellifera, D. cinerea	176 140	1 310	730	215	**2 255**
7	A. mellifera	680 335	1 916	491	116	**2 522**
8	T. prunioides	312 849	6 040	5 820	650	**12 510**
9	A. mellifera, T. cericea	548 916	1 002	476	286	**1 765**
10	A. mellifera, T. cericea	432 499	5 831	2 847	779	**9 457**
11	A. mellifera, T. prunioides	509 133	5 277	3 705	575	**9 557**
12	A. mellifera, T. cericea	110 477	4 200	1 583	175	**5 958**
13	T. cericea	1 258 116	1 223	456	108	**1 786**
14	T. cericea, A. mellifera	298 047	8 908	2 735	415	**12 058**
15	T. cericea, A. mellifera	271 529	5 306	1 244	300	**6 850**
16	T. cericea	185 472	12 917	5 654	467	**19 038**
17	T. cericea	175 155	875	546	64	**1 486**
18	D. cinerea, A. mellifera	600 779	1 234	489	121	**1 844**
19	A. mellifera	424 024	1 513	355	313	**2 180**
20	T. cericea	171 348	7 740	3 195	635	**11 570**
21	A. mellifera, T. cericea	799 614	1 890	542	154	**2 585**
22	A. mellifera	276 172	6 325	3 186	1 004	**10 514**

Source: LDN, CIAT

Furthermore, the appropriate method, range, and scope of de-bushing activities are also dependent on the local context. For example:

- large-scale mechanical harvesting methods would likely degrade more arid, fragile soils, where small-scale methods would be more suitable
- arboricides may have detrimental effects when used on sandier soils, where the chemicals can be more mobile and be transmitted to non-encroacher bushes and trees or pollute water bodies
- harvesting may not be economically viable in the more remote areas as yet, due to current harvesting inefficiencies.

4.1 Ecosystems

Bush encroachment affects multiple ecosystems within Otjozondjupa, including the Highland Acacia Savanna, Northern Kalahari Savanna, Karstveld, Dry Kalahari Woodlands, and small parts of the Western Highlands, as shown in Figure 4.3 (Harper-Simmonds et. al., 2016). There are also a number of urban ecosystem zones within the region, including Okahandja, Otjiwarongo, Okakarara, Otavi, and Grootfontein.

The *Development of an Inventory of Ecosystem Services in Namibia* was referred to in establishing the presence and influence of bush encroachment in each of the identified ecosystems in Namibia (Harper-Simmonds et. al., 2016). In all of these ecosystems, the effects of climate change may be realised through increased rates of bush encroachment as a result of increased carbon dioxide concentrations, but there is considerable uncertainty around this.

4.1.1 Highland Acacia Savanna

Overgrazing has reduced grass cover and available pasture, and fire control and prevention measures have reduced the frequency and intensity of bush fires in this ecosystem. This, in turn, has led to increased bush encroachment, which would otherwise be moderated by hot fires killing off small bushes, further reducing available pasture. The conversion of farms into resettlement farms[2] has also affected the use of the land, the availability of pasture and the incidence of overgrazing, and may limit incentives and capacity to invest in measures to combat bush encroachment.

The reduced grass cover has led to increased surface runoff, which after heavy rains can be particularly rapid and result in soil erosion. Conversely, slower flows that had been sustained by seepage have declined because of reduced rainfall infiltration.

4.1.2 Northern Kalahari Woodlands

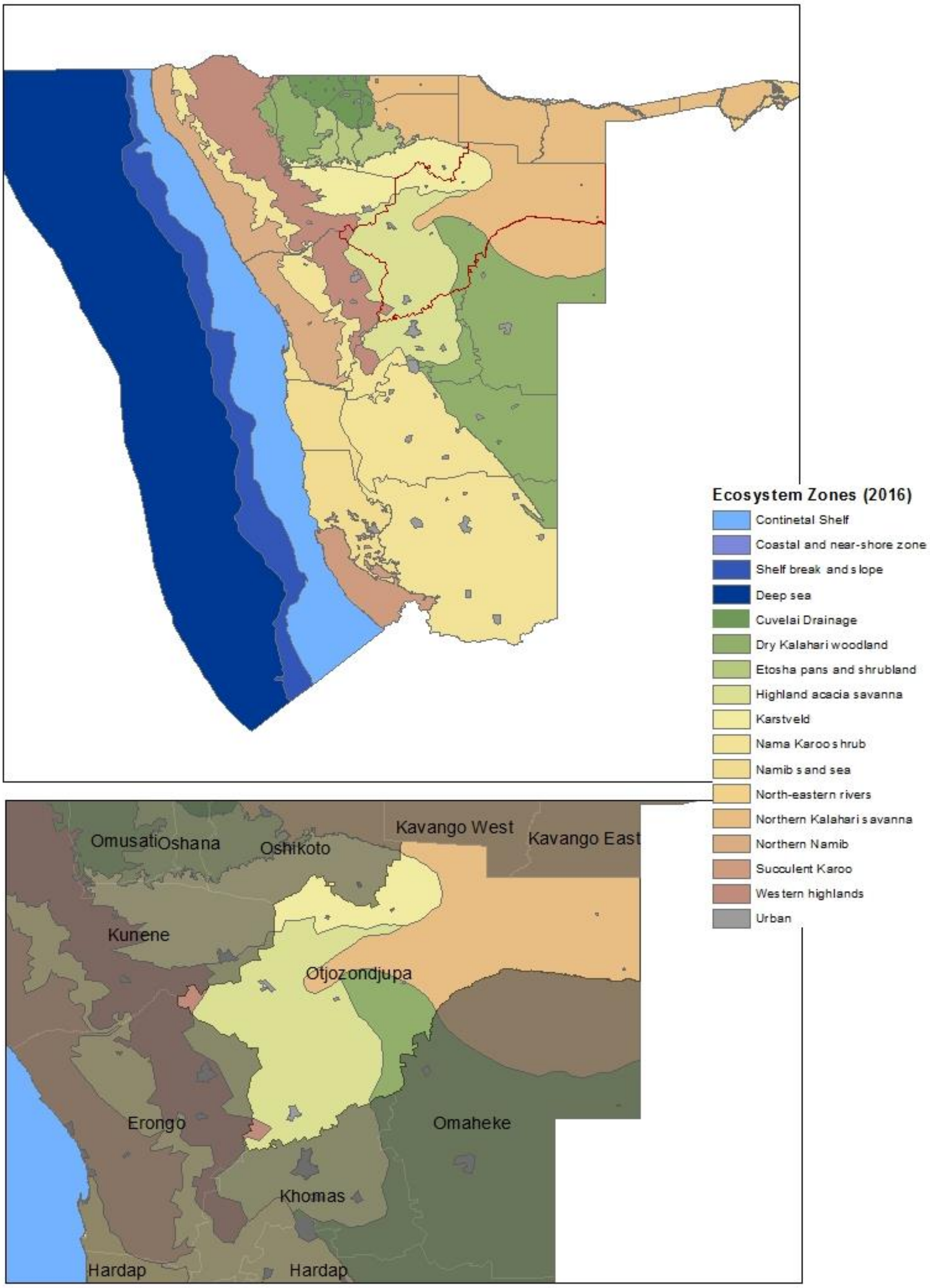
This zone experiences the same drivers of and results from bush encroachment as the Highland Acacia Savanna, Karstveld, and Dry Kalahari Woodlands.

4.1.3 Karstveld

As in the Highland Acacia Savanna zone, overgrazing and fire control and prevention measures have led to increased bush encroachment. This, is turn, has resulted in increased surface runoff and soil erosion in some areas, and reduced groundwater recharge. The conversion of farms into resettlement farms may limit incentives to invest in measures to combat bush encroachment. They are generally smaller in size, so lack economies of scale that larger farms have. There is also still some uncertainty surrounding ownership, which acts to disincentivise investment and maintenance, negatively affecting productivity.

[2] Resettlement is a “willing buyer, willing seller” scheme whereby farms are acquired, usually split up into smaller plots, and then allocated to previously disadvantaged Namibians.

Figure 4.3: Bush encroachment and ecosystems in Otjozondjupa



Source: Harper-Simmonds et. al. 2016, ELD

4.1.4 Dry Kalahari Woodlands

As in the Highland Acacia Savanna, Karstveld, and Northern Kalahari Woodlands, habitat change has occurred primarily as a result of overgrazing, driving bush encroachment and impacting services such as groundwater recharge.

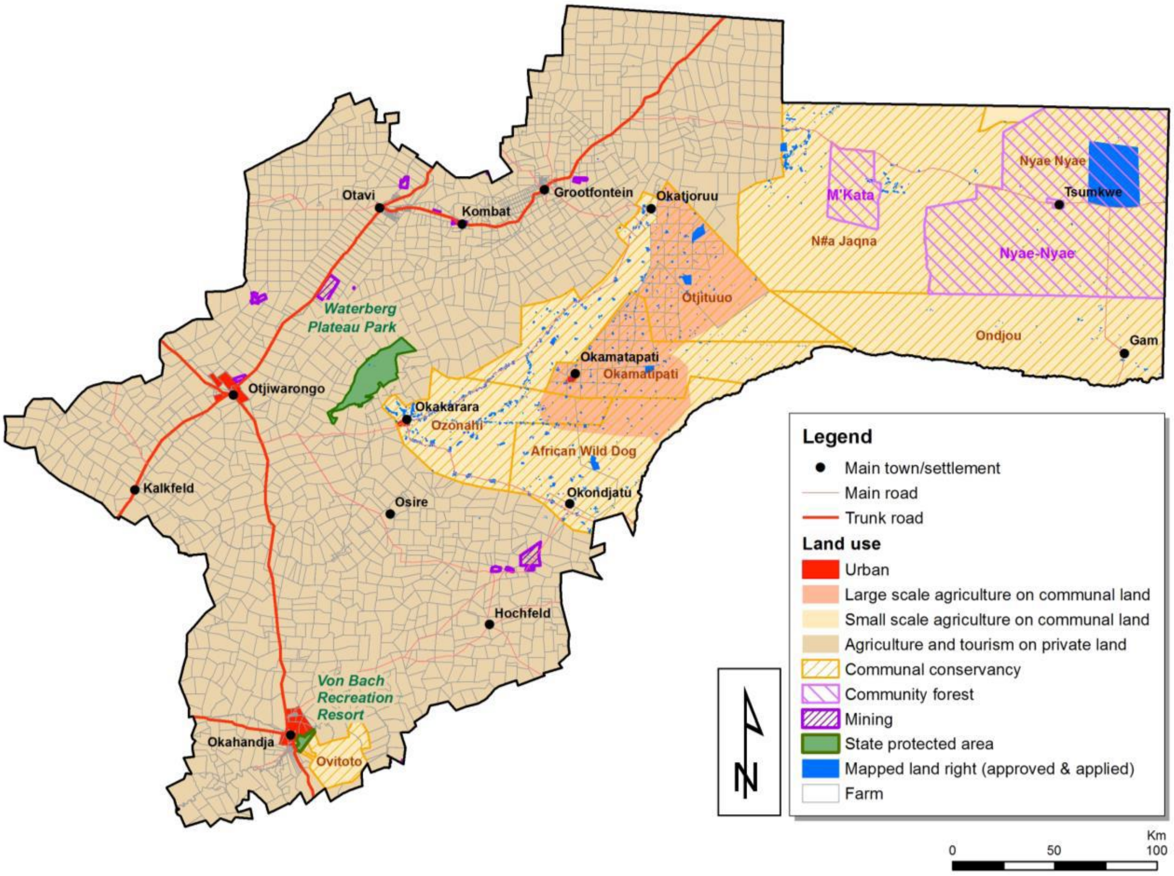
4.1.5 Western Highlands

As in many of the ecosystems described in this section, overgrazing is a significant issue, which has led to bush encroachment, land degradation, and a reduction in the productivity of pastures.

4.2 Land use

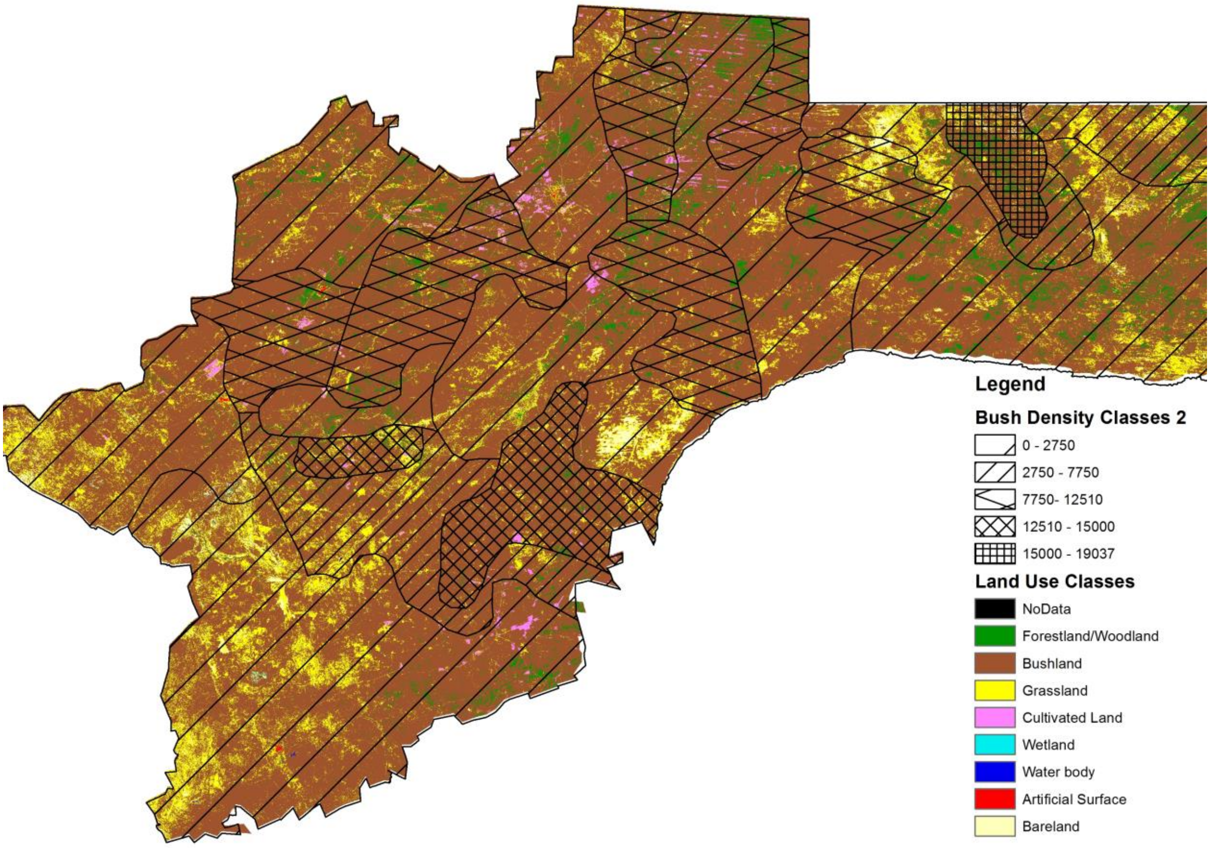
Bush encroachment is overwhelmingly a problem for commercial and communal agriculture, both large- and small-scale (see Figure 4.6). It also impacts tourism, such as game viewing and hunting, and affects some state-protected areas, most notably, Waterberg Plateau National Park.

Figure 4.4: Land use in Otjozondjupa



Source: Urban Dynamic

Figure 4.5: Land use classes in Otjozondjupa



Source: LDN, CIAT, ELD, Katharina Dierkes

4.2.1 Livestock farming

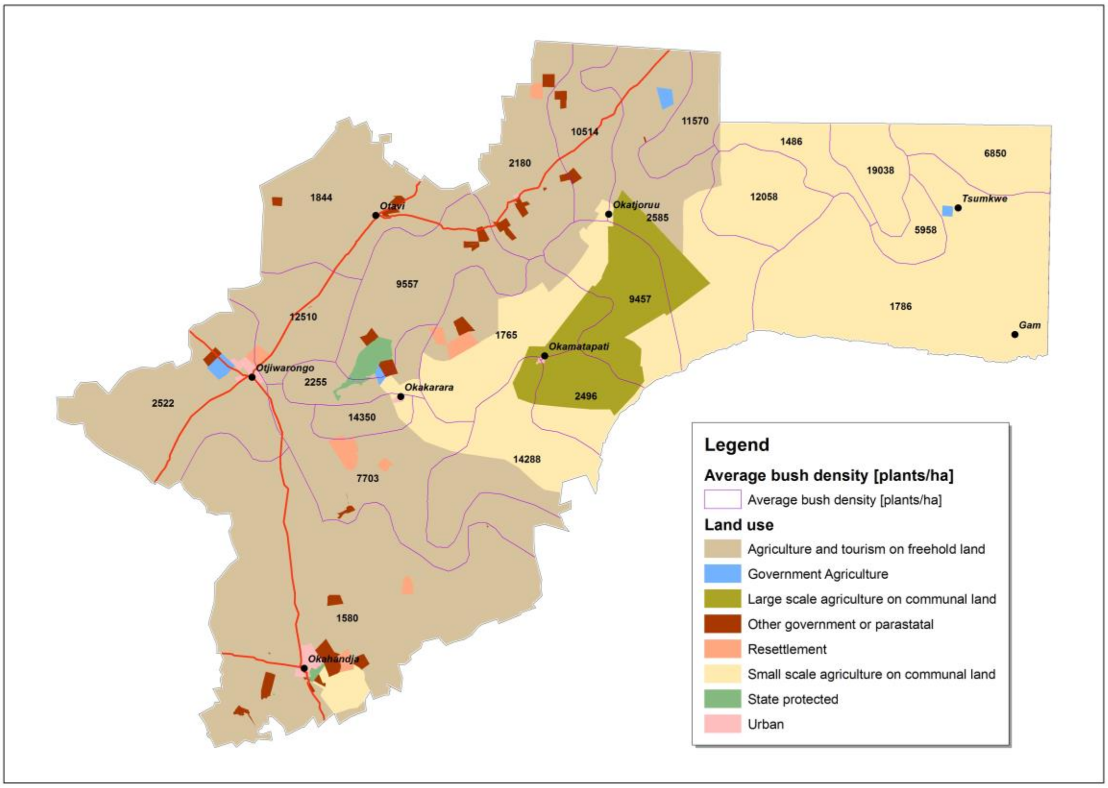
In terms of agriculture, bush encroachment mainly affects livestock farming (cultivation generally requires that the land is cleared, whether bush encroached or not). As discussed in Section 2, overgrazing, particularly by cattle, is a key contributor to bush encroachment, so it comes as no surprise that bush encroachment is concentrated in areas of livestock farming.

Bush encroachment reduces available pasture land for livestock, particularly cattle, but also sheep and other livestock. It does this by restricting access for livestock and by reducing grass cover used for feed. There is a vicious cycle of reduced grass cover resulting in greater pressure on remaining grass cover, contributing to higher encroachment rates and further reducing grass cover.

Livestock carrying capacities have been drastically reduced to the detriment of farmer incomes and profits. This has also compromised food security and nutrition, particularly in communal areas. Cattle farming, in particular, is a traditional way of life for many peoples in Namibia. In addition to its economic value, it has cultural, heritage, and symbolic value. These values have all been undermined by bush encroachment.

However, it must be noted that overgrazing, particularly by cattle, is a key contributor to bush encroachment. Therefore, if a de-bushing programme is implemented, good rangeland management practices must be followed to prevent future/repeat bush encroachment. This may mean that stocks should not be built back up to the numbers seen prior to significant bush encroachment or that more suitable grazing strategies, which do not weaken grass systems over time, should be selected.

Figure 4.6: Bush encroachment and land use in Otjozondjupa



Source: Katharina Dierkes, CIAT 2016

4.2.2 Game farming

This includes non-consumptive services, such as wildlife viewing, and consumptive services, such as trophy hunting and game products such as meat.

Bush encroachment can have conflicting impacts on game. On the downside, it may reduce available land for wildlife, or push out certain species, but on the upside, it may encourage some farmers to replace cattle and other domesticated animals with game. Furthermore, browsers (e.g. goats, kudu, eland, dik dik, black rhino) can actually benefit from a certain degree of bush encroachment, which expands their food source. However, if bush is too dense and dominant, this could disadvantage browsers by restricting movement and access and reducing the variety of their food.

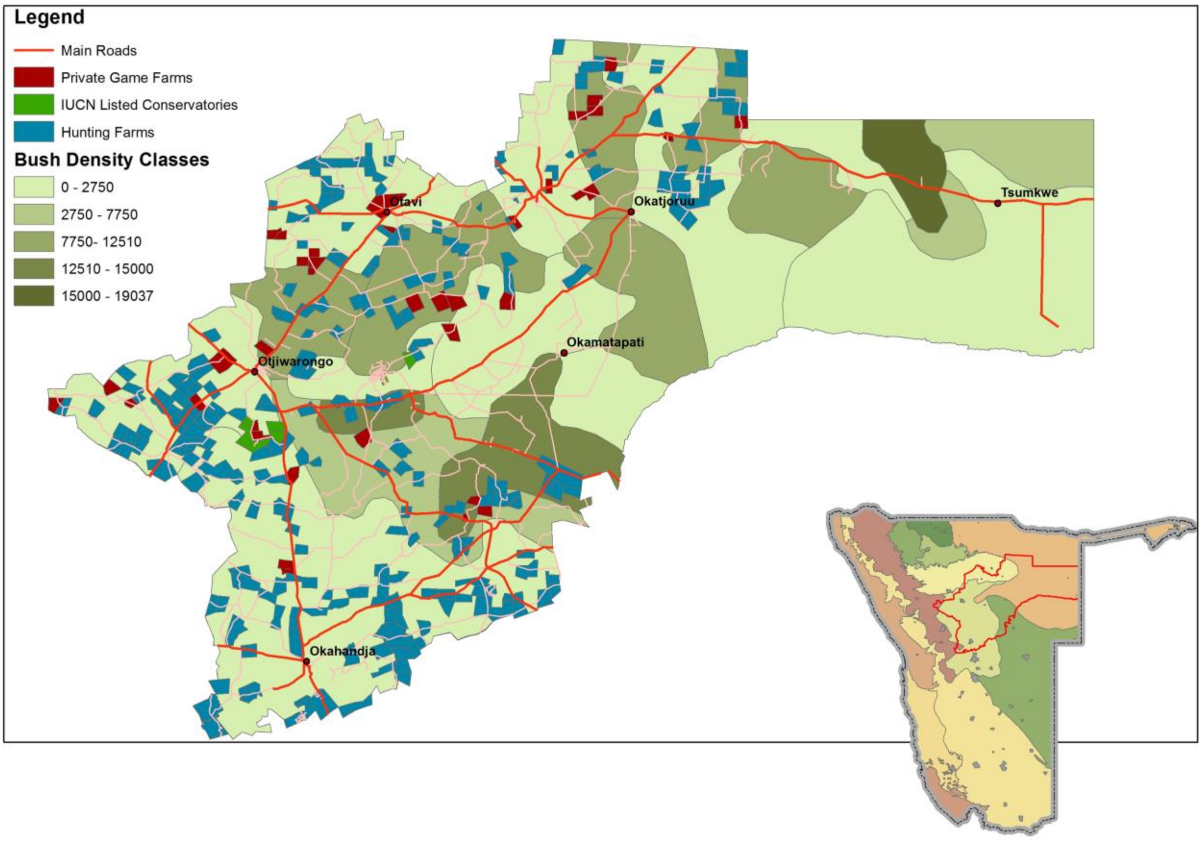
Dense bush can undermine wildlife viewing, hunting, other activities such as hiking, and landscape appreciation by reducing the opportunity and success rates for viewing or hunting, decreasing the diversity of species, and reducing the enjoyment that individuals gain from viewing wide, open landscapes which are symbolic of Namibia. This may result in fewer visitors, lower satisfaction levels, and less revenue.

From our conversations with game farmers, it became apparent that for wildlife viewing, the greatest benefit of de-bushing is that it makes animals easier to see for tourists, increasing success rates and satisfaction.

Our communication with game farmers and the NAU suggests that for consumptive purposes, de-bushing can increase the carrying capacity of game, allowing the sustainable offtake to rise and increasing revenue.

Figure 4.7 shows the location of private game farms, registered hunting farms, and IUCN-listed protected areas in Otjozondjupa. A private game farm has to be gazetted and by definition is a farm that is under conservation management, but does not allow commercial hunting. Hunting farms must be registered in order for commercial hunting operations to be permitted on the land. However, there are some issues with the data – some farms are classified as both a private game farm and a hunting farm, which should be impossible.

Figure 4.7: Private game farms, hunting farms, and IUCN-listed areas in Otjozondjupa



Source: Katharina Dierkes, ELD, CIAT 2016

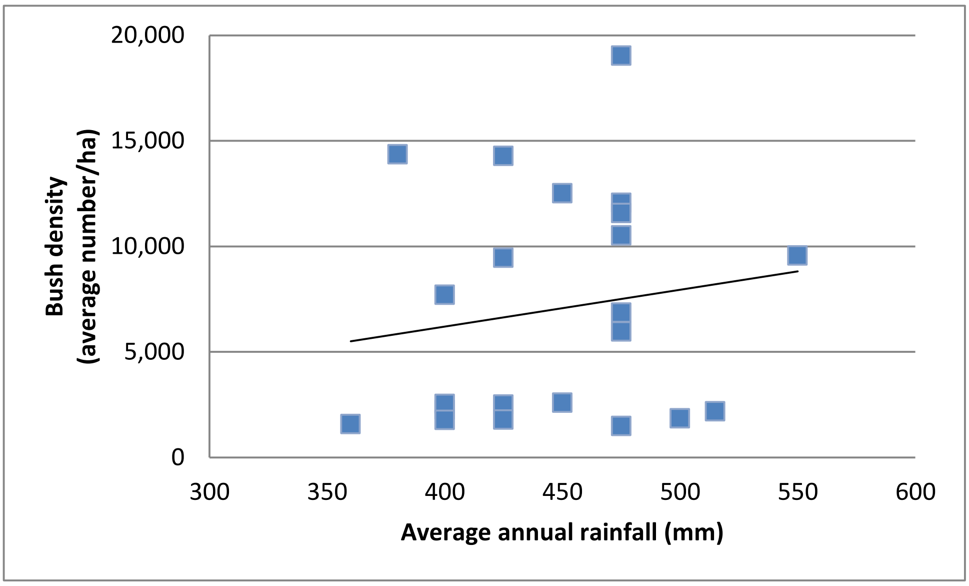
4.3 Rainfall and groundwater

Bush density tends to be higher in areas of greater rainfall. Higher volumes of water available for uptake by bushes support greater numbers and growth, particularly when grasses have been compromised by overgrazing and drought, reducing competition for water.

In Otjozondjupa, average annual rainfall varies from 360mm to 550mm, with an average across the entire region of 432mm. This is a much smaller band than the variance in average rainfall across Namibia (between 0mm and 600+mm per annum) so the relationship between rainfall and bush density is less pronounced (see

Figure 4.8).

Figure 4.8: Bush encroachment and rainfall in Otjozondjupa



Source: NNF, Atlas of Namibia

Rainfall directly affects groundwater recharge. It is estimated that 10.45Mm^3 of groundwater can be sustainably extracted using NamWater infrastructure in Otjozondjupa presently (see Section 8).

5 Identification of ecosystem services impacted by bush encroachment and de-bushing

This section reviews the potential impacts of bush encroachment on ecosystems and their services. This report adopts the Common International Classification of Ecosystem Services (CICES) classification (see Appendix I) in order to remain consistent with the *Development of an Inventory of Ecosystem Services in Namibia* (2016) and also the UN System of Environmental-Economic Accounting: Experimental Ecosystem Accounting (SEEA-EEA, 2014). The CICES classification recognises three categories of services: provisioning, regulation and maintenance, and cultural.

Bush encroachment is manifested largely through habitat change. As discussed in Section 2, overgrazing, the suppression of fires, and the displacement of browsers, all largely due to livestock farming, are key drivers of bush encroachment. Furthermore, climate change could be exacerbating bush encroachment via increased concentrations of carbon dioxide in the atmosphere, but there is significant uncertainty surrounding this.

The following tables outline the relevance of bush encroachment to each ecosystem service (i.e. how much the service is affected) and the likely direction of change in the service due to de-bushing. For many ecosystem services, there is little data or research on how they might be impacted by de-bushing. A more detailed discussion on the expected changes and how these may be valued can be found in Appendix II.

5.1 Provisioning

Provisioning services are "all nutritional, material and energetic outputs from living systems" (Haines-Young and Potschin 2013).

Table 5.1: Provisioning ecosystem services – impacts of de-bushing

Relevance	Ecosystem service class	Examples	Estimated direction of impact from de-bushing	Notes
High	Reared animals and their outputs	Meat and dairy products, cattle as capital	+	See Section 9
High	Groundwater for drinking and non-drinking purposes	Drinking water, water for domestic, agricultural, mining, wildlife use etc. from aquifers	+	See Section 8
High	Plant-based resources	Wood fuel, charcoal	+	See Section 11
High	Wild animals and their outputs	Game meat	+/-	See Section 10

High	Fibres and other materials for direct use or processing	Skins, horns, and trophies from livestock and wildlife, wool from sheep, materials for construction (e.g. timber, thatch grass), INPs (e.g. Devil's Claw)	+	See Sections 10, 11
High	Materials for agricultural use	Fodder, animal feed supplement	+	See Section 11
Medium	Cultivated crops	Maize, other cereals, vegetables, etc.	+	Only relevant over a limited area. Would require complete clearing. Crop farming on de-bushed land could reduce valuation of meat production.
Medium	Wild plants, algae and their outputs	Wild fruits	+	Only likely up to a point, after which the impact may be negative. Only relevant over a limited area. Valuation requires further research.
Medium	Surface water for drinking and non-drinking uses	Drinking water, water for domestic and industry use from dams	+/-	Depends on use of de-bushed land. Valuation requires further research.
Low/none	Animal-based resources	Donkeys for transporting people and goods	+	Only limited relevance, significant lack of data.

5.2 Regulation and Maintenance

Regulation and maintenance services "cover all the ways in which living organisms can mediate or moderate the ambient environment that affects human performance" (Haines-Young and Potschin 2013).

Table 5.2: Regulation and maintenance ecosystem services – impacts of de-bushing

Relevance	Ecosystem service class	Examples	Estimated direction of impact from de-bushing	Notes
High	Global climate regulation by reduction of greenhouse gas concentrations	Carbon sequestration	-	See Sections 7, 9, 11
High	Mass stabilisation and control of erosion rates	Control of soil erosion	+	Depends on the method of de-bushing. If positive impact, improved overall soil quality captures to large extent in meat production from livestock farming.

High	Buffering and attenuation of mass flows	Buffering of mass flows	+	Impact depends on location and nearby population and uses of the land. Avoided damages may be option for valuation if relevant. Further research needed.
High	Hydrological cycle and water flow maintenance	Groundwater recharge	+	Primarily captured by the valuation for groundwater recharge.
High	Maintaining nursery populations and habitats	Habitats for species	+/-	Conflicting impacts based on species. Value could be reflected in part by tourism services (experiential and physical use), and other cultural services (e.g. bequest and existence).
High	Weathering Processes	Restoration of soils	+	Impact of soil and grassland restoration largely captured by valuation of meat production.
High	Decomposition and fixing processes	Nitrogen fixing and nutrient replenishment	+/-	Depends on species of bush and extent of de-bushing. Potential positive impacts largely captured by valuation of meat production.
Medium	Ventilation and transpiration	Vegetation enabling air ventilation	-	Further research needed. Location dependent, as varies with local populations.
Medium	Chemical condition of freshwaters	Condition of water in rivers and dams	+/-	Depends on location and use of land after de-bushing. Some overlap with provisioning services relating to surface water.
Low/none	Mediation of smell/noise/visual impacts	Screening of transport corridors	-	Impact depends on location and population density. Valuation requires further research.
Low/none	Flood protection	Flood protection along rivers	-	Location dependent. Further research needed. Avoided damages may be option for valuation.
Low/none	Storm protection	Storm protection	-	Location dependent. Further research needed.
Low/none	Pollination and seed dispersal	Pollination	+/-	Further research needed. Location dependent. Interactions with other services relating to crops and livestock.
Unknown	Bio-remediation by micro-organisms, algae, plants and animals	Detoxification, decomposition and mineralisation	Unknown	Further research needed.

Unknown	Filtration / sequestration / storage / accumulation by micro-organisms, algae, plants and animals	Filtration and sequestration of pollutants in soil	Unknown	Further research needed. May depend on how bush is cleared, and what the alternative use of the land would be.
Unknown	Filtration / sequestration / storage / accumulation by ecosystems	Absorption of pollutants etc.	Unknown	Further research needed.
Unknown	Dilution by atmosphere, freshwater and marine ecosystems	Dilution of gases in atmosphere	Unknown	Further research needed.
Unknown	Pest control	Pest control	Unknown	Further research needed.
Unknown	Disease control	Disease control	Unknown	Further research needed.
Unknown	Micro and regional climate regulation	Local climate, air quality, regional precipitation	Unknown	Further research needed.

5.3 Cultural

Cultural services “cover all the non-material, and normally non-consumptive, outputs of ecosystems that affect physical and mental states of people” (Haines-Young and Potschin 2013).

Table 5.3: Cultural ecosystem services – impacts of de-bushing

Relevance	Ecosystem service class	Examples	Estimated direction of impact from de-bushing	Notes
High	Experiential use of plants, animals and landscapes	Wildlife viewing, landscape appreciation, hiking, other recreational tourism	+	See Section 10
High	Physical use of plants, animals and landscapes	Recreational and trophy hunting	+	See Section 10
Medium	Scientific	Research on wildlife, bush and ecosystems in general (e.g. Waterberg)	+/-	Limited impact. Change in land cover restricts some potential for scientific research and increases others.
Medium	Educational	Educational services from nature reserves, game parks	+/-	Similar to scientific services.

Medium	Heritage, cultural	Ways of life, Waterberg for Hereros, San, resettlement farms,	+/-	May relate to how land is used after de-bushing and presence of local populations. Further research needed for valuation.
Medium	Aesthetic	Aesthetic appreciation of landscape, Waterberg	+	Further research needed.
Medium	Symbolic	Symbolic identification of landscape features, livelihoods (e.g. keeping cattle)	+	Further research needed.
Medium	Existence	Existence value of wildlife, landscapes, ways of life, cultural practices to current generations	+	Further research needed. Interactions with other services related to wildlife populations.
Medium	Bequest	Bequest value of wildlife, landscapes, ways of life, cultural practices to future generations	+	Further research needed. Interactions with other services related to wildlife populations.
Low/none	Entertainment	Ex-situ viewing of wildlife/landscapes	+	Likely limited impact.
Unknown	Sacred and/or religious	Sacred practices of communities, Hereros, San	Unknown	Further research needed.

6 De-bushing

The Namibia Biomass Industry Group (N-BiG) is a newly established industry organisation positioned to serve and grow the Namibian biomass industry. N-BiG was founded through the support of the GIZ Support to De-bushing Project and its founding members and is growing its membership base and rolling out its services and projects in order to support its members and to develop the biomass industry in Namibia as a whole.

N-BiG provided analysis of the type of de-bushing operations suitable, according to the LDN study's bush density and species data, and estimates of the area that would be suitable for each type of operation, and the potential production. It should be noted that this is a scenario based on current and potential future biomass hubs and markets. N-BiG also provided estimates of the capex, opex, jobs, and labour costs associated with each type of operation.

See Section 21 for the detailed methodology and limitations and risks.

6.1 Total production and cost

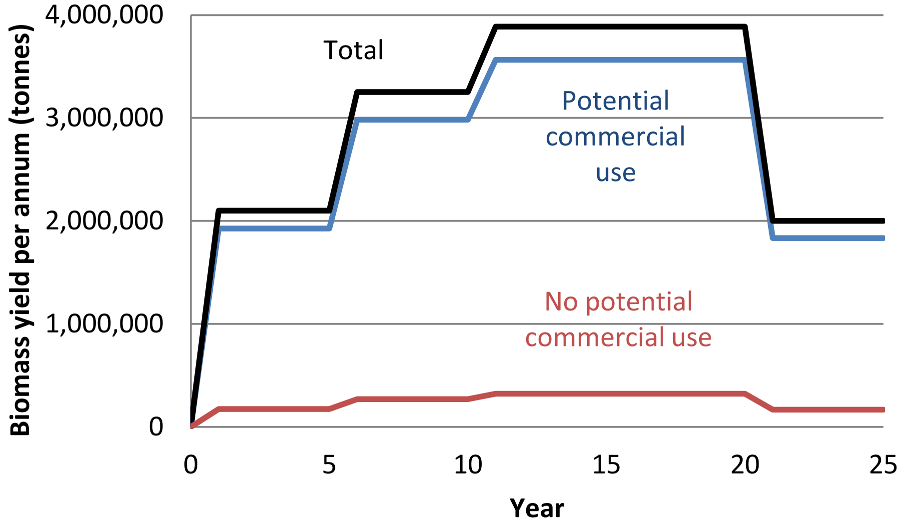
It was estimated that total production from the initial, follow up and after care rounds of de-bushing would sum to 75.6 million tonnes over 25 years, where 69.4 million tonnes of this is suitable for commercial use.

Table 6.1: Total production from de-bushing over 25 years

Type of de-bushing	Total biomass (m tonnes)
Large-scale mechanical	59.5
Small-to-medium-scale mechanical	9.9
Semi-mechanical and manual	6.3
Manual application of arboricides	
TOTAL	**75.6**

Source: N-BiG, Honsbein 2009

Chart 6.1: Biomass yield



Adding costs from the initial, follow up and after care rounds of de-bushing results in a total cost of N$24.6 million (2015 prices, undiscounted) over 25 years.

Table 6.2: Total costs of de-bushing over 25 years (2015 prices, undiscounted)

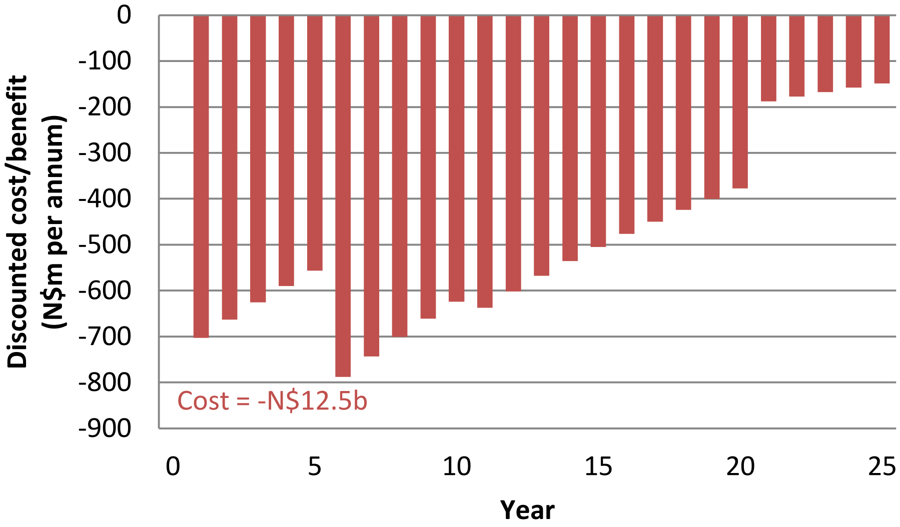
Type of de-bushing	Total cost (N$m, 2015 prices)
Large-scale mechanical	11,191
Small-to-medium-scale mechanical	7,383
Semi-mechanical and manual	2,244
Manual application of arboricides	3,796
TOTAL	**24,614**

Source: N-BiG, de Wet 2015, Honsbein 2009

The analysis showed that the initial round of de-bushing would cost around N$745 million per annum (undiscounted, 2015 prices) and that the follow ups and after care would add between N$372 million and N$639 million per annum, depending on the point in the cycle.

Once discounted at a rate of 6% (see Section 3.5.3), the total discounted cost was estimated at **N$12.5 billion** over the 25 year horizon.

Chart 6.2: Cost of de-bushing[3]



6.2 Sensitivity analysis

If the cost of de-bushing operations was 20% higher, the total cost is estimated to increase by almost N$2.5 billion to N$15.0 billion. If the cost of de-bushing was 20% lower, perhaps due to economies of scale, new technology, and optimisation of processes, then the estimated total cost could be as low as N$10.0 billion.

Table 6.3: Sensitivity analysis for de-bushing costs

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**12,469.9**	**0.0**	**-12,469.9**
Cost			
+20%	14,963.9	0.0	-14,963.9
-20%	9,976.0	0.0	-9,976.0

1: 2015 prices, discounted by 6% p.a.

[3] The year-to-year fluctuations can be explained by discounting and timing of follow ups and aftercare. For example, the cost decreases between Year 1 and Year 5 because it is being discounted. It then increases in Year 6 because the first follow up round has begun, in addition to the initial round of de-bushing.

7 Soil organic carbon

The level of carbon sequestered in the soil, as soil organic carbon (SOC), differs under different land cover. Based on a meta-analysis of scientific studies (Blaser et al. 2014), a shift from bush encroachment towards grasslands and lower bush density is estimated to result in a decrease in SOC on average. A two-step process was undertaken to estimate the cost of loss of SOC from de-bushing (compared with no de-bushing).

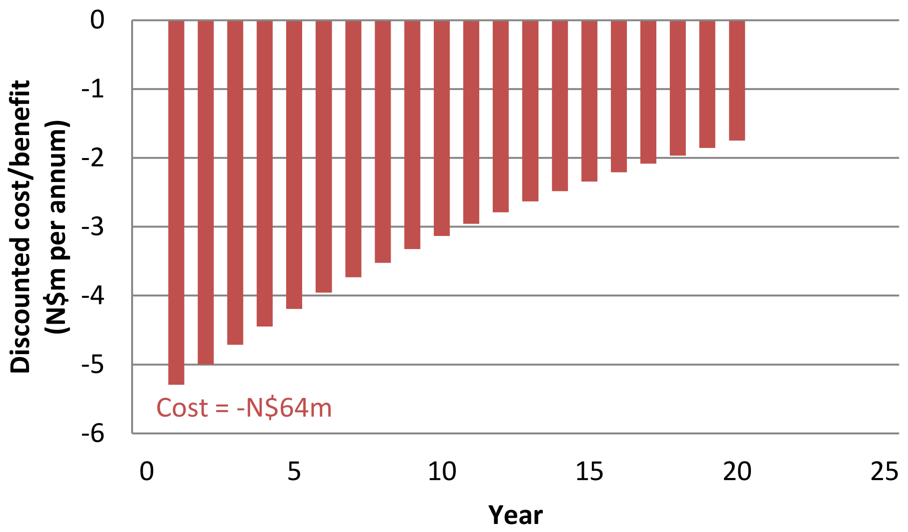
1. Estimate the change in SOC based on Blaser et al. (2014)
2. Estimate the value of the loss of SOC using the value of N$60/t$CO_2$e which is currently being used for the National Integrated Resource Plan review.

See Section 22 for the detailed methodology and limitations and risks.

7.1 Cost of loss of soil organic carbon

Over 25 years, the discounted cost from the loss of SOC was estimated at N$64.4 million (2015 prices).

Chart 7.1: Cost of loss of SOC



There will be further impacts on net carbon sequestration in Otjozondjupa based on how the de-bushed material and/or land are used. Two key issues are the use of de-bushed material to generate power for industry and electricity (see Sections 11.4 and 11.5), and the exploitation of the anticipated increased carrying capacity of land to farm more cattle (see Section 9).

7.2 Sensitivity analysis

The cost estimates use the Namibian carbon offset value of N$60 to generate a monetary value for CO_2 emissions, but there are alternative values. The Social Cost of Carbon (SCC) puts a particularly large value on CO_2 emissions as it is based on the potential cost of damages; other market-based values are currently significantly lower. Namibia does not appear to have clear guidance on how to value carbon emissions for policy appraisal at a domestic level.

As discussed above, in the absence of clear guidance at a domestic level, we have chosen to use a value of N$60/t$CO_2$e, which is currently being used for the National Integrated Resource Plan review. However, if the full economic and environmental costs are taken into account, then the adoption of the US SCC likely represents best practice.

Table 7.1 illustrates how the costs vary depending on the carbon value used. The central case, using the Namibian offset value, would result in a net cost of N$64.4 million over the 25-year horizon. Using the SCC, the net cost would be almost eleven times that, at N$695.9 billion.

Table 7.1: Sensitivity analysis for SOC

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**64.4**	**0.0**	**-64.4**
SCC	695.9	0.0	-695.9

1: 2015 prices, discounted by 6% p.a.

8 Groundwater

Namibia is the most arid country in Sub-Saharan Africa and is highly dependent on groundwater. Bush encroachment increases the rate of evapotranspiration, reducing groundwater recharge rates compared with grassland. Bushes intercept some rainwater before it reaches the ground which then evaporates into the atmosphere. They also compete with grasses to take up significant amounts of water from the soil through their root systems. Transpiration, the process of water being carried from roots to leaves and evaporating, is where the main loss of water occurs. De-bushing would reduce the amount of water used by encroacher bushes, increasing recharge (Christian et. al. 2010).

See Section 23 for the detailed methodology and limitations and risks.

8.1 Benefit for increased groundwater recharge/sustainable water supply

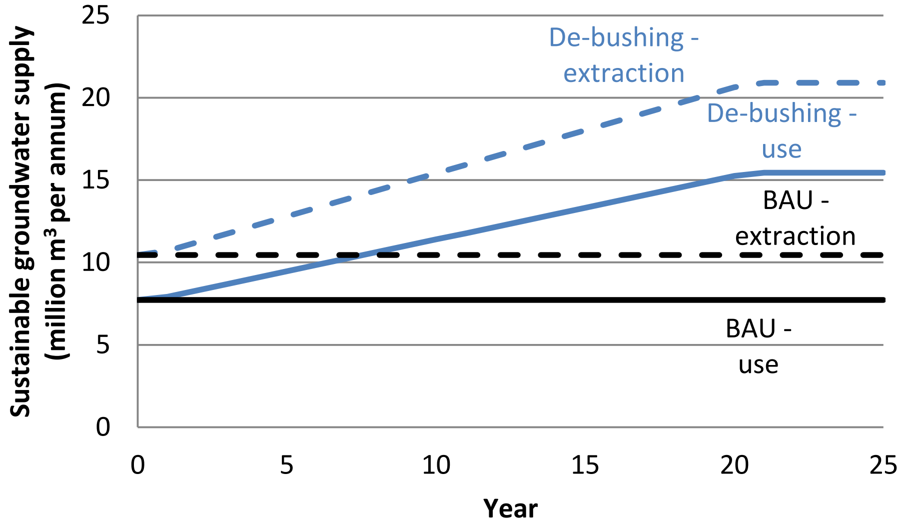
A two-step process was undertaken to estimate the potential benefit to groundwater recharge and sustainable water supply from de-bushing (compared with no de-bushing).

1. Estimate the change in groundwater recharge
2. Estimate the value of the additional sustainable water supply from groundwater each year

8.1.1 Estimating the increase in groundwater recharge

We took a conservative estimate of a rise in the recharge rate from 1% to 2% to be used in the central case. Assuming that 5% of the areas where groundwater infiltrate to these aquifers was de-bushed per annum, and assuming that groundwater recharge rates improved linearly, it was estimated that de-bushing could result in additional sustainable extraction of 10.45 million m^3 per annum using the current infrastructure after 21 years. This would result in an additional 7.72 million m^3 reaching users per annum (see Chart 8.1). Over 25 years, this represents additional sustainable extraction of 156.8 million m^3 and additional sustainable use of 115.8 million m^3.

Chart 8.1: Sustainable groundwater extraction and use – de-bushing versus BAU



8.1.2 Valuing the increase in sustainable water supply

For valuation purposes, we had to first subtract the volume of additional groundwater that would be used for the increased number of cattle due to de-bushing, as the value of this is implicit in the value of the additional beef production (see Section 9). We also had to subtract the volume of additional groundwater that would be used for the new biomass power plants (see Section 11.5).

We then used an avoided cost technique to estimate the implicit cost groundwater of around N$14.7 million per million m^3 of water. The implicit cost of water was then applied to the additional sustainable use volumes per annum to arrive at the estimated discounted benefit of **N$430.5 million** over the 25 year horizon.

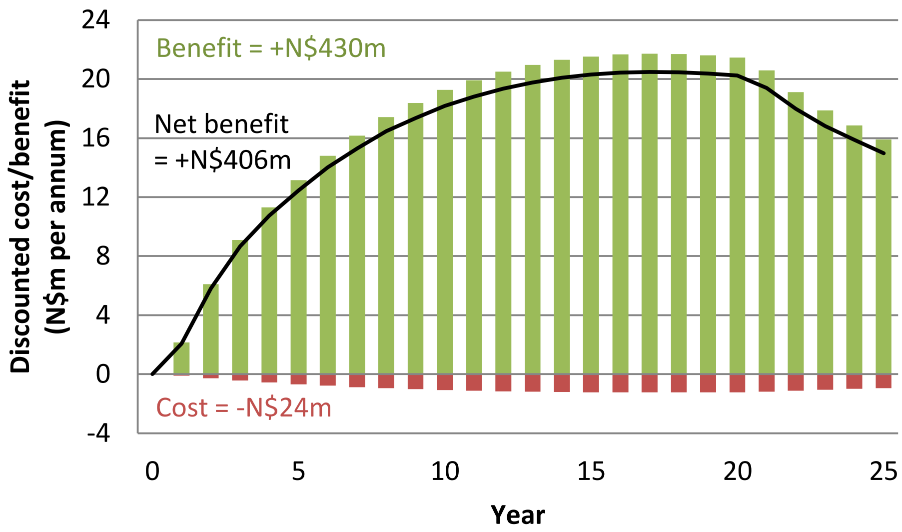
8.2 Cost of additional groundwater extraction

According to NamWater, the only significant cost associated with extracting larger volumes of groundwater would be the energy used to pump the water from the aquifer to ground level. Over the 25 years, it was estimated that it would cost **N$24.1 million** (2015 prices, discounted) to extract the additional groundwater.

8.3 Net benefit

The net benefit for additional sustainable extraction and use of groundwater was estimated at **N$406.4 million** (2015 prices, discounted).

Chart 8.2: Benefit, cost, and net benefit of increased sustainable groundwater use



8.4 Sensitivity analysis

Key variables, namely the change in recharge rate and the cost of electricity to pump water out of the ground, were varied in order to observe their impacts on the estimated cost, benefit, and net benefit. It was found that the estimated net benefit ranged from a low of N$83.9 million, when the groundwater recharge rate only increased to 1.5%, to a high of N$1.1 billion, when the recharge rate increased to 3%. Changes in the cost of electricity had a minor impact, with the estimated net benefit ranging from N$401.6 million, when the cost was 20% higher, to N$411.2 billion, when the cost was 20% lower.

Table 8.1: Sensitivity analysis for sustainable water supply from groundwater

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**24.1**	**430.5**	**406.4**
Recharge rate			
1.5%	12.0	95.9	83.9
3.0%	48.1	1,113.7	1,065.6
Cost of electricity			
+20%	28.9	430.5	401.6
-20%	19.2	430.5	411.2

1: 2015 prices, discounted by 6% p.a.

9 Livestock

Livestock farming, particularly cattle farming, is a significant land use, employer, and income generator in Otjozondjupa. In our analysis, we focus only on cattle farming, as this is the dominant type of farming. Between 2011 and 2015, Otjozondjupa accounted for an average of 16.9% of total cattle in Namibia, whereas the region accounted for just 3.7% of sheep and 5.6% of goats over the same period.

See Section 24 for the detailed methodology and limitations and risks.

9.1 Benefit for increased livestock production

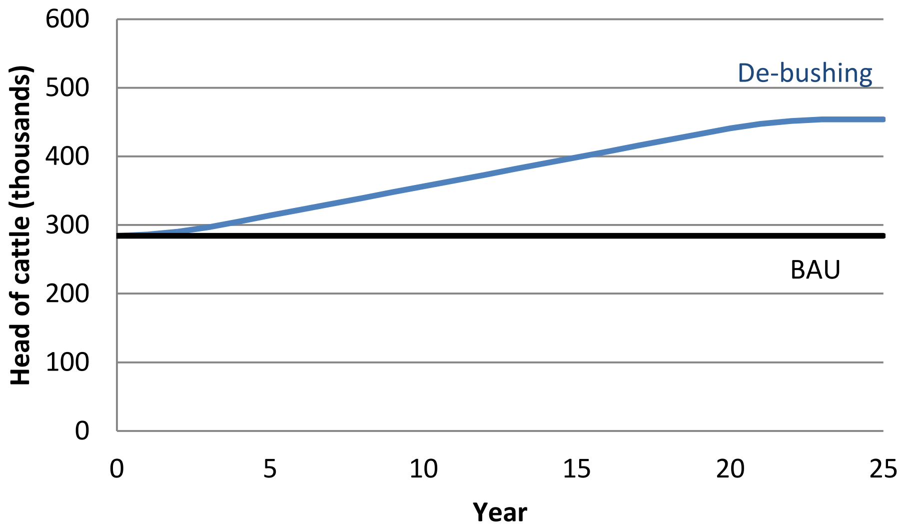
A two-step process was undertaken to estimate the potential benefit to cattle farming from de-bushing (compared with no de-bushing).

1. Estimate the change in cattle numbers
2. Estimate the value of the additional cattle that could be slaughtered each year using market prices

9.1.1 Estimating the increase in cattle numbers and beef production

Based on literature reviews and expert knowledge, the accepted rule of thumb is that a reduction in bush to an optimal density would at least double carrying capacity. This was applied to the current stock of cattle, according to livestock census data[4], adjusted for the extent of de-bushing in the zone and by whether they were commercial or communal farms above or below the veterinary cordon fence. It was assumed that following de-bushing of an area, it would take four years to reach the new carrying capacity in that area.

Chart 9.1: Head of cattle – de-bushing versus BAU



[4] Directorate of Veterinary Services

Offtake rates (the percentage of the herd that is slaughtered per annum) and a conversion factor of 246.9kg/head[5] was then applied to the number of cattle slaughtered to estimate meat production in kilograms.

9.1.2 Valuing the increase in beef production

The year average beef producer price for 2015 of N$27.3/kg[6] was applied to the offtake (in kg) to estimate revenue for commercial and communal (both north and south of the red line) farmers in the 22 bush encroached zones. This was then summed to arrive at total revenue. The analysis showed that de-bushing could result in an additional N$277 million per annum (undiscounted, 2015 prices). The discounted benefit was estimated at **N$1.1 billion** over the 25 year horizon.

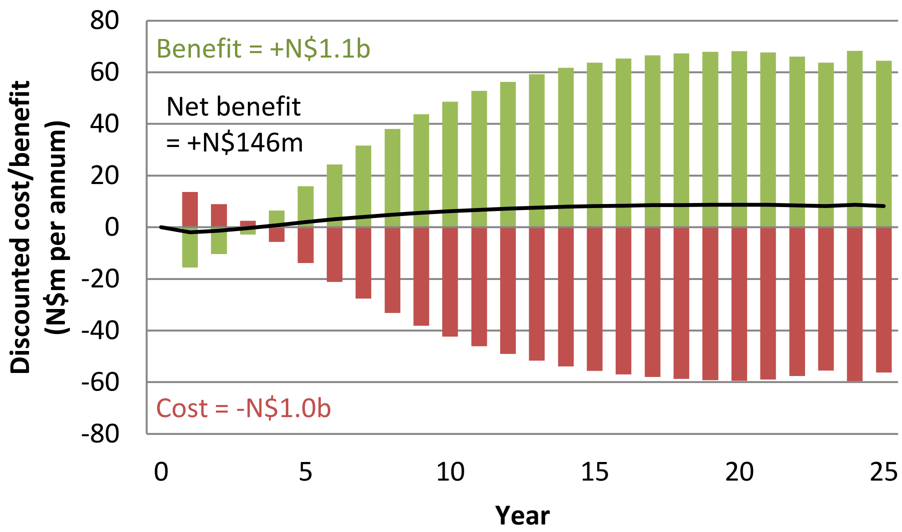
9.2 Financial cost of increased livestock production

NAU provided data on the production costs of a cow-ox cattle production system for a typical cattle farm. The discounted cost was estimated at **N$1.0 billion** over the 25 year horizon.

9.3 Net benefit

The net benefit for additional cattle production was estimated at **N$146.0 million** (2015 prices, discounted).

Chart 9.2: Benefit, cost, and net benefit of increased cattle production



9.4 Sensitivity analysis

Key variables, namely the change in carrying capacity, price, and cost were varied in order to observe their impacts on the estimated cost, benefit, and net benefit. It was found that the estimated net benefit ranged from a low of -N$81.9 million, when price decreased by 20%, and a high of N$373.8 million, when price decreased by 20%. Changes in costs had a similar impact. When the carrying capacity increase was half that of the central case, the net benefit was estimated at

[5] Namibian meat production data from the UN Food and Agriculture Organisation (FAO)
[6] Meat Board of Namibia

N$58.5 million, but when the carrying capacity increase was double that of the central case, the net benefit was estimated at N$320.9 million.

Table 9.1: Sensitivity analysis for livestock production

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**993.3**	**1,139.3**	**146.0**
Carrying capacity increase			
half central case	399.2	457.7	58.5
double central case	2,181.6	2,502.4	320.9
Price			
+20%	993.3	1,367.1	373.8
-20%	993.3	911.4	-81.9
Cost			
+20%	1,192.0	1,139.3	-52.7
-20%	794.6	1,139.3	344.6

1: 2015 prices, discounted by 6% p.a.

Over recent years, cattle farming has become less profitable:

> "Over the past eight years, production costs on a cattle farm increased by 120%, while the beef price increased by only 73%. Subsequently, farmers without an additional source of income cannot afford to apply sustained bush control measures." (SAIEA 2016, p29).

It is likely that we will see the price increase, relative to the cost, in the near future, when the drought breaks and slaughter rates go down. In this case, the net benefit would be larger.

9.5 Estimating the option value on the addition to the stock of cattle

We also need to take into account the increase in wealth represented by the additional cattle. We can do this by using an option value – at the end of the 25 year period, if the additional cattle were sold off, how much would this be worth?

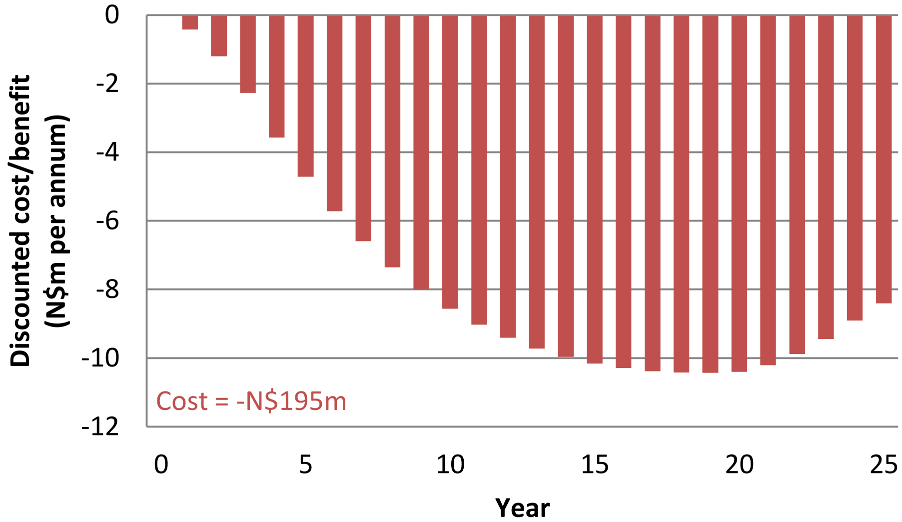
In Section 9.1.1, it was estimated that almost 170,000 cattle could be added to the herd. Based on the NAU's model of herd dynamics, the total option value was estimated at **N$215.7 million** (2015 prices, discounted).

9.6 Cost of additional emissions from livestock

Although de-bushing offers significant benefits in terms of additional rangeland carrying capacity and the associated increase in beef production, greater numbers of cattle will increase greenhouse gas (GHG) emissions; an additional kilogram live-weight of cattle is estimated to contribute an additional 11.93 kgCO_2e per annum[7]. This can be valued using the Namibian carbon offset value as demonstrated in Section 7, resulting in an estimated discounted cost of **N$195.5 million**.

[7] http://beefandlamb.ahdb.org.uk/news/livestock-and-the-environment/livestock-and-climate-change-the-facts/.

Chart 9.3: Cost of additional emissions from cattle



9.6.1 Sensitivity analysis

If the SCC is used to value the additional emissions from livestock (see Section 7.2), the net cost would be N$2.4 billion over the 25 years, more than twelve times the net cost in the central case.

Table 9.2: Sensitivity analysis for additional emissions from livestock

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**195.5**	**0.0**	**-195.5**
SCC	2,390.9	0.0	-2,390.9

1: 2015 prices, discounted by 6% p.a.

10 Wildlife viewing, trophy hunting, and game products

Wildlife viewing is a significant tourism activity on private farms, in conservancies, and in protected areas in Otjozondjupa. Trophy hunting is also an important source of revenue for private farms and conservancies, and the use and sale of game meat brings in revenue and improves nutrition and food security in rural areas.

In Otjozondjupa, registered hunting farms cover approximately 1,248,300 ha. These also include mixed use farms, where livestock production and hunting of game both occur. Private game farms (no hunting) cover an estimated 183,000 ha and IUCN-listed protected areas cover an estimated 38,600 ha.

10.1 Wildlife viewing

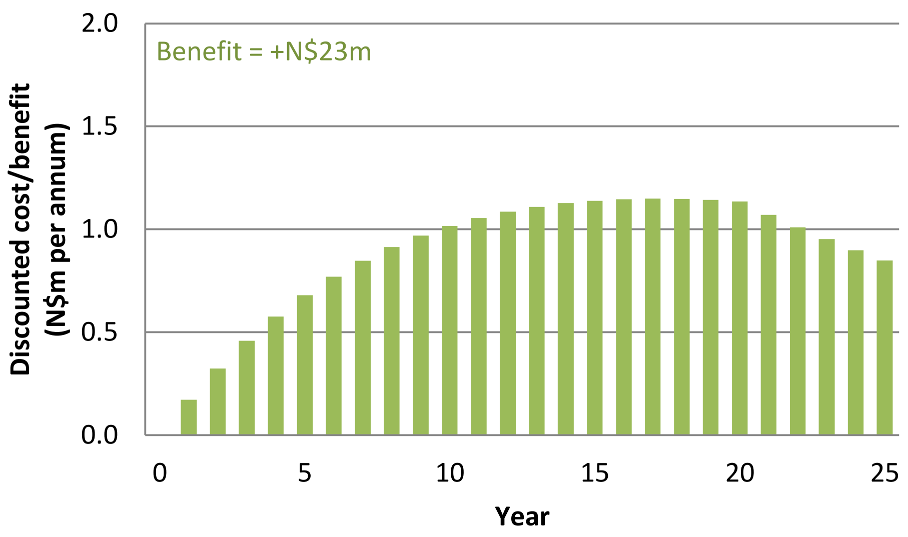
See Section 25.1 for the detailed methodology and limitations and risks.

This analysis takes a broad look at how wildlife viewing might be impacted by de-bushing on private land. Although wildlife viewing activities also take place in communal conservancies and protected areas in Otjozondjupa, there was not enough information or experience to get a clear idea of the impacts.

10.1.1 Benefit

The impacts of de-bushing on the value of wildlife viewing are very difficult to isolate. De-bushing has the potential to increase the carrying capacity of game and also to make animals easier to see for tourists, increasing success rates and satisfaction. However, there is very little literature on quantifying these effects. We used estimates from the Okonjima Game Reserve to estimate the impact of de-bushing. Over 25 years, the discounted benefit for wildlife viewing was estimated at **N$22.7 million** (2015 prices).

Chart 10.1: Benefit for wildlife viewing



10.2 Trophy hunting and game products

In this analysis, we look at how trophy hunting, live game auctions, and game products on private game farms would be impacted by de-bushing. Hunting farms tend to only be partly de-bushed so that a variety of habitats exist (e.g. savannah, woodland, shrubland). We break down our analysis by established farms and new farms, and by mixed use and game only farms.

See Section 25.2 for the detailed methodology and limitations and risks.

10.2.1 Benefit

10.2.1.1 Established farms

Registered hunting farms cover approximately 1,248,300 ha in Otjozondjupa. Venter (2015) estimates that 15% of cattle farms are also hunting farms (i.e. mixed use). We assume that 75% of the land occupied by hunting farms is mixed use, while the remaining 25% is game only.

We spoke to a number of farmers who estimated that de-bushing had resulted in an increase in carrying capacity of stock on their land of at least 30% and up to 80%. We take an increase of 50% as a conservative average.

Venter (2015) profiles the revenue from hunting and game for three mixed use farms and one game only farm. Assuming that the sustainable offtake rate of game (for trophies and game products) remains the same, and using Venter's data, we estimate that by the time that stock has increased by 50% across the entire area in Year 23, additional revenue of N$60.7 million per annum (2015 prices, undiscounted) would be generated by mixed use farms and N$74.5 million per annum by game only farms. This results in an additional N$135.2 million per annum for established hunting farms.

10.2.1.2 New farms

De-bushing could mean that such hunting operations become increasingly viable over a wider area of land as wildlife carrying capacities increase and the hunting experience is improved. Therefore, we can also look at the potential benefits from new mixed use and game only hunting farms on de-bushed land. This could include cattle farms adding hunting operations, cattle farms being converted to game only farms, or other de-bushed land being converted to game only farms.

We assume that land for mixed use farms and game only farms is expanded by 10% which results in an additional N$33.0 million per annum for new hunting farms.

10.2.1.3 Total

The discounted benefit for trophy hunting and game products for both new and established farms was estimated at **N$1.1 billion** (2015 prices).

10.2.2 Cost

Land costs are not included as they would be transferred within the system.

10.2.2.1 Established farms

We assume that operating and maintenance costs would increase for established farms in line with revenue and that the only additional investment cost would be buying in stock. Other new investments would be required whether stock had increased or not, although perhaps at a slower rate in the BAU case.

Venter (2015) also profiles operating and maintenance costs. The opex were then calculated as a proportion of revenue which results in additional opex costs of up to N$26.2 million per annum (2015 prices, undiscounted) for established mixed use farms and up to N$46.1 million per annum (2015 prices, undiscounted) for game only farms.

Venter (2015) also provides estimates for the game stock value which were used to calculate buy in costs of N$15.7 million per annum between Years 4 and 20 for both mixed use and game only farms.

10.2.2.2 New farms

The above process for estimating operating and maintenance costs was also used for the new mixed use and game only farms, according to the escalation in revenue. Investment costs, including buy in of stock, would obviously be larger for new farms, and were also taken from Venter (2015).

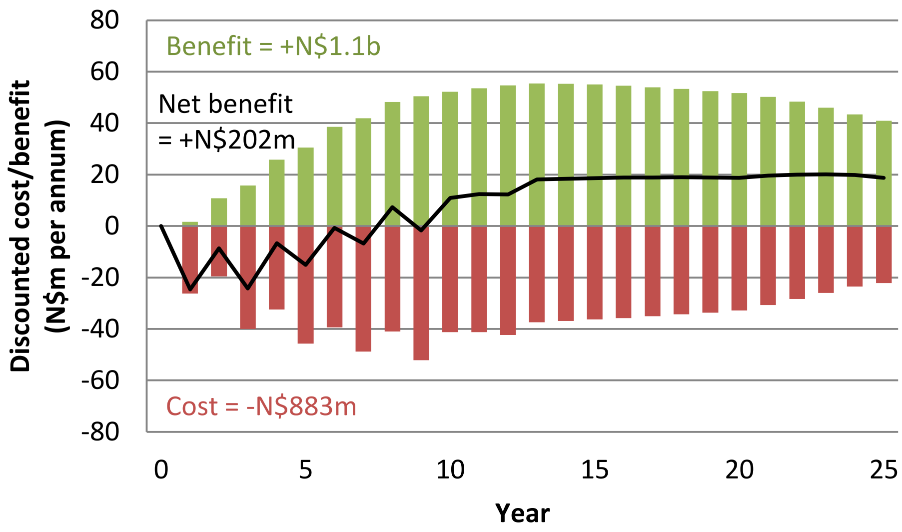
10.2.2.3 Total

Overall, the discounted cost for trophy hunting and game products for both new and established farms was estimated at **N$882.9 million** (2015 prices).

10.2.3 Net benefit

The discounted benefit for trophy hunting and game products was estimated at **N$202.0 million** (2015 prices).

Chart 10.2: Benefit, cost, and net benefit for trophy hunting and game products



10.2.4 Sensitivity analysis

When the carrying capacity increased by 30% instead of 50%, the net benefit was estimated at N$122.2 million, but when carrying capacity increased by 80%, the net benefit was estimated at N$321.6 million.

Table 10.1: Sensitivity analysis for trophy hunting and game products

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**882.9**	**1,084.9**	**202.0**
Carrying capacity			
+30%	622.6	744.8	122.2
+80%	1,273.4	1,595.0	321.6

1: 2015 prices, discounted by 6% p.a.

10.2.5 Estimating the option value on the addition to the stock of game

We also need to take into account the increase in wealth represented by the additional game. We can do this by using an option value – at the end of the 25 year period, if the additional game were sold off, how much would this be worth?

Although we have not used game population numbers, we do know the stock value. For established farms, we added the undiscounted value of the buy in over the 25 years to get the value of the additional stock. For new farms, we added the value of the buy in for each of the 12 farms.

The total option value was estimated at **N$94.3 million** (2015 prices, discounted).

11 Utilisation of biomass

We calculate the costs and benefits for five uses of encroacher biomass: charcoal, firewood, and animal feed production, thermal power generation for industry, and electricity generation. We also calculate the benefit from leaving a proportion of the biomass on the ground, to protect the soil and return nutrients.

The cost of buying the biomass to use as an input is not included here as it is implicit in the cost of de-bushing. The cost to the purchasers of the biomass would exactly equal the payment (benefit) to the suppliers, so it cancels out within the system. Transport costs are not included as they would depend on distance and volume from biomass production hubs to points of use.

11.1 Charcoal production

The charcoal industry has been present in Namibia for the past thirty years, operating mainly on farmland in central and northern Namibia (NCA 2016).

See Section 26.1 for the detailed methodology and limitations and risks.

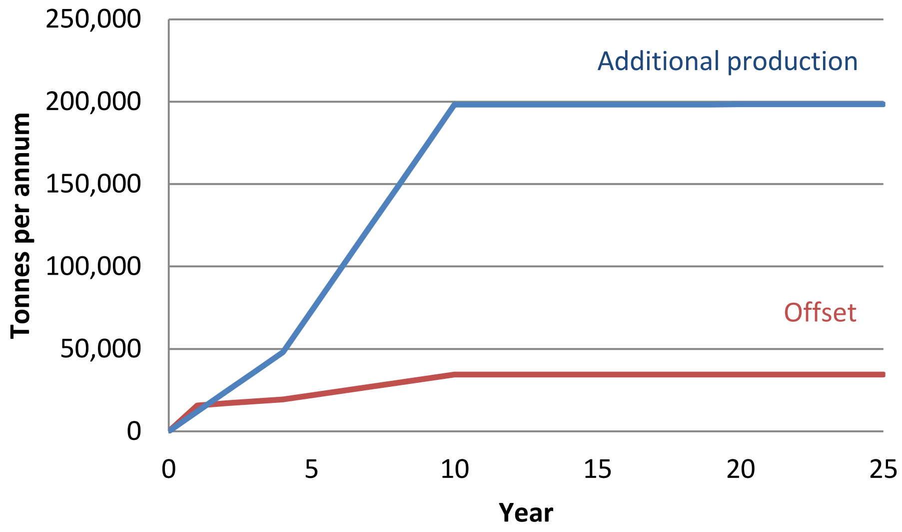
11.1.1 Benefit

Between 2013 and 2015, Namibia exported around 120,000 tonnes of charcoal per annum and domestic demand was around 1,000 tonnes per annum, resulting in total national production of around 121,000 tonnes per annum. The Namibia Charcoal Association[8] estimated that 60% of this is produced in Otjozondjupa, around the hubs of Grootfontein, Otavi, Okahandja, and Otjiwarongo. This means that Otjozondjupa currently produces 72,000 tonnes for export and 600 tonnes for domestic demand per annum, for a total of 72,600 tonnes per annum.

By Year 25, we estimate that an additional 198,459 tonnes of charcoal could be produced per annum and that 34,366 tonnes would be produced using encroacher bush rather than non-encroacher bush and trees (see Chart 11.1).

[8] NCA 2016, pers. comm.

Chart 11.1: Additional charcoal production and offset production from non-encroacher bush and trees due to de-bushing



The additional (non-offset) volumes of charcoal produced were then multiplied by the current real average wholesale price of charcoal of N$1,600 per tonne. The offset volumes were multiplied by N$100 per tonne, the approximate difference between fair trade and standard wholesale prices of firewood. The discounted benefit was estimated at **N$2.5 billion** (2015 prices) over the 25 year horizon.

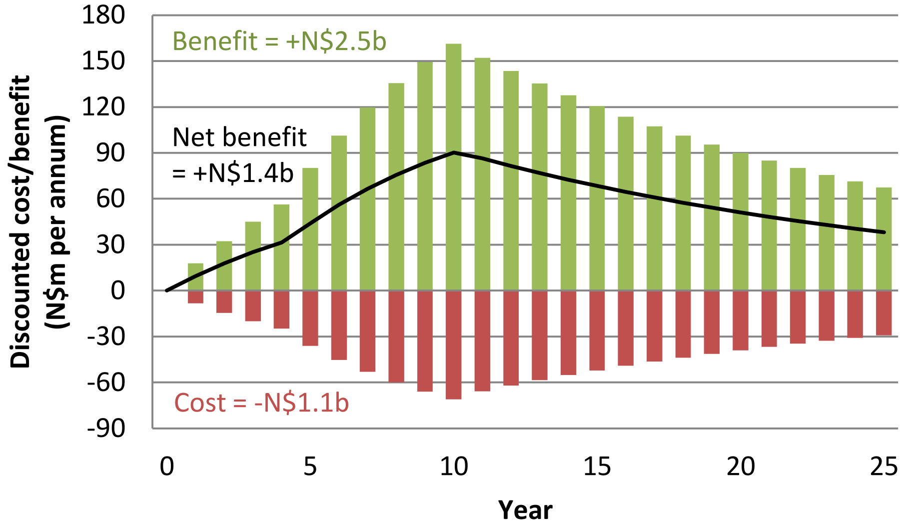
11.1.2 Cost

We take estimates from NCA (2016) for capex and opex for charcoal production which results in an estimated discounted cost of **N$1.1 billion** (2015 prices) over the 25 year horizon.

11.1.3 Net benefit

The net benefit for charcoal production was estimated at **N$1.4 billion** (2015 prices, discounted).

Chart 11.2: Benefit, cost, and net benefit of increased charcoal production



11.1.4 Sensitivity analysis

The price of charcoal and cost of producing charcoal were varied in order to observe the impact on the estimated cost, benefit, and net benefit. It was found that the estimated net benefit ranged from a low of N$896.5 million, when the price was 20% lower, and a high of N$1.9 billion, when the price was 20% higher.

Table 11.1: Sensitivity analysis for charcoal production

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**1,076.5**	**2,466.3**	**1,389.7**
Price			
+20%	1,076.5	2,959.5	1,883.0
-20%	1,076.5	1,973.0	896.5
Cost			
+20%	1,291.8	2,466.3	1,174.4
-20%	861.2	2,466.3	1,605.1

1: 2015 prices, discounted by 6% p.a.

11.2 Firewood

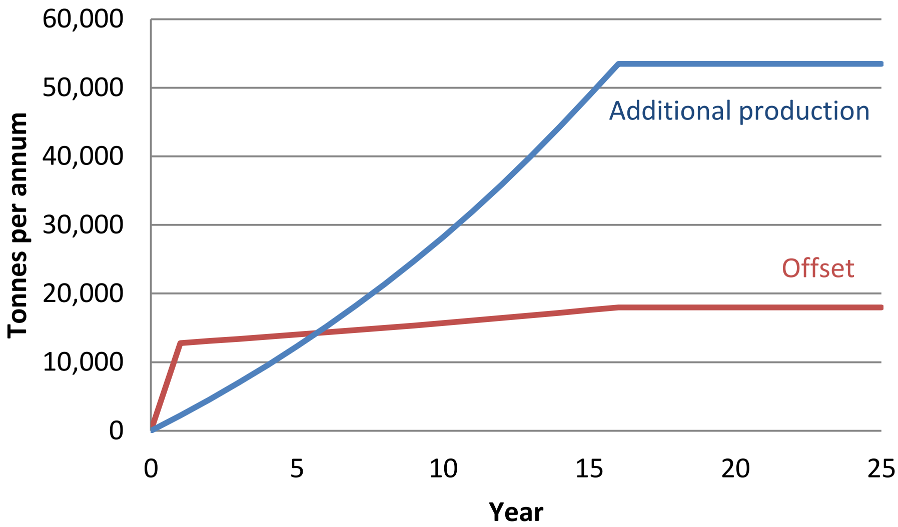
Firewood is the primary fuel source for many rural households and informal settlements in Namibia. Much of it is collected for own use or informally sold by roadsides and in markets, but some is retailed at supermarkets and petrol stations. It is thought that a significant amount of firewood is collected from non-encroacher bushes and trees, which can have negative environmental impacts.

See Section 26.2 for the detailed methodology and limitations and risks.

11.2.1 Benefit

Current demand for firewood in Namibia is estimated at 550,000 tonnes per annum (Development Consultants for Southern Africa 2015b). We assume that a quarter of the 50,000 tonnes currently produced in Otjozondjupa, or 12,500 tonnes, would represent an offset of non-encroacher firewood production in Year 1, with further offsets rising in line with Namibia's population growth of 2.3[9] per cent per annum. Total firewood production was estimated to increase by 5% per annum until it reaches 109,000 tonnes by Year 16, then plateaus.

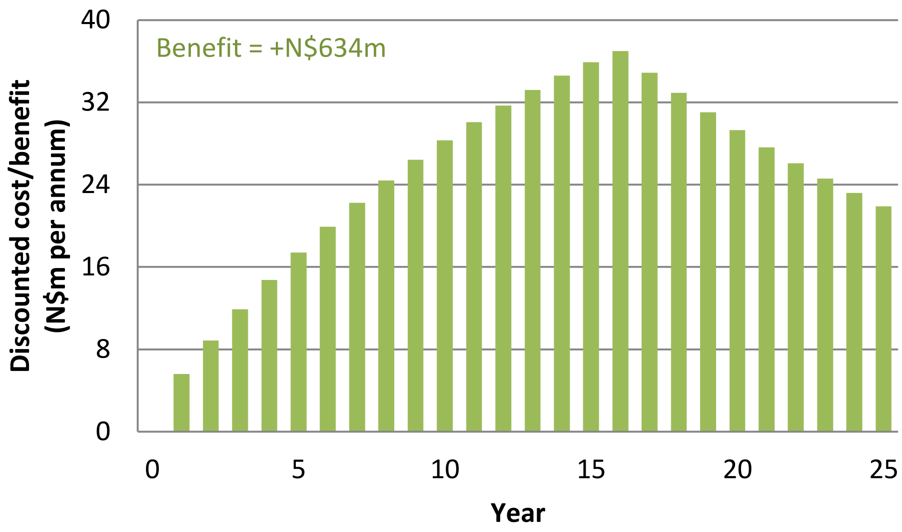
Chart 11.3: Additional and offsetting firewood production due to de-bushing



The additional volumes were multiplied by the current retail price of firewood of N$1,700 per tonne. To value the offset volumes, we applied the proportional difference between fair trade and non-fair trade prices for charcoal (also derived from woody plants) which is equal to around 10%, to the retail price of firewood. In total, the discounted benefit was estimated at **N$633.8 million** over the 25 year horizon.

[9] http://databank.worldbank.org/data/reports.aspx?source=2&country=NAM

Chart 11.4: Benefit of increased firewood production



11.2.2 Cost

The costs of additional firewood production were not calculated. There would be some additional transport costs and perhaps some labour costs. However, as mentioned above, it is thought that a significant proportion of firewood is collected informally and transported on foot. Overall, we believe that the additional costs would be relatively small.

11.2.3 Sensitivity analysis

The price of firewood was varied in order to observe the impact on the estimated benefit. It was found that the estimated benefit ranged from a low of N$507 million, when the price was 20% lower, and a high of N$760.5 million, when the price was 20% higher.

Table 11.2: Sensitivity analysis for firewood

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**0.0**	**633.8**	**633.8**
Price			
+20%	0.0	760.5	760.5
-20%	0.0	507.0	507.0

1: 2015 prices, discounted by 6% p.a.

11.3 Animal feed

Biomass from encroacher bush can be used as an input into animal feed. Bush can make up between 50-85% of animal feed[10], with supplements such as molasses (to improve palatability and nutritional content), urea (for additional protein), polyethylene glycol (as a tannin binding agent), and sodium hydroxide (to aid digestibility) also being added (Pasiecznik 2016).

[10] Tambuti 2015, pers. comm.

Although animal feed is an input into cattle production, we assume that in de-bushed areas, increased grass production would be sufficient and animal feed would not be required. Animal feed could be marketed to farms which haven't been included in the de-bushing programme within Otjozondjupa, or in different regions, and which don't have sufficient fodder. This avoids double-counting.

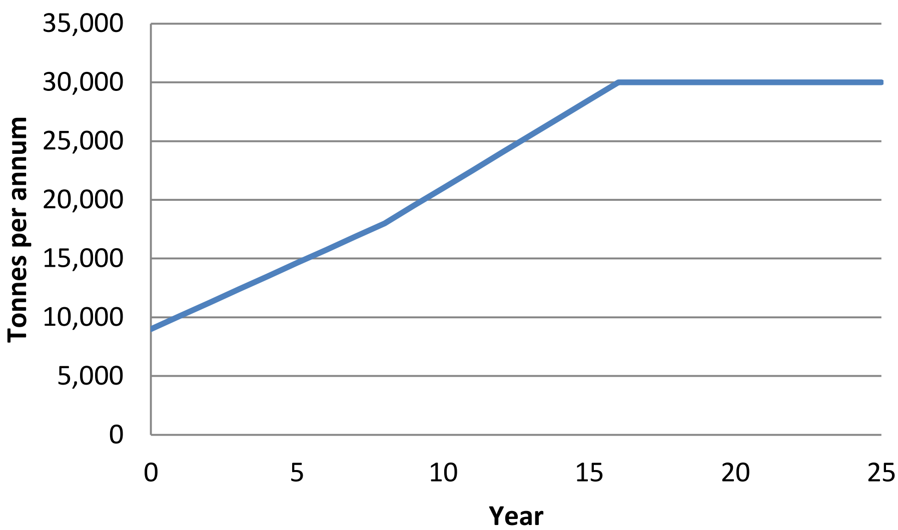
Given that feed production from encroacher bush is relatively new, and that pilot programmes are still underway to determine feasibility of expansion, nutritional content, and other factors, this analysis is very general and some assumptions are informed by anecdotal evidence and data from individual producers.

See Section 26.3 for the detailed methodology and limitations and risks.

11.3.1 Benefit

We used production and revenue estimates from Tambuti, a mixed-use farm in the Otavi area which produces animal feed from de-bushed biomass on its property. We project that production could increase from the current estimate of 9,000 tonnes per annum in Otjoondjupa to 30,000 tonnes per annum by Year 16 before plateauing.

Chart 11.5: Animal feed production



According to Larry Bussey from Tambuti, the 2015 market price for animal feed was between N$200 to N$325 per 40kg bag, depending on the recipe. On average, this equals N$6,562.50 per tonne. This price was applied to the additional production per annum to estimate the discounted benefit of **N$952.3 million** (2015 prices) over the 25 year horizon.

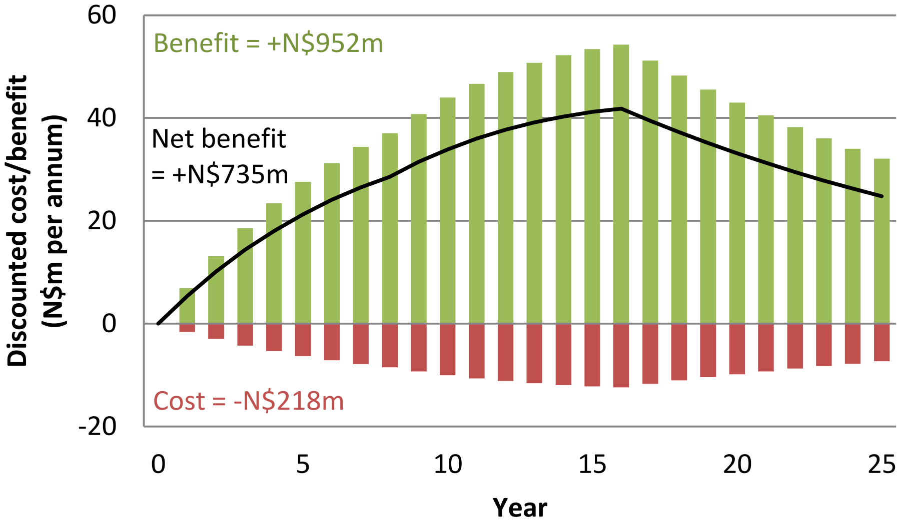
11.3.2 Cost

N-BiG provided figures for the combined capex and opex for animal feed production of between N$1.2 and N$1.8 per kilogram based on interviews with farmers. This equates to an average of N$1,500 per tonne. At Tambuti, the average operating cost is around N$1,600 per tonne, including the cost of additives, but this depends on the recipe. The cost of N$1,500 per tonne was applied to the additional production per annum. The discounted cost was estimated at **N$217.7 million** (2015 prices) over the 25 year horizon.

11.3.3 Net benefit

The net benefit for animal feed was estimated at **N$734.7 million** (2015 prices, discounted).

Chart 11.6: Benefit, cost, and net benefit of increased animal feed production



11.3.4 Sensitivity analysis

The price of animal feed and cost of producing animal feed were varied in order to observe the impact on the estimated cost, benefit, and net benefit. It was found that the estimated net benefit ranged from a low of N$544.2 million, when the price was 20% lower, and a high of N$925.1 million, when the price was 20% higher.

Table 11.3: Sensitivity analysis for animal feed production

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**217.7**	**952.3**	**734.7**
Price			
+20%	217.7	1,142.8	925.1
-20%	217.7	761.9	544.2
Cost			
+20%	261.2	952.3	691.1
-20%	174.1	952.3	778.2

1: 2015 prices, discounted by 6% p.a.

11.4 Power for industry

We used two real life examples to analyse how de-bushing could impact power generation for industry:

1. Ohorongo cement – constrained supply of biomass

2. Replacing HFO use with a biomass boiler – Namibia Breweries (Windhoek) example

See Section 26.4 for the detailed methodology and limitations and risks.

11.4.1 Ohorongo cement

Ohorongo is Namibia's only cement-producing company and the plant is located near Otavi in Otjozondjupa. Ohorongo invested in a kiln that can process wood chips as well as coal (at a 1:1.6 ratio of tonnes of coal to woodchips) to generate energy for cement production. It aims to replace 75% of coal with woodchips but is currently restricted to only 50% of this capacity due to supply constraints[11].

If the supply of woodchips increased enough, it would mean that the use of coal could be reduced by an additional 30,000 tonnes per annum. If production and proportion of woodchips used remained constant over the rest of the forecast horizon, then the use of coal could be reduced by a total of 690,000 tonnes.

The average South African export price of coal in 2015 was ZAR723.3/tonne (N$723.3/tonne)[12]. When applied to the avoided use of coal, this represents an avoided cost of up to N$21.7 million per annum. This results in a discounted benefit of **N$238.7 million** (2015 prices) over the 25 year horizon.

As the investment has already been made and there would be no difference in operating and maintenance costs, there would be no additional costs. The costs of the woodchips are implicit in the costs of de-bushing.

11.4.2 Replacing HFO use with a biomass boiler

Namibia Breweries has invested in a biomass boiler worth N$50 million for its Windhoek plant[13]. This boiler will allow 3,100 tonnes of the current 3,600 tonnes of heavy fuel oil (HFO) used per year to be replaced by 7,500 tonnes of woodchips. This technology can be used in other industries, for example, in meat production.

We assumed that five similar conversions to biomass boilers could occur in Otjozondjupa, starting from Year 2 with a new conversion occurring every three years. This would result in a reduction in HFO use of up to 15,500 tonnes per annum.

The average international price of HFO in 2015 was US$291.25/tonne[14]. This would likely be higher when taking into account the cost of importing to Namibia. When converted to Namibian dollars using the average exchange rate for 2015 of N$12.75/US$[15], the price of HFO is N$3,714.2/tonne. When applied to the reduction in use of HFO, this represents an avoided cost of up to N$57.6 million

[11] Ohorongo, pers. comm. 2016
[12] http://www.indexmundi.com/commodities/?commodity=coal-south-african&months=60&currency=zar
[13] http://www.namibian.com.na/index.php?page=archive-read&id=147980
[14] http://www.insee.fr/en/bases-de-donnees/bsweb/serie.asp?idbank=001642883
[15] https://www.oanda.com/currency/average

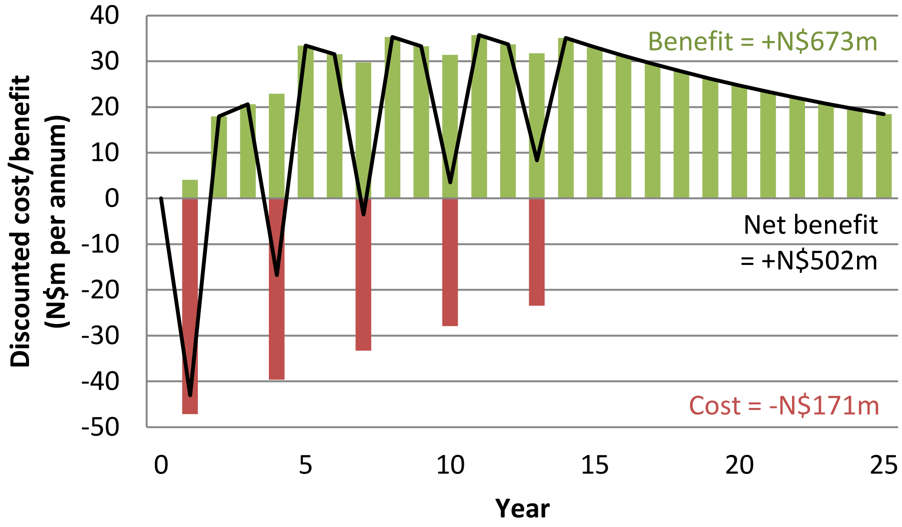
per annum. This results in a discounted benefit of **N$434.2 million** (2015 prices) over the 25 year horizon.

In terms of costs, the N$50 million of investment would be incurred in the year prior to each boiler becoming operational. We assume operating and maintenance costs would be the same compared with continued use of HFO.

11.4.3 Total benefit, cost, and net benefit

In total, replacing coal and HFO with woody biomass, according to the above examples, could result in a total discounted benefit of N$672.9 million and total discounted cost of N$171.4 million. Consequently, the net benefit biomass generated power for industry was estimated at **N$501.5 million** (2015 prices, discounted).

Chart 11.7: Benefit, cost, and net benefit of biomass generated power for industry



11.4.4 Sensitivity analysis

The capacity of industry power from biomass was varied by +/- 2 biomass boilers becoming operational. The net benefit ranged from a low of N$455.2 million to a high of N$514.9 million. The price of HFO (avoided cost) was also varied by +/- 20%. The net benefit ranged from a low of N$414.7 million to a high of N$588.4 million.

Table 11.4: Sensitivity analysis for power generation for industry

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**171.4**	**672.9**	**501.5**
Capacity			
+ 2 extra boilers	207.6	722.5	514.9
- 2 fewer boilers	120.0	565.2	445.2
HFO price			
+20%	171.4	759.8	588.4
-20%	171.4	586.1	414.7

1: 2015 prices, discounted by 6% p.a.

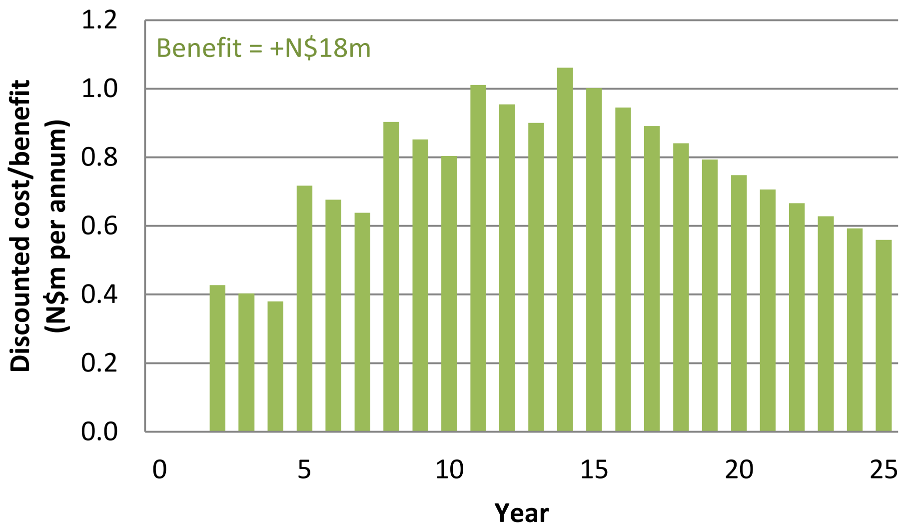
11.4.5 Benefit of emissions offsets

Ohorongo's emissions factor is confidential, so only the emissions offsets for using biomass boilers instead of HFO are calculated.

Namibia Breweries estimates that carbon emissions will be reduced by 8,000 tonnes per annum by replacing 80% of its use of HFO with woodchips. In Otjozondjupa, once all biomass boilers are operations, carbon emissions would be reduced by around 40,000 tonnes per annum. This represents a reduction of 720,000 tonnes over the 25 year horizon.

This reduction in emissions can be valued in the same way as in Section **Error! Reference source not found.**, i.e. using a carbon price of N$60/t$CO_2$e. An avoided cost of up to N$2.4 million (2015 prices, undiscounted) could be achieved per annum. Over the 25 year horizon, the discounted benefit was estimated at N$18.1 million (2015 prices).

Chart 11.8: Benefit of carbon offsets of biomass power generation for industry



11.4.5.1 Sensitivity analysis

If the SCC is used to value the offset emissions from power generation for industry (see Section 7.2), the net benefit would be N$215.8 million over the 25 years, almost twelve times the net benefit in the central case.

Table 11.5: Sensitivity analysis for offset emissions from power generation for industry

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**0.0**	**18.1**	**18.1**
SCC	0.0	215.8	215.8

1: 2015 prices, discounted by 6% p.a.

11.5 Electricity generation

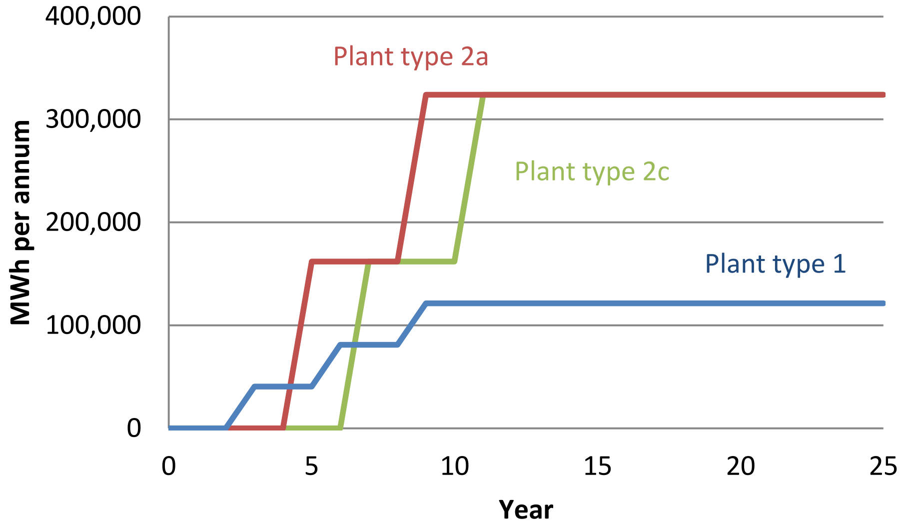
Our analysis of the potential benefits and costs of electricity generation is based on scenarios outlined in WSP (2012a, 2012b, 2012c): *Prefeasibility Study for Biomass Power Plant, Namibia: Power Plant Technical Assessment; Commercial Assessment; and Preliminary Carbon Funding Analysis*. Updated and more robust feasibility studies are expected to get underway shortly.

See Section 26.5 for the detailed methodology and limitations and risks.

11.5.1 Benefits of electricity generation from biomass

The development of three 5MW plants (type 1), two 20MW plants using grate combustion with steam turbine, with the additional energy input of heated air (type 2a), and two 20MW plants using grate combustion with steam turbine, with no additional energy input (type 2c) was envisaged along an assumed timeline (see Chart 11.9).

Chart 11.9: Electricity generation from de-bushed biomass



Based on this timeline, estimates of biomass consumption and output by WSP (2012a), and the average price of electricity (the 2015 average tariff of N$1.28/kWh), the discounted benefit was estimated at **N$7.4 billion** over the 25 year horizon.

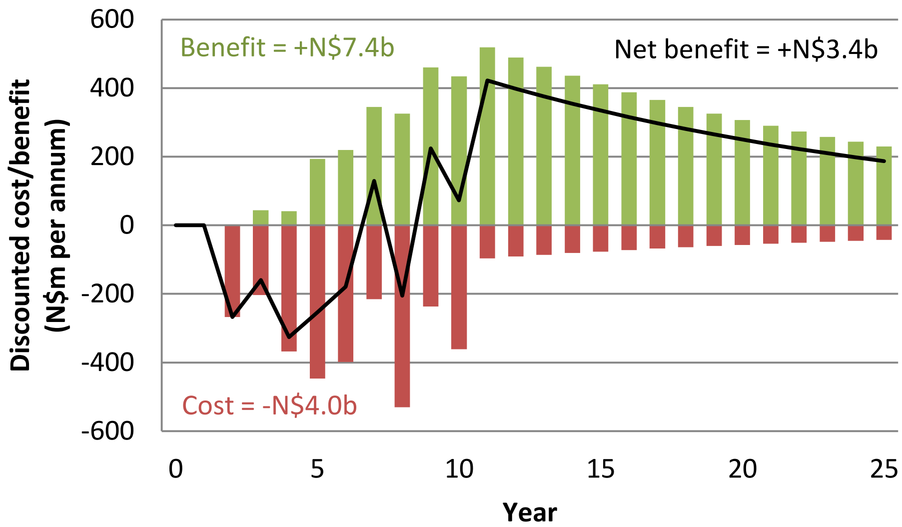
11.5.2 Financial cost of electricity generation from biomass

The capex and opex according to WSP (2012a) were used to estimate a discounted cost of **N$4.0 billion** over the 25 year horizon.

11.5.3 Net benefit

The net benefit for biomass electricity generation was estimated at **N$3.4 billion** (2015 prices, discounted).

Chart 11.10: Benefit, cost, and net benefit of biomass electricity generation



11.5.4 Sensitivity analysis

The capacity, price, and cost of electricity generation were varied. An increase from 95MW to 140MW would result in an estimated net benefit of N$4.9 billion while a decrease to 50MW would result in an estimated net benefit of N$1.1 billion.

NamPower estimates that the breakeven price for biomass-fuelled electricity would be N$2.00 to N$2.20/kWh[16][17]. This would be significantly higher than the current electricity tariff of around N$1.28/kWh. It is therefore reasonable to expect that the government would have to subsidise electricity to the tune of N$0.72/kWh, which represents a cost to society (see Section **Error! Reference source not found.** for more information). Consequently, the net economic value of the additional electricity supply could be much lower. If the net economic value (price) was 20% lower,

[16] NamPower (pers. comm.)
[17] Although this is higher than the current tariff of N$1.28, it is lower than the Kudu power plant's estimated breakeven price of N$2.55. This implies lower production costs for a biomass power plant compared with the Kudu plant proposal.

the net benefit is estimated at N$1.9 billion over the 25 year horizon, but it could be much lower than this.

When the cost of production was varied by +/-20%, the estimated net benefit ranged from N$2.6 billion to N$4.2 billion.

Table 11.6: Sensitivity analysis for electricity production

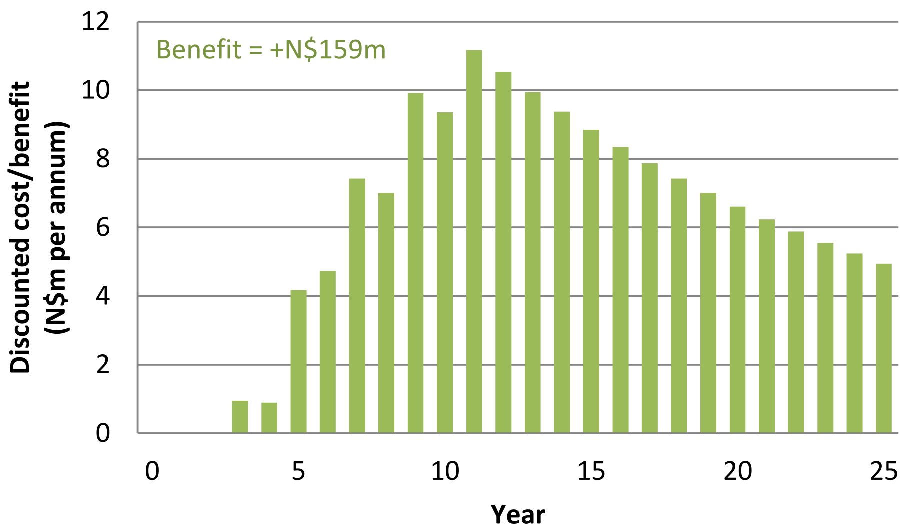
Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**4,022.8**	**7,403.7**	**3,380.9**
Capacity			
+45MW	4,362.7	9,293.2	4,930.5
-45MW	3,523.5	4,575.3	1,051.8
Price			
+20%	4,022.8	8,884.5	4,861.6
-20%	4,022.8	5,923.0	1,900.1
Cost			
+20%	4,827.4	7,403.7	2,576.3
-20%	3,218.3	7,403.7	4,185.5

1: 2015 prices, discounted by 6% p.a.

11.5.5 Benefit of emissions offsets

The impact of electricity generation from biomass on net carbon sequestration in Otjozondjupa was estimated using assumptions of emissions in WSP (2012c). The discounted benefit was estimated at **N$159.4 million** (2015 prices) over 25 years.

Chart 11.11: Benefit of carbon offsets of electricity generation from biomass power plants



11.5.5.1 Sensitivity analysis

If the SCC is used to value the offset emissions from electricity generation (see Section 7.2), the net benefit would be N$1.9 billion over the 25 years, around twelve times the net benefit in the central case.

Table 11.7: Sensitivity analysis for offset emissions from electricity generation

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**0.0**	**159.4**	**159.4**
SCC	0.0	1,917.7	1,917.7

1: 2015 prices, discounted by 6% p.a.

11.6 Residual biomass and bush banks

Most studies recommend that some of the de-bushed biomass be left on the land, rather all of it being removed, in order to return nutrients to the soil and provide some protection for new grasses coming through. Hengari (2016) recommends that all encroacher bushes be shredded and left on the ground to improve water and nutrient retention and protect the soil, to ultimately increase productivity. In financial terms, this would be unlikely to be feasible, as we find that utilisation of the biomass is key to offsetting the costs of de-bushing. However, we accept that it is vital to leave some of the de-bushed material on the land for the above reasons.

See Section 26.6 for the detailed methodology and limitations and risks.

11.6.1 Benefit

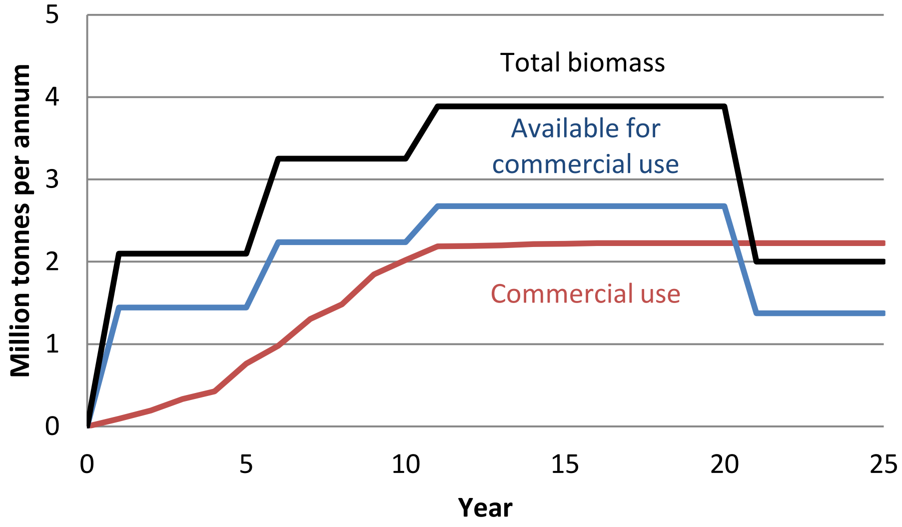
Leaves and twigs are not considered useful for charcoal, electricity, and firewood production, so we suggest that these are left on the land. Smit et. al. (2015) provide estimates of leaf and twig mass to woody mass in different encroacher bushes. We take an estimate of 15% from here. This means that for the commercially utilisable de-bushed biomass (i.e. produced by large scale and small-to-medium scale mechanical harvesting), 15% of all material de-bushed in the initial, follow up and aftercare rounds would be left on the land.

Furthermore, N-BiG recommends that biomass produced by semi-mechanical and manual de-bushing and by the manual application of arboricides are not suitable for large-scale commercial utilisation. We assume that all of the biomass produced by semi-mechanical and manual de-bushing would be left on the ground but disregarded the bushes treated by arboricides.

In total, this would equate to 16.7 million tonnes of biomass being left on the ground over the 25 years.

According to the analysis of the utilisation of biomass (Sections 11.1, 11.2, 11.3, 11.4, and 11.5), Otjozondjupa/Namibia would not have the capacity to utilise all of the produced biomass until Year 21, after the initial round of de-bushing has been completed. This is shown in Chart 11.12.

Chart 11.12: De-bushed biomass, biomass available for commercial use, and actual commercial use of biomass



This leaves two options:

1. Leave the residual amount on the ground
2. Store it for future use in a bush bank

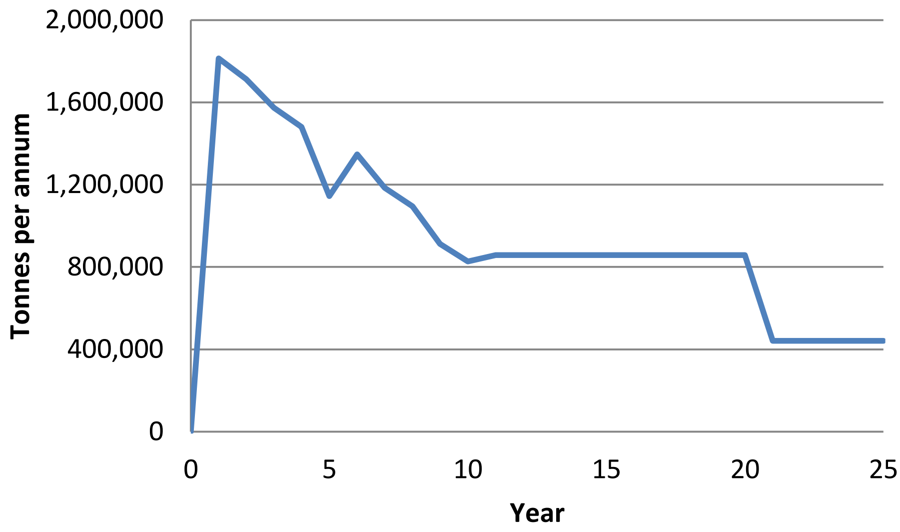
We look at a scenario that includes both options.

In our scenario, we take Ndilula, Kangombe, and Zireva's (2016) cost estimate for a bush bank, which results in a discounted total cost of **N$131.7 million**.

We assume that no surplus biomass would be stored in Years 1 to 5 – this would instead be left on the ground. We assume that 50% of surplus biomass would be stored in Years 6 to 10 – the other 50% would be left on the ground. We then assume that all surplus biomass from Years 11 to 20 would be stored for future use.

When we include the additional biomass to be left on the ground to the initial estimates above, this would result in a total of 23.9 million tonnes of biomass being left on the ground over the 25 years (Chart 11.13).

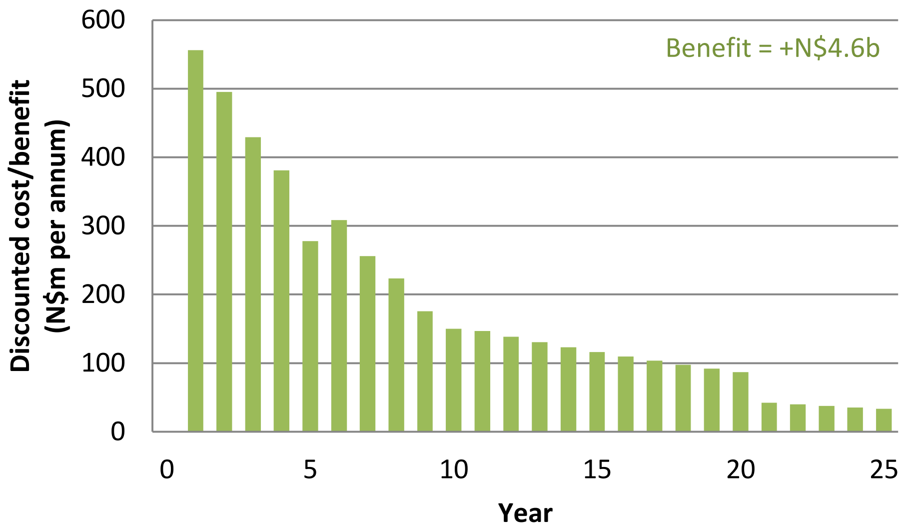
Chart 11.13: Residual biomass from de-bushing



To value the benefits of this residual biomass that is left on the ground, we take a price for mulch. For a cubic metre of mulch in South Africa, the price is R130 (=N$130)[18]. A weight-to-volume estimate of 400kg/m^3 was used to arrive at a price of N$325/tonne of residual biomass.

The volume of volume of biomass left on the ground after de-bushing was then multiplied by this price to estimate its value. The discounted benefit was estimated at **N$4.6 billion** over the 25 year horizon.

Chart 11.14: Benefit of leaving residual biomass on the land



[18] http://www.reliance.co.za/productpricelist.html

12 Social and economic impacts

12.1 Social benefits of additional employment and household income

Employment is considered a cost in cost-benefit analysis. Labour costs are included in cost estimates in Sections 6 to 11. However, additional employment can also offer benefits, particularly in a country like Namibia where unemployment is incredibly high and youth employment is even higher. The social benefits of employment can include income security and higher living standards, improvements in health and education, decreased crime and drug use, decreased family disruption, and so on.

Additional jobs and household income (labour costs) per annum were estimated for five sectors impacted by de-bushing: de-bushing operations, livestock production, hunting and game, charcoal production, and electricity production. Chart 12.1 and Chart 12.2 illustrate the additional jobs and household income that would be generated in each sector.

Chart 12.1: Additional jobs by sector

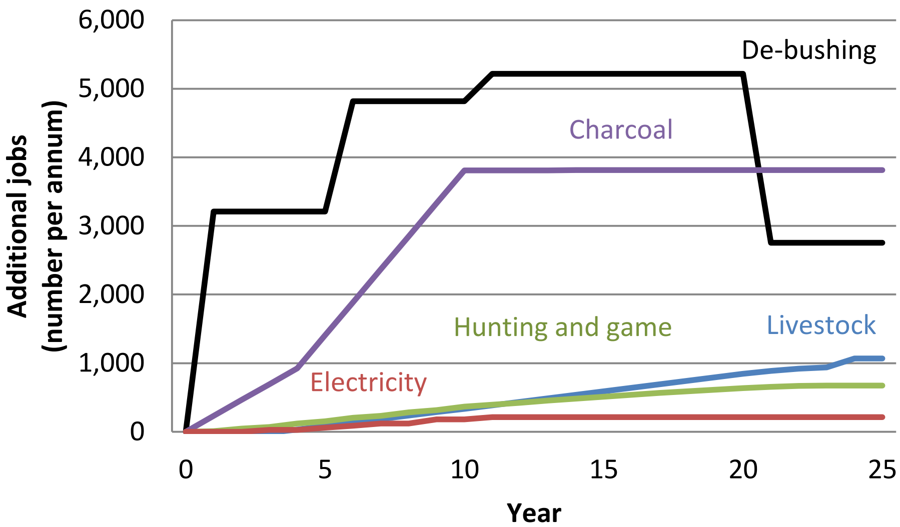
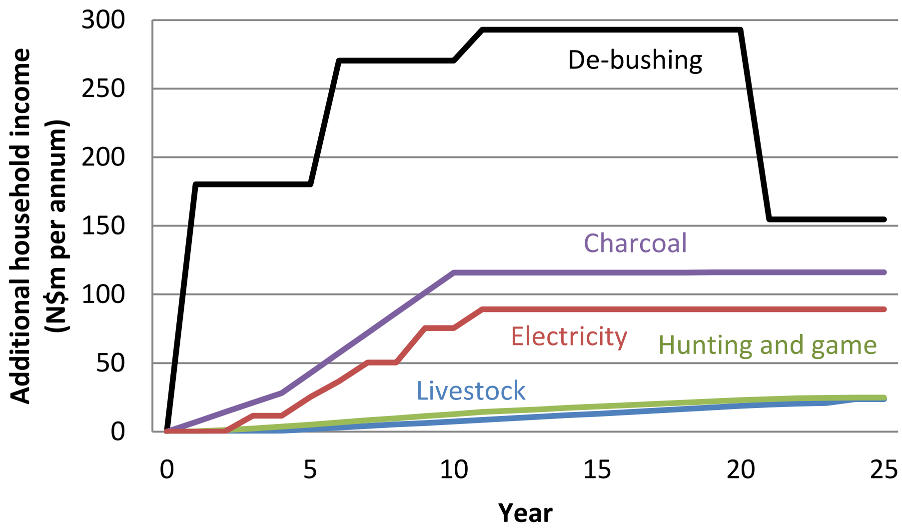


Chart 12.2: Additional household income by sector



12.2 Wider economic impacts

Additional employment and household income also have positive impacts on the wider economy. The income that these newly employed workers earn will be spent on goods and services, which creates income for the providers of these goods and services. This income will then be spent on more goods and services, and so on. This is called the multiplier effect.

We now estimate the value of this multiplier effect. It should be noted that this analysis only includes economic multiplier effects of additional income in five of the sectors directly impacted by de-bushing. It does not take into account income in secondary industries that support these sectors, such as transport, meat processing, export industries, and retail. If these secondary industries were taken into account, the positive economic benefits would be larger.

We need to take into account the proportion of the income that will be actually spent on goods and services in Namibia, thereby stimulating the Namibian economy. The marginal tax rate (MTR) is applied to the additional income to calculate the additional disposable income. The marginal propensity to consume (MPC) is the proportion of additional disposable income that is actually spent (the rest is assumed to be saved). The marginal propensity to import (MPI) is applied to isolate the additional income that is spent on Namibian goods and services (stimulating the Namibian economy rather than other countries' economies). The formula for multiplier effects is shown below:

$$\textit{Multiplier effects} = 1 / (1 - (MPC * (1 - MTR) - MPI))$$

UNDP (2010) quote Odada et. al.'s (2009) estimates for the MPC (0.89), the MTR (0.282), and the MPI (0.543) for Namibia. These are input into the formula:

$$\textit{Multiplier effects} = 1 / (1 - (0.89 * (1 – 0.282) – 0.543))$$
$$= 1.1$$

This means that every N$1 of new income generates an additional N$1.1 of extra income within Namibia.

There is generally a lag before the full effect of the multiplier is realised, as it takes time for the money to change hands. Therefore, we assumed that half the effects would be realised in the same year as the increase in income, and that the remaining half would be realised the following year.

The discounted benefits of these multiplier effects are shown in Chart 12.3 (per annum) and Table 12.1 (over 25 years). The total discounted benefit is estimated at **N$5.3 billion** (2015 prices) over 25 years.

Chart 12.3: Benefits of multiplier effects by sector

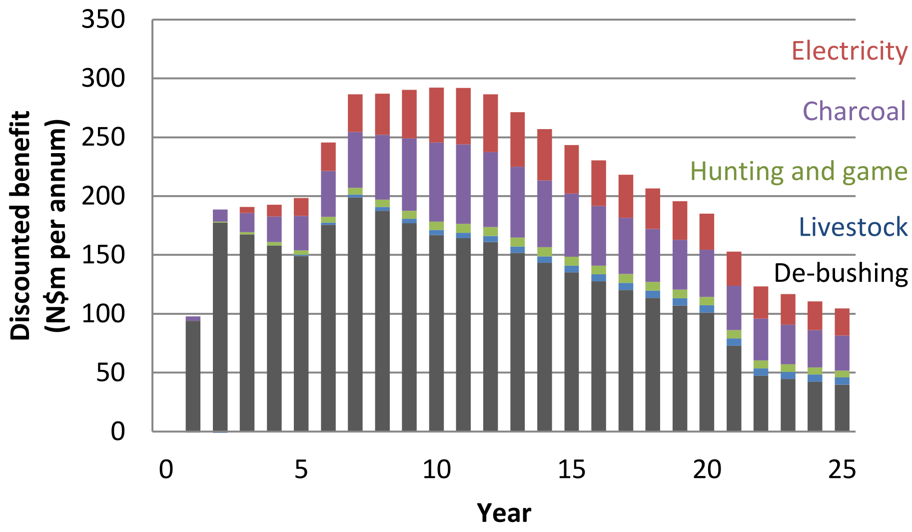


Table 12.1: Benefits from multiplier effects over 25 years

Sector	Multiplier effects (N$m[1])
De-bushing	3,224
Livestock production	102
Hunting and game products	147
Charcoal	1,047
Electricity generation	741
Total	**5,261**

1: 2015 prices, discounted, over 25 years

12.2.1 Limitations and risks

The values given for MPC, MTR, and MPI are averages for Namibia. They do not take into account whether the income goes to high, medium, or low income households. As many additional jobs in de-bushing, cattle and game farming, and charcoal production would be unskilled, a significant proportion of the additional income would go towards low income households, which are likely to have a higher MPC and lower MTR and MPI. Therefore, the multiplier effects could be considerably larger.

12.3 Social costs of de-bushing operations

There are some social costs that should be considered with regard to de-bushing operations. If temporary workers are employed to de-bush on farms, this can pose some potential challenges. For example, one farmer who was interviewed chose to use aerial arboricides as their initial de-bushing strategy rather than employing workers to de-bush mechanically. This was partly due to concerns related to having a group of itinerant workers on their property, such as social disruption and potential poaching, as well as having to build or provide amenities for the workers. Other social costs could include the spread of HIV-AIDS and other diseases, crime, and impacts on local services.

13 Cost-benefit analysis

13.1 Central case

In the central case, the net benefits of de-bushing accrued to an estimated **N$4.9 billion** (2015 prices, discounted at 6%) over 25 years (see Table 13.1). Benefits were estimated at **N$25.1 billion** and costs were estimated at **N$20.3 billion**. This is based on the central assumptions discussed in Sections 3 and 6 to 12.

Table 13.1: Cost-benefit analysis – central case

N$m[1]	Cost	Benefit	Net benefit
De-bushing	**12 469.9**	**0.0**	**- 12 469.9**
Initial round	8 544.3	0.0	- 8 544.3
Follow ups	3 925.7	0.0	- 3 925.7
Ecosystem services	**2 160.2**	**2 854.9**	**694.8**
Cattle production	993.3	1 139.3	146.0
Water	24.1	430.5	406.4
Wildlife viewing	0.0	22.7	22.7
Hunting and game products	882.9	1 084.9	202.0
Carbon sequestration	259.9	177.5	- 82.4
SOC	*64.4*	*0.0*	*- 64.4*
Offsets	*0.0*	*177.5*	*177.5*
Cattle	*195.5*	*0.0*	*- 195.5*
Utilisation	**5 488.5**	**16 716.0**	**11 227.5**
Charcoal	1 076.5	2 466.3	1 389.7
Firewood	0.0	633.8	633.8
Animal feed	217.7	952.3	734.7
Industry power	171.4	672.9	501.5
Electricity generation	4 022.8	7 403.7	3 380.9
Residual biomass	0.0	4 587.0	4 587.0
Bush bank	**131.7**	**0.0**	**- 131.7**
Option values	**0.0**	**310.0**	**310.0**
Cattle	0.0	215.7	215.7
Game	0.0	94.3	94.3
Multiplier effects	**0.0**	**5 254.0**	**5 254.0**
De-bushing	0.0	3 223.8	3 223.8
Cattle production	0.0	101.9	101.9
Hunting and game products	0.0	139.7	139.7
Charcoal	0.0	1 047.4	1 047.4
Electricity generation	0.0	741.1	741.1
TOTAL	**20 250.2**	**25 134.9**	**4 884.7**

1: 2015 prices, discounted at 6%

13.2 Scenario and sensitivity analysis

13.2.1 Best case scenario

In the best case scenario, we estimate that net benefit could be as high as **N$10.6 billion**.

Table 13.2: Cost-benefit analysis – best case scenario

N$m[1]	Cost	Benefit	Net benefit
De-bushing	**9 976.0**	**0.0**	**- 9 976.0**
Ecosystem services	**2 574.7**	**4 312.1**	**1 737.4**
Cattle production	993.3	1 367.1	373.8
Water	48.1	1 109.0	1 060.9
Wildlife viewing	0.0	22.7	22.7
Hunting and game products	1 273.4	1 595.0	321.6
Carbon sequestration	259.9	218.2	- 41.7
SOC	*64.4*	*0.0*	*- 64.4*
Offsets	*0.0*	*218.2*	*218.2*
Cattle	*195.5*	*0.0*	*- 195.5*
Utilisation	**5 828.4**	**19 502.8**	**13 674.4**
Charcoal	1 076.5	2 959.5	1 883.0
Firewood	0.0	760.5	760.5
Animal feed	217.7	1 142.8	925.1
Industry power	171.4	759.8	588.4
Electricity generation	4 362.7	9 293.2	4 930.5
Residual biomass	0.0	4 587.0	4 587.0
Bush bank	**131.7**	**0.0**	**- 131.7**
Option values	**0.0**	**401.3**	**401.3**
Cattle	0.0	258.8	258.8
Game	0.0	142.4	142.4
Multiplier effects	**0.0**	**4 846.0**	**4 846.0**
De-bushing	0.0	2 579.1	2 579.1
Cattle production	0.0	101.9	101.9
Hunting and game products	0.0	204.7	204.7
Charcoal	0.0	1 047.4	1 047.4
Electricity generation	0.0	913.0	913.0
TOTAL	**18 510.7**	**29 062.2**	**10 551.5**

1: 2015 prices, discounted at 6%

This is in line with the following assumptions, which differ from the central case:

- De-bushing costs are 20% lower
- Carbon is valued at N$60 per tonne as in the central case
- Groundwater recharge increases to 3% of rainfall (rather than 2%)

- Beef price increases by 20%
- Game carrying capacity increases by 80% (rather than 50%)
- Charcoal, firewood, and animal feed price is 20% higher
- HFO price is 20% higher
- Capacity of electricity generation increases to 140MW (rather than 95MW)

13.2.2 Worst case scenario

In the worst case scenario, we estimate that the potential net benefit could be as low as **-N$2.9 billion**.

Table 13.3: Cost-benefit analysis – worst case scenario

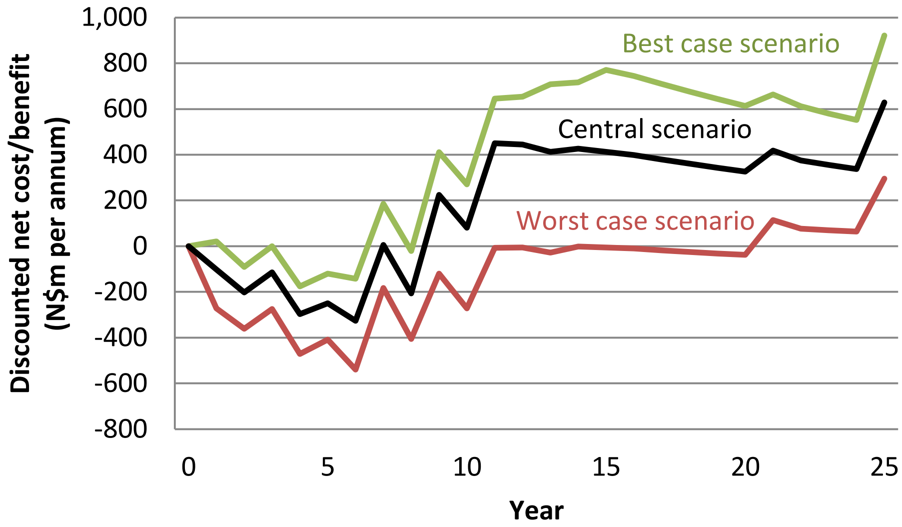
N$m[1]	Cost	Benefit	Net benefit
De-bushing	**14 963.9**	**0.0**	**- 14 963.9**
Ecosystem services	**4 714.7**	**3 149.5**	**- 1 565.2**
Cattle production	993.3	911.4	- 81.9
Water	12.0	91.2	79.2
Wildlife viewing	0.0	22.7	22.7
Hunting and game products	622.6	744.8	122.2
Carbon sequestration	3 086.8	1 379.2	- 1 707.5
SOC	*695.9*	*0.0*	*- 695.9*
Offsets	*0.0*	*1 379.2*	*1 379.2*
Cattle	*2 390.9*	*0.0*	*- 2 390.9*
Utilisation	**4 989.1**	**12 990.2**	**8 001.1**
Charcoal	1 076.5	1 973.0	896.5
Firewood	0.0	507.0	507.0
Animal feed	217.7	761.9	544.2
Industry power	171.4	586.1	414.7
Electricity generation	3 523.5	4 575.3	1 051.8
Residual biomass	0.0	4 587.0	4 587.0
Bush bank	**131.7**	**0.0**	**- 131.7**
Option values	**0.0**	**234.8**	**234.8**
Cattle	0.0	172.6	172.6
Game	0.0	62.2	62.2
Multiplier effects	**0.0**	**5 565.8**	**5 565.8**
De-bushing	0.0	3 832.1	3 832.1
Cattle production	0.0	101.9	101.9
Hunting and game products	0.0	96.4	96.4
Charcoal	0.0	1 047.4	1 047.4
Electricity generation	0.0	488.1	488.1
TOTAL	**24 799.4**	**21 940.3**	**- 2 859.1**

1: 2015 prices, discounted at 6%

This is in line with the following assumptions, which differ from the central case:

- De-bushing costs are 20% higher
- Carbon is valued at the SCC
- Groundwater recharge increases to 1.5% of rainfall (rather than 2%)
- Beef price decreases by 20%
- Game carrying capacity increases by 30% (rather than 50%)
- Charcoal, firewood, and animal feed price is 20% lower
- HFO price is 20% lower
- Capacity of electricity generation increases to 50MW (rather than 95MW)

Chart 13.1: Costs and benefits in the central, best, and worst case scenario



13.2.3 Discount rates

One of the most important variables to undergo sensitivity analysis is the discount rate, as the choice of rate can be quite subjective and it can significantly impact the final outcome. In the central case, a real discount rate of 6% per annum was used. This is consistent with the real discount rate used in the Wildlife Resource Accounts of Namibia (Barnes et. al. 2009).

Table 13.4 shows how the net benefit (2015 prices) in the central case varies at discount rates ranging from 4% to 12%. The net benefit is estimated at **N$1.3 billion** at a discount rate of 12%, but at a discount rate of 4%, the net benefit is estimated at **N$7.3 billion**. The net benefits tend to decrease as the discount rate rises because the benefits of de-bushing tend to be weighted towards the middle and end of the time horizon and are consequently more heavily discounted.

Table 13.4: Cost, benefit, and net benefit at varied discount rates

Discount rate (%)	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
4	25,019.6	32,339.2	7,319.5
6	**20,250.2**	**25,134.9**	**4,884.7**
8	16,689.7	19,929.1	3,239.4
12	11,890.6	13,232.8	1,342.2

1: 2015 prices, discounted

14 Business cases

14.1 Value addition industries

The cost-benefit analysis in Section 13 does not allocate the cost of de-bushing (or of woodchips) to each sector, based on the amount of harvested biomass that they would demand. In Table 14.1, we estimate the sector-specific cost of de-bushing (i.e. how much it would cost in de-bushing to harvest enough biomass for commercial use), while taking into account the need to leave 15% of biomass on the ground as well as a waste factor of 10%. When the sector-specific cost of de-bushing is subtracted from the net benefit for each industry, estimated in Section 13.1, we find the industry net benefit.

Animal feed (N$686 million), biomass power generation for industry (N$282 million), and electricity generation from biomass (N$1.9 billion) all have a positive net benefit (2015 prices, discounted) over the 25 years when also taking into account the sector-specific cost of de-bushing. On the other hand, we find that the charcoal industry would incur a net cost of N$1.6 billion.

Table 14.1: Industry net benefit and social net benefit for value addition industries

N$m 2015 prices, discounted[1] Industry	Net benefit (ex-de-bushing costs)	Sector-specific cost of de-bushing	Industry net benefit	Industry multiplier effects	De-bushing multiplier effects	Social net benefit
Charcoal	1 389.7	3 012.8	**-1 623.1**	1 047.4	727.4	**151.7**
Animal feed	734.7	48.3	**686.4**	nc	nc	**686.4**
Power for industry	501.5	219.4	**282.2**	nc	nc	**282.2**
Electricity	3 380.9	1 477.6	**1 903.3**	741.1	359.3	**3 003.8**

nc: not calculated
1: over 25 years

However, we still need to account for the multiplier effects from additional employment (and income) for each industry and for the de-bushing that each industry would necessitate, regardless of whether the de-bushing is conducted directly by the industry or indirectly through external agents. These have only been calculated for the charcoal and electricity industries. Added to the industry net benefit, this represents the social net benefit.

We find that despite charcoal having a negative industry net benefit, once the wider economic impacts are taken into account, the social net benefit is positive at around N$152 million (2015 prices, discounted) over the 25 years. The social net benefit for electricity generation for industry is easily the biggest of all sectors, at N$3.0 billion.

14.2 Cattle, mixed use, and game farming

We looked at the business case for a single, established farm of each type (cattle only, mixed use, and game only).

The assumptions for farm-specific revenue (beef and game meat production, trophy hunting) were the same as in Sections 9 and 10.2. We assumed three options for de-bushing:

1. **Contracted de-bushing, at cost**, where the farmer pays for the de-bushing and doesn't sell or use the biomass.

2. **Contracted de-bushing, no cost**, where an external contractor carries out the de-bushing without charging the farmer and sells or uses the biomass for their own benefit.
3. **Own/contracted de-bushing and sale of chips**, where the farmer or an external contractor carries out the de-bushing and the farmer sells the biomass.

For option 1, it was assumed that semi-mechanical and manual de-bushing would be used to keep costs down and given that the biomass would not be used commercially. For options 2 and 3, as the biomass would be used commercially, it was assumed that small-to-medium-scale de-bushing would be used. 75% of the biomass could be sold (subtracting 15% to be left on the ground and a waste factor of 10%). The current market price is between N$850-900 per tonne.

Over 25 years, and assuming the initial round of de-bushing was carried out in Year 1, it was found that none of the farms would make a profit if they had to pay for the de-bushing themselves without profiting from the biomass (option 1). Under option 2, the game farm would be the most profitable with a net benefit of N$5 million, followed by mixed use (N$3.5 million) and cattle (N$1.4 million). Game farms were also most profitable when farmers sold the produced woodchips.

Table 14.2: Business cases for a single farm – cattle, mixed use, and game

N$m 2015 prices, discounted[1] Farm type	Contracted de-bushing, at cost	Contracted de-bushing, no cost	Own/contracted de-bushing and sale of chips
Cattle farm (5000ha)	-5.8	1.4	3.9
Mixed use (7500ha)	-3.7	3.5	6.0
Game farm (7500ha)	-2.2	5.0	7.5

1: over 25 years Source: Venter 2015, N-BiG

14.3 Grass farming

Grass farming is small but growing industry that would also benefit from de-bushing. It requires the land to be completely cleared, rather than de-bushing selectively.

One farmer, Michael Happel[19], in the Hochland-Okahandja area, reports very impressive results. The land is cleared at a cost of N$3,000/ha. Additional costs include treating the land with urea and/or other fertilisers. The given yield for grass farming was 2000 kg/ha of grass, harvested in February/March, while grass is still green and with seed. The aforementioned yield is per harvest, which during a good rainy year can be doubled.

In terms of revenue, during a drought year, 2000kg of grass could be harvested over 500 ha and sold at N$2.5/kg (N$50 for a 20kg bail). This amounts to $2.5 million per annum. During a wet year, two harvests could generate revenue of N$5.0 million per annum. This could generate sufficient income to cover all farm operational costs.

[19] www.onjona.com

15 Policy recommendations

This study finds that a comprehensive programme of de-bushing could generate an estimated net benefit of **N$4.9 billion** (2015 prices, discounted at 6%) over 25 years when compared with a scenario of no de-bushing. Total cost is estimated at **N$20.3 billion** and total benefit is estimated at **N$25.1 billion**, which includes benefits for the wider economy of **N$5.3 billion**.

De-bushing could generate a net benefit for **livestock production**, **groundwater recharge and supply**, **wildlife viewing**, and **hunting and game products**, as well as **charcoal**, **firewood**, and **animal feed production**, and **power and electricity generation** (and **carbon offsets** for electricity). Furthermore, **wider economic (and social) benefits** would arise from the additional jobs and household income. However, it would result in net costs through **de-bushing operations**, additional **emissions from livestock**, and loss of **soil organic carbon**.

Sensitivity and scenario analysis indicate that the net benefit could range from -**N$2.9 billion** to **N$10.6 billion** (2015 prices, discounted). However, we believe that the worst case scenario is highly unlikely and instead that it would be reasonable to expect a higher net benefit than the central case.

It is estimated that up to **5,220 jobs per annum** could be generated by de-bushing operations and that by the end of the 25 years, **more than 5,700 additional full time jobs per annum** could be created and sustained in sectors benefited by de-bushing, namely cattle farming, game farming, charcoal production, and electricity generation. Furthermore, the additional household income in these industries would generate wider economic benefits of around **N$5.3 billion** (2015 prices, discounted) over the 25 years. This represents a substantial gain for Namibia's economy and social welfare.

Business case analysis shows that of the value addition industries, **animal feed**, **charcoal production**, and **electricity generation** all have estimated positive industry net benefits and social net benefits. Although the social net benefit for **charcoal production** is estimated to be positive, the industry net benefit is estimated to be negative. More efficient technology, and therefore lower demand for biomass, would close this gap somewhat. In terms of farming, **game farms** are estimated to generate the largest net benefit under three different payment options for de-bushing the land, followed by **mixed use farms**, and **cattle farms**.

Overall, these results suggest that the net benefit of a **comprehensive de-bushing programme in Otjozondjupa** would be significantly positive and make a considerable contribution to Otjozondjupa and Namibia's economy and social welfare. Furthermore, as we believe that many of the unquantified ecosystem services would be positively affected by de-bushing, it is reasonable to expect that there is **upside risk** to our estimates.

A comprehensive de-bushing programme deserves support from the **private sector**, which stands to reap returns in the long run, and the **public sector**, given the social, environmental, and economic benefits. In addition, it is in the interest of Namibians in Otjozondjupa and across the country, as well as the global community, to support an initiative that would **improve biodiversity and other unquantified ecosystem services**. Further research, focussing on the effects of de-bushing on ecosystem services that are currently unquantifiable or uncertain, the environmental impacts of de-bushing, and potential mitigation measures, would also be valuable.

We recommend a **pilot programme of de-bushing with two main objectives: to reduce bush encroachment and to facilitate research and data collection**. Research should focus on the effects of de-bushing on relevant ecosystem services that are currently unquantifiable or uncertain, such as groundwater recharge, the environmental impacts of de-bushing, and potential mitigation measures.

We have discussed the potential environmental costs of de-bushing operations but little progress been made in quantification and valuation. These potential costs could have a material impact on the outcome. For example, if de-bushing destabilises the soil, increasing erosion and runoff, this could further degrade the land rather than improve it. The decision to de-bush and the harvest method should be appropriate to each specific location.

A notable risk of de-bushing is that increased stocking rates (in response to increased carrying capacity) could potentially lead to overgrazing, which would in turn encourage bush encroachment. Good rangeland management practices will be crucial in preventing a vicious cycle of bush encroachment, de-bushing, restocking, overgrazing, and back to bush encroachment.

The complementarity between the sector approaches could also be explored in greater depth. In our analysis, we have estimated how additional cattle stocking rates would affect groundwater extraction and emissions from livestock and how biomass-fuelled power and electricity generation would affect groundwater extraction and offset emissions from alternative sources (such as coal-fired plants), but there are multiple other linkages. Furthermore, a biomass value adding and agri-industrial park could provide economies of scale and add value to the use of biomass.

As this analysis focusses on Otjozondjupa, it is congruent with the current IRLUP process in the region. This model for Otjzondjupa could also be expanded to the other bush-encroached areas of Namibia. However, it would firstly need to be adapted based on location specific factors, including land uses, encroacher species, other species, ecosystems, soil types, population pressures, and proximity to markets, before it would be relevant to other regional land use plans.

In conclusion, our assessment of the economics of land degradation related to bush encroachment in Otjozondjupa indicates that de-bushing has the potential to generate a substantial net benefit for Otjozondjupa and Namibia of N$4.9 billion (2015 prices, discounted) over 25 years and thus contribute to Namibia’s economic growth and social welfare. We recommend a pilot programme of de-bushing that should be supported by both the public and private sector.

16 Conclusion

This report presents a cost-benefit analysis of de-bushing in Otjozondjupa, Namibia. New data on bush density was collected by the LDN project and used in this analysis. From this, bush encroachment was delineated according to location and density and assessed in relation to ecosystems, land use, and rainfall. Ecosystem services impacted by bush encroachment were identified and their likely direction of change in response to de-bushing was discussed.

Key ecosystems services, for which there were adequate data, were quantified and valued to determine the costs and benefits that would be the result of de-bushing. The investment, operating, and maintenance costs that would be required to realise the benefits for ecosystem services and value addition industries were also estimated. Furthermore, the rise in wealth associated with increases in stock of cattle and game and the wider economic impacts of additional jobs and income were estimated. These values were fed into a cost-benefit model to determine the net benefit by sector and overall.

Otjozondjupa is severely impacted by bush encroachment; the majority of the region's 10.5 million hectares are affected and it has negative impacts on the region's livestock and game farmers, both commercial and communal. Bush encroachment is largely the result of habitat change. Overgrazing is thought to be a key driver of bush encroachment, but the displacement of browsers by livestock, the suppression of high intensity fires due to cattle farming, and increased atmospheric CO_2 concentrations are also likely contributors.

De-bushing was estimated to generate a positive net benefit for livestock production, groundwater recharge, wildlife viewing, hunting and game products, and biodiversity. It would also provide biomass for value addition industries, such as charcoal, firewood, and animal feed production, power generation for industry, and electricity generation, as well as construction materials and crafts.

However, de-bushing is also likely to have some negative effects. Mechanical means of de-bushing can disrupt the soil and non-encroacher vegetation while chemical means have the potential to poison non-target vegetation and water sources. As bushes are a carbon sink, de-bushing was estimated to decrease the amount of carbon sequestered, in the soil as well as in the woody component. Furthermore, if cattle stocks are increased in response to de-bushing, this would increase greenhouse gas emissions.

In the central case, it was estimated that the net benefit of de-bushing would amount to N$4.9 billion (2015 prices, discounted) over 25 years. However, under varying assumptions and scenarios, net benefits ranged from -N$2.9 billion to N$10.6 billion. As we expect that many of the non-quantified ecosystem services would likely benefit from de-bushing, there is upside risk to our estimates.

In terms of value addition industries, it was found that electricity generation would realise the greatest net benefit, both for the industry itself and for the wider economy and society via multiplier effects. Charcoal was found to have a negative industry net benefit, but this could be improved with more efficient technology. It was estimated to have a positive social net benefit. In terms of land use, game farms were found to reap the greatest net benefit from de-bushing, followed by mixed use farms and cattle farms.

Overall, we believe that a comprehensive de-bushing programme in Otjozondjupa has the potential to generate substantial net benefits and contribute to Namibia's social welfare. A well-designed and regulated de-bushing programme warrants support from both the public and private sectors.

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18 Appendix I: the CICES

18.1 Provisioning services

Provisioning services are "*all nutritional, material and energetic outputs from living systems*". The nutritional and material divisions are disaggregated into groups that distinguish those arising from biological materials (biomass) and water, while for energetic outputs there is a distinction between biomass-based energy sources and mechanical energy. Table 3 illustrates the breakdown of provisioning services.

Table 18.1: Provisioning services in CICES

Division	Group	Class	*Examples*
Nutrition	Biomass	Cultivated crops	*Cereals, vegetables, fruits etc.*
		Reared animals and their outputs	*Meat, dairy products, honey etc.*
		Wild plants, algae and their outputs	*Wild berries, fruits*
		Wild animals and their outputs	*Game, fish*
		Plants and algae from in-situ aquaculture	*In situ seaweed farming*
		Animals from in-situ aquaculture	*In-situ farming of fish*
	Water	Surface water for drinking	*Collected precipitation for drinking*
		Ground water for drinking	*Freshwater abstracted from (non-fossil) groundwater layers for drinking*
Materials	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	*Wood, timber, skin which are not further processed; material for production e.g. devil's claw*
		Materials from plants, algae and animals for agricultural use	*Materials for fodder and fertilizer in agriculture and aquaculture*
		Genetic materials from all biota	*Genetic material (DNA) from wild plants, for biochemical industrial and pharmaceutical processes e.g. medicines*
	Water	Surface water for non-drinking purposes	*Collected precipitation for domestic, agricultural and/or industrial use*
		Ground water for non-drinking purposes	*Freshwater abstracted from (non-fossil) groundwater layers for domestic, agricultural and/or industrial use*
Energy	Biomass-based energy sources	Plant-based resources	*Wood fuel, straw for burning and energy production*
		Animal-based resources	*Fat, oils, from animals for burning and energy production*
	Mechanical energy	Animal-based energy	*Physical labour provided by animals*

18.2 Regulation and maintenance services

Regulation and maintenance services "*cover all the ways in which living organisms can mediate or moderate the ambient environment that affects human performance*". There are consequently three major divisions of regulation and maintenances services: the mediation of waste, toxics and other nuisances; the mediations of flows; and the maintenance of physical, chemical and biological conditions. The various groups and classes that relate to these divisions are presented in Table 4.

Table 18.2: Regulation and maintenance services in CICES

Division	Group	Class	*Examples*
Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants, and animals	*Bio-chemical detoxification/decomposition/ mineralisation in land/soil, freshwater and marine systems*
		Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	*Biological filtration/sequestration/storage/ accumulation of pollutants in land/soil*
	Mediation by ecosystems	Filtration/sequestration/storage/accumulation by ecosystems	*Bio-physicochemical filtration/sequestration/storage/accumulation of pollutants in land/soil*
		Dilution by atmosphere, freshwater and marine ecosystems	*Bio-physical-chemical dilution of fluids, wastewater in lakes, rivers, sea*
		Mediation of smell/noise/visual impacts	*Visual screening of transport corridors e.g. by trees*
Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates	*Erosion protection*
		Buffering and attenuation of mass flows	*Transport and storage of sediment by rivers*
	Liquid flows	Hydrological cycle and water flow maintenance	*Capacity of maintaining baseline flows for water supply and discharge*
		Flood protection	*Flood protection by appropriate land coverage*
	Gaseous / air flows	Storm protection	*Natural or planted vegetation serving as shelter*
		Ventilation and transpiration	*Natural or planted vegetation that enables air ventilation*
Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal	*Seed dispersal by insects, birds and other animals*
		Maintaining nursery populations and habitats	*Habitats for plant and animal nursery and reproduction*
	Pest and disease control	Pest control	*Pest and disease control e.g. invasive alien species*
		Disease control	*In cultivated and natural ecosystems and human populations*
	Soil formation and composition	Weathering processes	*Maintenance of bio-geochemical conditions of soils*
		Decomposition and fixing processes	*Maintenance of bio-geochemical conditions of soils by decomposition of dead organic material*
	Water conditions	Chemical condition of freshwaters	*Maintenance of chemical composition of freshwater column*
		Chemical condition of salt waters	*Maintenance of chemical composition of seawater column*

	Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations	*Global climate regulation by greenhouse gas/carbon sequestration by terrestrial ecosystems*
		Micro and regional climate regulation	*Maintenance of rural and urban climate and air quality and regional precipitation/temperature patterns*

18.3 Cultural services

Cultural services "*cover all the non-material, and normally non-consumptive, outputs of ecosystems that affect physical and mental states of people*". The cultural category can be problematic as a result of the way the terminology is used; there is often not a clear distinction between services and benefits (see Section 2.2). Consequently CICES suggests that cultural services are primarily regarded as "*the physical settings, locations or situations that give rise to changes in the physical or mental states of people, and whose character are fundamentally dependent on living processes*".

Two divisions of cultural services are specified: physical and intellectual interactions with ecosystems and land-/seascapes; and spiritual, symbolic and other interactions with ecosystem and land-/seascapes. The detailed breakdown of cultural services is presented in Table 5.

Table 18.3: Cultural services in CICES

Division	Group	Class	*Examples*
Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings	*In-situ whale and bird watching, snorkelling, diving etc.*
		Physical use of land-/seascapes in different environmental settings	*Walking, hiking, climbing, recreational fishing (angling), recreational hunting*
	Intellectual and representative interactions	Scientific	*Subject matter for research*
		Educational	*Subject matter of education*
		Heritage, cultural	*Cultural heritage*
		Entertainment	*Ex-situ viewing/experience of natural world through different media*
		Aesthetic	*Sense of place, artistic representations of nature*
Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Spiritual and/or emblematic	Symbolic	*Emblematic plants and animals e.g. Namibian Oryx, Welwitschia*
		Sacred and/or religious	*Spiritual identity; sacred plants and animals and their parts*
	Other cultural outputs	Existence	*Enjoyment provided by wild species, wilderness, ecosystems, land-/seascapes*
		Bequest	*Willingness to preserve plants, animals, ecosystems, land-/seascapes for the experience and use of future generations*

18.4 CICES, final ecosystem services and double-counting

CICES makes clear that it focuses on final ecosystem services, which as noted in Section 2.1 represent the point of interaction between humans and ecosystems. This distinction is important to avoid double-counting in the contribution of ecosystem services to benefits. Indeed, the SEEA-EEA recognises that "*ecosystem services…should be measured only when SNA or non-SNA benefits can be identified*".

However it is not necessarily possible to identify the benefits for each of the ecosystem services within the CICES framework. One example can be seen in the presence of separate provisioning ecosystem service classes of *reared animals and their outputs* (e.g. meat) and *surface water for non-drinking purposes* (e.g. water for livestock), where the latter can clearly represent an input to the former. Consequently the ultimate benefit derived from the provisioning service of water for livestock in this example is realised when it is used to produce meat, and taking them individually would double count the ultimate contribution of ecosystem services to benefits.

In order to avoid this issue of double-counting, the version of CICES adopted by SEEA is slightly different to that presented in this report. Instead of recognising the amount of meat or crops harvested as the ecosystem service with respect to reared animals or cultivated crops (the 'harvest approach'), it classifies as ecosystem services the flows related to nutrients, water and various regulating services (e.g. pollination) that contribute to their growth. The alternate version of CICES adopted by SEEA and a more detailed discussion can be found in SEEA-EEA p50.

Despite not being able to identify a direct and final contribution to a distinct benefit for each ecosystem service, this report maintains the full classification of CICES (as detailed in Table 3 – 5); it represents the most recent version of CICES and is appropriate for the purposes of developing an inventory of ecosystem services. The version presented in SEEA is conceptually significantly more complex, and it is not clear that the certainty of avoiding double-counting is worth this added complexity.

19 Appendix II: Ecosystem services – impacts of de-bushing

19.1 Provisioning

19.1.1 Cultivated crops

Bush encroachment theoretically reduces the available land for farming cultivated crops (e.g. maize, vegetables, sorghum, pearl millet, peanuts, sunflowers) or encroaches on fallow land, encouraging the opening of virgin land. In theory, it could also hamper growing conditions by increasing competition for water and nutrients at a landscape level. De-bushing for cultivation could therefore improve this service or offset other detrimental practices.

There is not enough data currently available to value the impact of de-bushing on crop production, but a methodology similar to that used for the valuation of livestock production (see below) could be used or an avoided loss value of opening up virgin land could be employed.

19.1.2 Reared animals and their outputs

Bush encroachment reduces available pasture land for livestock, particularly cattle, but also sheep and other livestock. It does this by restricting access for livestock and by reducing grass cover used for feed. Studies and anecdotal evidence suggest that current carrying capacities may be half of those experienced prior to severe bush encroachment. De-bushing should therefore increase carrying capacity.

19.1.3 Wild plants, algae and their outputs

Wild plants, often referred to in Namibia as Indigenous Natural Products (INP), can provide a source of food for humans (e.g. truffles, indigenous fruits such as marula and bird plum) and animals, including livestock (e.g. grasses, woody plants, indigenous fruits). They can also have medicinal uses (e.g. Devil's Claw).

With the exception of Mopane (which can be used for essential oils), bush encroachment likely has some opposing effects on this ecosystem service. The increased prevalence of certain woody plants comes at the expense of other trees and reduced grass cover. Dense bush could negatively impact the growth and harvest of wild plants, by reducing INP production through increasing competition for water, nutrients, and space and reducing harvest accessibility. De-bushing (up to a point) should therefore increase diversity, volume, and accessibility of INPs.

19.1.4 Wild animals and their outputs

While bush encroachment may reduce available land for wildlife, the switch to wildlife-based land uses (i.e. replacing cattle and other domesticated animals with game) could offset this to some extent, so the overall impact is unclear. It is therefore difficult to assess whether bush encroachment results in a net gain or loss of outputs such as game meat and skins. Browsers (e.g. goats, kudu, eland, dik dik, black rhino) can benefit from a certain degree of bush encroachment, which expands their food source. However, if bush is too dense and dominant, this could disadvantage browsers by restricting movement and access and reducing the variety of their food.

De-bushing that leaves a mosaic of habitats should therefore maximise wildlife diversity, numbers and accessibility. However, the lack of data and the uncertainty surrounding the net impact have prevented a robust valuation of this service. Section **Error! Reference source not found.** offers a ough estimate of the scale of potential benefits from de-bushing in relation to hunting, by assessing the potential benefits from hunting operations.

19.1.5 Plants and algae from in-situ aquaculture

This service is not considered relevant to bush encroachment.

19.1.6 Animals from in-situ aquaculture

This service is not considered relevant to bush encroachment.

19.1.7 Surface water for drinking

Bush encroachment can negatively affect surface water by increasing siltation in rivers and dams via erosion, polluting surface water and reducing dam capacity. However, if de-bushing leads to increased stocking rates of animals such as cattle, this can also contribute to agricultural runoff and silting. If bush is so dense as to restrict accessibility to rivers or dams the flow of surface water for drinking may also be reduced. Investigation into specific areas where this may occur would be needed to determine the impact.

19.1.8 Ground water for drinking

Greater densities of bush increase the rate of evapotranspiration, reducing groundwater recharge rates. Bushes intercept some rainwater before it reaches the ground which then evaporates into the atmosphere. They also compete with grasses to take up significant amounts of water from the soil through their root systems. Transpiration, the process of water being carried from roots to leaves and evaporating, is where the main loss of water occurs. De-bushing would reduce the amount of water used by encroacher bushes, increasing recharge. Some studies suggest that recharge rates could increase up to eightfold (Christian et. al. 2010).

19.1.9 Fibres and other materials from plants, algae and animals for direct use or processing

Bush encroachment increases the biomass available to be used as materials for construction, such as poles, wood-cement bonded bricks or boards, and fibreboards. De-bushing would therefore increase the flow of this service. More data is needed on rate of use and prices of the different products to be able to value the overall use. Encroacher bush material could also be used for crafts, which could be valued using price of a representative unit. However studies indicate that the type and extent of de-bushing affects the nature of regrowth which can severely limit further exploitation.

19.1.10 Materials from plants, algae and animals for agricultural use

Bush encroachment increases the biomass available to be utilised as animal feed supplement. De-bushing would therefore increase the flow of this service, which may to a limited extent offset the grazing losses and livestock provisioning. However, for valuation purposes, this limited offset would be incorporated into the value of the meat produced from those animals fed the supplement and is not therefore calculated.

19.1.11 Genetic materials from all biota

Genetic material (DNA) from wild plants, algae and animals can be used for biochemical industrial and pharmaceutical processes and for bio-prospecting activities. If encroacher bushes dominate an area, this can reduce the species and genetic diversity of plants and animals, diminishing the availability and diversity of genetic material.

De-bushing could improve the stock of genetic materials if it is done in a way that rehabilitates the land and ecosystem back to its previous attributes.

19.1.12 Surface water for non-drinking purposes

Bush encroachment and the reduced basal cover that results can negatively affect surface water by increasing siltation in rivers and dams via erosion, polluting surface water and reducing dam capacity. De-bushing could alleviate this, however, if it leads to increased stocking rates of animals such as cattle, this could also contribute to agricultural runoff and silting. It should also be considered that certain types of de-bushing could create an initial erosion risk, with the subsequent impacts and environmental costs.

19.1.13 Ground water for non-drinking purposes

The flow and stock of this service would be impacted in the same way as the “ground water for drinking purposes” as discussed above. In the context of Namibia, bush encroachment and the consequent reduction in groundwater recharge can impact on industrial water provisioning as water is drawn across vast areas. For valuation purposes, however, the value of the amount of groundwater that was used in the production of agricultural products (e.g. watering cattle) is subtracted, as it is incorporated into the valuation of the production of these products (e.g. beef). Otherwise it would be double-counted.

19.1.14 Plant-based resources

Biomass from de-bushing has the potential to be utilised in several methods of energy production. De-bushing could therefore increase this service significantly.

Firewood is used widely as an energy source in rural and lower-socioeconomic urban areas, particularly for cooking. Wood chips are an input into charcoal production, which caters to both domestic and export demand. Wood chips can also be used as fuel for biomass power plants to generate electricity.

19.1.15 Animal-based resources

De-bushing could theoretically improve the amount of animal-based resources, such as fat, oil, carcasses, and dung, which are used for energy production, via increased carrying capacity. However, without an idea of the amount of production of these resources for energy production in Namibia, it is difficult to quantify the impact of bush encroachment or the change in value that would occur under a de-bushing scheme.

19.1.16 Animal-based energy

The use of donkeys and horses for the transport of people and goods is unlikely to be materially impacted by bush encroachment, unless there are cases where the bush is so dense as to restrict movement and accessibility.

19.2 Regulation and maintenance

19.2.1 Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals

This service includes the biological filtration, sequestration, storage, and accumulation of pollutants in soil. The net impact of bush encroachment on this service is uncertain. If bush density restricts agriculture, reducing or eliminating the use of pesticides, it could relieve pressure on this service. If bush is cleared using arboricides, this could put pressure on the capacity of this service, as there is still uncertainty as to the full effects of arboricides on the immediate ecosystem.

19.2.2 Filtration/sequestration/storage/accumulation by ecosystems

This service includes the bio-physicochemical filtration, sequestration, storage, and accumulation of pollutants in soil. It is unknown how this is affected by bush encroachment.

19.2.3 Dilution by atmosphere, freshwater and marine ecosystems

It is unknown whether or how this service is affected by bush encroachment.

19.2.4 Mediation of smell/noise/visual impacts

Dense bush may have a positive impact by screening transport corridors, despite having perhaps a negative visual impact itself, for example for the purposes of game viewing or hunting. In the context of Namibia, this impact is at best limited.

19.2.5 Bio-remediation by micro-organisms, algae, plants, and animals

This service includes bio-chemical detoxification, decomposition, and mineralisation in land, freshwater and marine systems. More research needs to be done to determine whether and how bush encroachment affects this service.

19.2.6 Mass stabilisation and control of erosion rates

Bush encroachment tends to increase erosion rates. Grasses help stabilise the soil, preventing erosion, so when grass cover beneath the bush canopy is reduced due to encroachment, this can expose the soil to erosion. However, it is thought that some methods of de-bushing, particularly on more fragile soils, can also exacerbate erosion. Therefore, the choice of harvesting approach should take into account the risk of erosion. Selective harvesting and leaving sufficient bush coverage can reduce the risk of erosion from de-bushing. Furthermore, if stems and leaves are left on the ground rather than taken away after harvesting, they may help to reduce erosion.

More research is needed to determine the magnitude of the impact of bush encroachment, as well as de-bushing, on erosion rates, and how the impacts vary by harvesting scenario, ecosystem, land use, and soil type.

19.2.7 Buffering and attenuation of mass flows

Under conditions of bush encroachment, soil can form a hard crust (see below), creating high runoff regimes. De-bushing could negate this effect.

19.2.8 Hydrological cycle and water flow maintenance

Groundwater recharge is thought to suffer significantly under conditions of bush encroachment. As discussed above, as bush density rises, evapotranspiration rates also rise, reducing the amount of rainfall that reaches the deep soil and aquifers. Furthermore, if grass cover is reduced, exposing bare soil to rain and animals, this can cause soil crusting. The hard surface of the soil can then make it even more difficult for rain to infiltrate, reducing the retention capacity of water in soils and restricting groundwater recharge even further.

De-bushing has the potential to improve groundwater recharge rates by reducing the amount of evapotranspiration by bushes and assisting infiltration by increasing grass cover. However, if de-bushing further degrades the soil, there could be additional declines in groundwater recharge rates.

This is a key impact of bush encroachment that needs to be further researched. At this stage, we only have limited data from localised studies; this undermines the accuracy of the quantification, and also valuation, of the impact.

19.2.9 Flood protection

Bushes growing on riverbanks are thought to provide some degree of flood protection by stabilising the soil with their roots. De-bushing on riverbanks could therefore lead to a reduction in the quality of this ecosystem service, but as this is prohibited by law, it is not a significant concern.

Data and knowledge on the levels of flood protection that different densities of bush provide are currently lacking. In the future, the value of flood protection provided by bush encroachment could perhaps be estimated using the avoided cost method.

19.2.10 Storm protection

It is thought that bush encroachment has little material impact on storm protection.

19.2.11 Ventilation and transpiration

The services relating to ventilation and transpiration are generally not well understood in terms of their flows. However, it seems reasonable to assume that the increase in vegetation cover due to bush encroachment could enable higher rates of air ventilation. Consequently, de-bushing could have a negative impact on this service.

19.2.12 Pollination and seed dispersal

Under bush encroachment, less grass cover provides fewer seeds for dispersal. However, if perennial grasses are shielded from grazing by bushes, this may protect the seeds. Extracting significant quantities of bush for harvest can have a detrimental effect on seed dispersal due to the removal of nutrients and protection, but if stems and leaves are left on the ground after harvesting, they may help to trap grass seeds.

Not enough is known about how the diversity, distribution, and populations of pollinators, such as birds, bees and other insects, and other animals, are affected by bush encroachment.

19.2.13 Maintaining nursery populations and habitats

Bushes offer habitats, nesting places, protection, and food sources for arthropods, reptiles, birds, and small mammals. Thicker bush offers shelter and protection to smaller game (e.g. dik dik), but conversely, this makes it harder for predators to hunt successfully. De-bushing could therefore drive conflicting flows in this service, making it difficult to determine the net impact.

Valuation of this service is currently not possible, but measures of biodiversity and quantity of wildlife could be useful here to represent the quality of the habitat. The value would also be at least partly reflected in the value of tourism.

19.2.14 Pest control

Little is known about how or whether different bush densities affect pest control.

19.2.15 Disease control

Little is known about how or whether different bush densities affect disease control.

19.2.16 Weathering processes

A reduction in grass cover due to bush encroachment can leave the soil exposed to rain and animals, causing the surface of the soil to compact. The hard surface of the soil can then prevent rain from infiltrating, reducing the retention capacity of water in soils and making it even harder for grasses to re-establish. If de-bushing allows grasses to recover, this can improve the ecosystem’s weathering processes. Leaving some biomass on the ground after harvesting can also help to protect the soil and assist restoration.

19.2.17 Decomposition and fixing processes

Some encroacher bushes, including *Acacia* species and *Dichrostachys cinerea*, are nitrogen fixers, and consequently contribute to soil fertility. Removing these bushes therefore represents a decline in soil nitrogen levels and other nutrients, which are locked up in the wood. This is one reason why so much of the literature on de-bushing emphasises the importance of leaving some of the biomass on the ground, so that these nutrients can be returned to the soil. The use of biochar, a by-product of charcoal production, to return carbon to the soil is also a promising mitigation measure.

It should be a research priority to gain a better understanding of how bush encroachment, de-bushing, and bush harvesting (including overharvesting) affect soil quality. This is incredibly important in the context of Namibia’s largely arid, low quality soils, particularly in the most fragile regions.

The value of the expected improvement in the soil quality due to de-bushing would be partly reflected in the rise in the value of livestock production, given that this phenomenon is dependent upon the quality of the soil. The residual value is impossible to estimate based on the available data.

19.2.18 Chemical condition of freshwaters

Bush encroachment can negatively affect the chemical condition of freshwaters by increasing siltation in rivers and dams via erosion, polluting surface water. However, if de-bushing leads to increased stocking rates of animals such as cattle, this can also contribute to agricultural runoff and silting unless managed properly.

19.2.19 Chemical condition of salt waters

This service is not considered relevant to bush encroachment.

19.2.20 Global climate regulation by reduction of greenhouse gas concentrations

Bush encroachment and de-bushing have numerous, and often conflicting, effects on the flows of greenhouse gas emissions. The rise in woody biomass due to bush encroachment increases the amount of carbon sequestered in both the biomass and in the soil (soil organic carbon). However, as this tends to be accompanied by a decrease in grass cover, it is somewhat offset by a reduction in the carbon sequestered in grasses and their underground root systems.

De-bushing conversely leads to a reduction in the carbon sequestered in soil and in bushes in the short term (as the dead bushes decompose and release their carbon or as the biomass is burnt for energy production or clearing) and an increase in carbon sequestered in grasses over the longer term. Bush regrowth after the initial harvest also increases sequestration levels.

The livestock sector (particularly beef and cattle milk production) is a significant contributor to global GHG emissions, via factors including methane emissions from cows, dung fermentation, feed production, and transport of products. An increase in livestock production, enabled by an increase in carrying capacity due to lower bush density, would therefore be associated with an increase in greenhouse gas emissions in this sector.

19.2.21 Micro and regional climate regulation

Very little is known about how and by how much different bush densities affect climate, air quality, and regional precipitation and temperature patterns.

19.3 Cultural

19.3.1 Experiential use of plants, animals and land-/seascapes in different environmental settings

If wildlife viewing and landscape appreciation are undermined by dense bush, de-bushing can increase the value of this service by improving opportunities and success rates for wildlife viewing, increasing the diversity of species, and boosting the enjoyment that individuals gain from viewing wide, open landscapes which are symbolic of Namibia. This could have a positive effect on tourism in Namibia by attracting more visitors, increasing satisfaction levels, and raising revenue.

With regard to valuation, a revealed preference method, such as travel cost, could be used to estimate the change in willingness to pay pre- and post-de-bushing. Alternatively, a stated preference method, such as choice modelling, could also be used, with bush density as one of the variables. However, there are many costs to take into account (such as large capital investment costs or the costs of buying in wildlife for game parks) when estimating the overall impact of this which adds to the complexity of the valuation.

19.3.2 Physical use of land-/seascapes in different environmental settings

In addition to the negative impacts on wildlife viewing discussed above, dense bush can make activities such as hiking and hunting less appealing, by reducing the opportunity, success rates, and overall enjoyment of these activities. However, the relationship between bush encroachment and these tourism-centric activities is quite tenuous, and it would be hard to isolate the impact of de-bushing on these.

One approach to capture at least some of the value of the change in this service is to look at the benefits from a trophy hunting operation. However, the infrastructure that needs to be put in place to realise these benefits complicates the valuation. Section **Error! Reference source not found.** ffers a rough estimate of the scale of potential benefits from de-bushing in relation to tourism, by assessing the potential benefits from hunting operations.

19.3.3 Scientific

Scientific research services may be decreased by bush encroachment, due to reduced opportunities for research on topics such as cattle rearing and the ecology of natural rangelands. De-bushing could therefore improve this service. However, this service may also be increased by opportunities to study the ecological impacts of bush encroachment and methods of rehabilitating the land.

19.3.4 Educational

The impact of bush encroachment on education services is likely to be similar to that of scientific services.

19.3.5 Heritage, cultural

The heritage and cultural services associated with rangelands include certain ways of life and livelihoods, such as those of the San people. If their livelihoods were negatively impacted by bush encroachment, this would devalue the service. De-bushing could have a positive impact, but if it is not managed well and further degrades the soil, this could also be to the detriment of this service.

This service also includes the values of national and cultural identities. For example, Namibia's national anthem includes the line "Beloved land of savannas", highlighting the importance of the wide, open savanna to Namibians' identity. The quantification of this service is currently not very well understood.

19.3.6 Entertainment

De-bushing may increase the value of the ex-situ viewing or experience of Namibia's rangelands through different media (i.e. indirectly). For example, if de-bushing makes it easier to record video footage of wildlife and landscapes (perhaps increasing the stock and flow of video footage) both privately and for public broadcast, the value would increase. However, it is very difficult to measure symbolic value, which can overlap with other ecosystem services.

19.3.7 Aesthetic

A decrease in bush density would likely increase aesthetic appreciation, given Namibia's association with wide, open spaces and wildlife viewing. However, this change is difficult to measure. It could be valued using a revealed preference approach, such as the travel cost method, or a stated preference approach, such as choice modelling.

19.3.8 Symbolic

Some of the key features that individuals identify with Namibia include wide open spaces, wildlife viewing, and cattle rearing. De-bushing could improve all of these services. However, it is very difficult to measure symbolic value, which can overlap with other ecosystem services, such as existence value.

19.3.9 Sacred and/or religious

This ecosystem service provides value to individuals and communities through the ability to carry out sacred and religious practices. If de-bushing increases the carrying capacity of species such as eland, which are of sacred importance to the San, this could improve the value of this service.

It is very difficult to measure sacred or religious value.

19.3.10 Existence

Existence value is the value attached by individuals to the knowledge that the particular ecosystems and species continue to exist. Bush encroachment could have a negative impact on this service by reducing the prevalence of some species or eliminating ecosystem services such as the provision of meat and the keeping of cattle in some areas. De-bushing could therefore improve the value of this service.

This is a conceptual ecosystem service that is not well understood currently. Its value can only be ascertained via survey-based stated preference techniques.

19.3.11 Bequest

Bequest value is the value attached by individuals to the preservation of plants, animals, ecosystems, landscapes, and seascapes for the experience and use of future generations. Bush encroachment could have a negative impact on this service by reducing wildlife populations and diminishing the ability to keep cattle. De-bushing could therefore improve this service.

The quantification of this service is not well understood currently. As it has non-use value, a stated preference method, such as contingent valuation or choice modelling, must be used to elicit the value individuals place upon the future experience use of the ecosystems affected by bush encroachment.

19.4 Biodiversity

Biodiversity is not explicitly categorised as an ecosystem service, but it has a strong correlation with many ecosystem services. Diversity in animals, plants, and soil organisms can improve water and soil quality, increase the yield of several services (such as crop production), reduce yield variance, and improve resilience of ecosystems and their services to negative outside impacts. It can boost tourism and other cultural services and improve regulation and maintenance services. As such, many of the values of biodiversity are captured in the values of ecosystem services.

Bush encroachment can have mixed impacts on biodiversity. As rangelands deviate from the optimal mix of vegetation, this alters the balance of wildlife and tends to benefit some species to the detriment of others. Negative impacts on some species can lead to local extinctions. Birds, reptiles, invertebrates, mammals, other plant species, and soil organisms have all been found to be impacted by bush encroachment, and can therefore be assumed to be impacted by de-bushing.

De-bushing operations themselves can also have an impact on biodiversity. For example, Buyer et. al. (2016) found that de-bushing results in changes to the soil microbial community structure, compared with bush-encroached areas, although the magnitude of this change decreases with time following the de-bushing. De-bushing can also uncover burrows which house animals such as snakes, pangolins, aardvarks, aardwolves, and warthogs. De-bushing workers have an incentive to capture or kill animals they find in the burrows to sell or use for meat. This can include rare and endangered species, such as pangolins, the most trafficked mammal in the world[20].

Higher bush density can provide some animals with more protection from predators, but on the flipside, this increases the difficulty of hunting for the predators. Browsers (e.g. goats, kudu, eland, dik dik, black rhino) can benefit from a certain degree of bush encroachment, which expands their food source. However, if bush is too dense or encroacher species too dominant, this could disadvantage browsers by restricting movement and access and reducing the variety of their food. Grazers on the other hand can find their food source reduced by bush encroachment.

Karuaera (2011) found that bush encroachment did not have a significant impact on small mammal populations but Blaum et. al. (2007) that high degrees of bush encroachment (shrub cover >18%) negatively affects mammalian carnivore species. Cheetahs have been found to prefer more open or cleared land compared with encroached areas (Nghikembua 2016). This is unsurprising as their hunting technique requires open ground. Hunting in areas of thicker bush increases their risk of injury when they run at high speed.

Meik et. al. (2002) found that three out of four common diurnal lizard species in central Namibia were either absent from bush encroached areas and present in all savannah areas or less abundant in bush-encroached areas compared with open savannah. Blaum et. al. (2009) found that as shrub cover increased, ant, scorpion, and dung beetle abundance also increased, while grasshopper and solifuge abundance declined. Spider and beetle abundance tended to rise in line with shrub cover to a threshold and then decline.

[20] Diekmann, M 2016. Pers. comm.

Sirami et. al. (2009) found that bird species composition tended to change as the landscape moved from savannah to shrubland, and that widespread bush encroachment could lead to loss of some bird species and a reduction in bird diversity at the landscape level. Simmons et. al. (2010) found that bush encroachment makes it more difficult for vultures to detect and access carcasses and could be contributing to the population decline.

Joubert and Zimmerman (2002) found that under a scenario of de-bushing which followed Forestry Stewardship Council Principles and Forestry Guidelines, biodiversity and ecological processes would be improved. However, if de-bushing were unsustainably or improperly managed, perhaps to meet demand for woody biomass for various industries, this would have a negative impact on biodiversity and would likely result in local extinctions, particularly of arboreal species and species which require bush for shelter.

There are obviously conflicting impacts of bush encroachment and de-bushing on biodiversity. It is apparent that the displacement of grassland by encroacher bush could lead to the local extinctions of animals specialising in grassland habitats. However, if de-bushing is carried out unsustainably or without regard for the environmental impacts of de-bushing operations, it would likely have a negative impact on biodiversity, as well as ecosystem services.

De-bushing should therefore leave a mosaic of habitats in order to maximise wildlife diversity, numbers and accessibility. The characteristics of the landscape should also be taken into account when deciding on the optimal type of de-bushing operation.

20 Appendix III: Environmental costs

As well as the direct costs, de-bushing, whether by mechanical or manual means or using arboricides, incurs environmental costs which we have not been able to quantify here. Further research should be carried out to ascertain the potential magnitude of these costs as they are an important consideration.

Mechanical methods involve cutting bushes down, removing the bush and its root system, or flattening bushes (in the case of rollers). Disturbance to the soil increases soil instability, leading to erosion and greater runoff. This could potentially constrain groundwater recharge even more than under conditions of bush encroachment. Harvesting bush also removes nutrients, such as carbon and potassium, from the system, which can represent a significant cost. The loss of soil organic carbon from de-bushing is quantified and valued in Section 7.

If bushes are cut above ground, some species' coppicing ability could mean that significant regrowth could occur quite quickly, worsening the bush encroachment problem. If bushes are cut below ground, regrowth is reduced, but it results in greater soil destabilisation and removes more nutrients from the environment. Consequently, there are pros and cons to different methods of harvest.

Small scale, mostly manual operations are likely to cause the least disturbance to the surrounding environment. They are highly selective and can minimise the soil area affected. However, it still involves the removal of nutrients from the soil and can contribute to soil instability. Furthermore, transport of any harvesting equipment off-road can also damage the soil, organisms, and other plants.

The environmental costs are assumed to escalate as the size of the de-bushing operation increases. The light-duty, semi-mechanised operations use trolley saw trolleys which must be rolled along the ground, but their impact on the immediate surroundings of each bush that is cut is relatively confined. Medium-duty, fully-mechanised operations use excavators which are much heavier, causing greater disturbance to the ground they roll on. They are also less selective and affect a wider area around the targeted bushes.

The commercial-scale, fully-mechanised operation requires a bigger, heavier excavator and multiple tractors and trailers to transport the wood chips, as does the large commercial-scale operation, putting additional pressures on the soil, organisms, and other plants.

There remains uncertainty as to the full effects of arboricides on the environment. Arboricides can be toxic to animals, can accumulate in plants, soil, and water, and can travel through the ground, particularly in sandier soils, and be transmitted to non-encroacher bushes and trees. In these cases, they have the potential to impose severe environmental costs. Although arboricides are likely to be safely used in specific contexts, depending on factors such as type and bush species, continued widespread availability of arboricides remains uncertain.

21 Appendix IV: De-bushing

The Namibia Biomass Industry Group (N-BiG) is a newly established industry organisation positioned to serve and grow the Namibian biomass industry. N-BiG was founded through the support of the GIZ Support to De-bushing Project and its founding members and is growing its membership base and rolling out its services and projects in order to support its members and to develop the biomass industry in Namibia as a whole.

N-BiG provided analysis of the type of de-bushing operations suitable, according to the LDN study's bush density and species data, and estimates of the area that would be suitable for each type of operation, and the potential production. It should be noted that this is a scenario based on current and potential future biomass hubs and markets. N-BiG also provided estimates of the capex, opex, jobs, and labour costs associated with each type of operation.

21.1 Direct costs of de-bushing

21.1.1 Area targeted and volume of potential biomass yield from initial round of de-bushing

Firstly, the 22 bush encroached zones and their average densities identified in the mapping (see Section 2) were used to approximate which areas and what proportion of those areas would be suitable for commercial biomass harvesting, and whether that harvesting would be more suited for large scale or for small-medium scale mechanical harvesting operations.

The areas where large scale biomass harvesting was deemed more suitable was initially determined through the proximity to current and future markets. Therefore, it is assumed that large scale mechanical operations are more suited to areas within a 100 km radius of the current or future biomass markets. The identified current and future biomass markets within the Otjozondjupa region are the towns and surrounds of Otjiwarongo, Otavi, Okakarara, and Grootfontein. Additionally, apart from the proximity to the market, biomass yield per hectare is also an important factor for large scale mechanical harvesting. The higher the bush density, the higher the biomass yield, which relate to more profitable operations for large scale mechanical harvesting. Therefore, zones within the first density bracket (0-2750) and/or areas with predicted yields of lower than 10 tonnes per hectare of removable biomass were not considered economically suitable for large scale mechanical harvesting. The importance of production and logistics efficiencies, encapsulated by market proximity and biomass yield are core to a commoditised biomass industry.

For small-medium scale harvesting, it was assumed that more geographically dispersed and other niche markets would be more suitable, servicing areas otherwise considered too remote or with yields too unfavourable for the larger scale harvesting operators to consider. Therefore, it was assumed that small-medium scale mechanical harvesters would have the greatest impact on either higher density areas that are further than the above stated 100 km threshold or areas which are less densely encroached (with biomass yields lower than 10 tonnes per hectare), but which are much nearer to the main off-takers and/or biomass hubs (within a radius of 50 km). In reality, however, it is likely that both large, medium and small mechanical harvesting will operate within the same spheres initially, due to the shear vastness of the biomass resource. However, as is the case with commoditised industries, economies of scale will play a crucial role within the Namibian biomass market, forcing smaller scale operations to seek out more geographically disperse and/or niche markets to service, while the larger operations compete for the more centralised, price sensitive biomass markets.

All remaining areas (either considered too remote or not densely encroached enough to suit mechanical harvesting) were assigned to either semi-mechanical and manual clearing or to use of arboricides. However, typically no more than 20% of those remaining areas were assigned to semi-mechanical and manual clearing, primarily due to the capacity and cost constraints associated with such ineffective de-bushing methods. Any and all remaining areas within the parameters were designated to arboricides, which are hugely versatile, relatively cost effective and already widespread in their use. However, in relation to the above de-bushing methods, and unlike that of the mechanised harvesting, it is largely assumed that these two de-bushing methodologies will not yield any significant commercial biomass or biomass products. Therefore, these activities would primarily be driven through both state funded de-bushing initiatives and individual land-owner driven initiatives, neither necessarily linked to commercial sustainability.

Although the biomass produced from semi-mechanical and manual clearing is not considered suitable for commercial use, if left on the land, it returns nutrients to the soil and provides microhabitats, representing an environmental benefit (see Section 26.6).

Secondly, it was determined that non-encroacher species should not be targeted for de-bushing. Furthermore, in accordance with environmental management practices, 10% of the encroacher biomass should remain unharvested, so the biomass yield estimates are related to the 90% of encroacher bush which can be sustainably harvested.

This results in an overall reduction in average bush density of 38.5% across Otjozondjupa, weighted by area (see Table 21.1). Although the units are different (bushes/ha versus tonnes), this appears to be broadly in line with the recommendation of Smit et. al. (2015, p105) to only harvest between 30-35% of the available wood biomass.

Table 21.1: Bush density pre- and post-de-bushing

BE zone	Original			De-bushed			Overall reduction in density (%)
	Encroacher species (bushes/ha)	Non-encroacher species (bushes/ha)	Total (bushes/ha)	Encroacher species (bushes/ha)	Non-encroacher species (bushes/ha)	Total (bushes/ha)	
1	473	1,107	1,580	47	1,107	1,154	26.9
2	9,150	5,200	14,350	915	5,200	6,115	57.4
3	3,792	3,911	7,703	379	3,911	4,290	44.3
4	7,917	6,371	14,288	792	6,371	7,163	49.9
5	1,000	1,496	2,496	100	1,496	1,596	36.1
6	1,360	895	2,255	136	895	1,031	54.3
7	813	1,709	2,522	81	1,709	1,791	29.0
8	6,000	6,510	12,510	600	6,510	7,110	43.2
9	775	990	1,765	78	990	1,067	39.5
10	4,119	5,338	9,457	412	5,338	5,750	39.2
11	5,143	4,414	9,557	514	4,414	4,928	48.4
12	2,358	3,600	5,958	236	3,600	3,836	35.6
13	464	1,323	1,786	46	1,323	1,369	23.4
14	3,610	8,448	12,058	361	8,448	8,809	26.9
15	3,263	3,588	6,850	326	3,588	3,914	42.9
16	8,750	10,288	19,038	875	10,288	11,163	41.4
17	86	1,400	1,486	9	1,400	1,409	5.2
18	654	1,190	1,844	65	1,190	1,255	31.9
19	388	1,793	2,180	39	1,793	1,831	16.0
20	870	10,700	11,570	87	10,700	10,787	6.8
21	1,073	1,513	2,585	107	1,513	1,620	37.3
22	4,486	6,029	10,514	449	6,029	6,477	38.4
AVG*	**2,182**	**2,924**	**5,106**	**218**	**2,924**	**3,142**	**38.5**

*weighted by area — Source: LDN 2016, N-BiG

Thirdly, an average estimated weight per tree equivalent unit was assigned to each encroacher bush plant species and category, depending on its size and whether or not it has a main stem. For example, it was assumed that the average harvestable weight per *Acacia mellifera* under 1.5 m is 4 kg (when harvested at the base of the trunk), the average *A. mellifera* over 1.5 m, without a main stem is estimated at 8 kg and finally an *A.mellifera* with a main stem is estimated to weigh about 12 kg (it is expected that a *A.mellifera* with a main stem will be heavier because its main stem will have a larger diameter than a multiple stemmed *A.mellifera*) (see Table 21.2). These weights are approximations based off of real world data for *A.mellifera*. The weights are also considered to be fairly conservative, as the tree equivalents are weighed without side branches or the crowns. The other species, primarily the two *Terminalias*, were estimated with much lower plant weights, due to their differing morphologies (0 kg, 6 kg, 8 kg, respectively, when compared to *A.mellifera*). Small *Terminalias* are not typically desirable for mechanical harvesting, due to their thin branch diameters.

Table 21.2: Average harvestable weight when harvested at base of trunk (kg)

Species	<1.5m	>1.5m, no main stem	>1.5m, main stem
Acacia mellifera	4kg	8kg	12kg
Terminalia cericea	0kg	6kg	8kg

Source: N-BiG

Fourthly, using the above assumptions, the tonnage per hectare of harvestable encroacher bush biomass was calculated by multiplying the above stated plant weights in relation to the encroachment species within the given zone densities. This was then multiplied by the area targeted for de-bushing to arrive at the potential biomass yield in tonnes by zone.

The results of this analysis are presented in Table 21.3, Table 21.4, Table 21.5 and Table 21.6.

Table 21.3: Area suitable for large-scale mechanical harvesting and potential biomass yield

Area	Main encroacher species	Average density (bushes/ha)	Area (ha)	Area suitable (%)	Area suitable (ha)	Removable biomass (t/ha)	Total potential biomass yield* (t)
1	Acacia mellifera	1,580	1,856,773	0%	0	1.0	0
2	Acacia mellifera	14,350	109,282	100%	109,282	41.0	4,480,576
3	Acacia mellifera	7,703	620,177	80%	496,142	19.0	9,426,692
4	Acacia mellifera	14,288	474,894	80%	379,915	35.0	13,297,028
5	Terminalia cericea	2,496	228,993	0%	0	3.5	0
6	Acacia mellifera, Dichrostachys cinerea	2,255	176,140	0%	0	4.0	0
7	Acacia mellifera	2,522	680,335	0%	0	2.0	0
8	Terminalia prunioides	12,510	312,849	100%	312,849	25.0	7,821,233
9	Acacia mellifera, Terminalia cericea	1,765	548,916	0%	0	4.0	0
10	Acacia mellifera, Terminalia cericea	9,457	432,499	50%	216,250	13.0	2,811,247
11	Acacia mellifera, Terminalia prunioides	9,557	509,133	100%	509,133	24.0	12,219,204
12	Acacia mellifera, Terminalia cericea	5,958	110,477	0%	0	8.5	0
13	Terminalia cericea	1,786	1,258,116	0%	0	1.2	0
14	Terminalia cericea, Acacia mellifera	12,058	298,047	0%	0	11.4	0
15	Terminalia cericea, Acacia mellifera	6,850	271,529	0%	0	7.0	0
16	Terminalia cericea	19,038	185,472	0%	0	20.7	0
17	Terminalia cericea	1,486	175,155	0%	0	0.0	0
18	Dichrostachys cinerea, Acacia mellifera	1,844	600,779	0%	0	1.0	0
19	Acacia mellifera	2,180	424,024	0%	0	1.4	0
20	Terminalia cericea	11,570	171,348	0%	0	3.0	0
21	Acacia mellifera, Terminalia cericea	2,585	799,614	0%	0	4.0	0
22	Acacia mellifera	10,514	276,172	100%	276,172	18.0	4,971,090
TOTAL			**10,520,723**	**22%**	**2,299,743**		**55,027,069**

*commercial

Source: N-BiG

Table 21.4: Area suitable for small-to-medium-scale mechanical harvesting and potential biomass yield

Area	Main encroacher species	Average density (bushes/ha)	Area (ha)	Area suitable (%)	Area suitable (ha)	Removable biomass (t/ha)	Total potential biomass yield* (t)
1	Acacia mellifera	1,580	1,856,773	0%	0	1.0	0
2	Acacia mellifera	14,350	109,282	0%	0	41.0	0
3	Acacia mellifera	7,703	620,177	20%	124,035	19.0	2,356,673
4	Acacia mellifera	14,288	474,894	20%	94,979	35.0	3,324,257
5	Terminalia cericea	2,496	228,993	0%	0	3.5	0
6	Acacia mellifera, Dichrostachys cinerea	2,255	176,140	50%	88,070	4.0	352,281
7	Acacia mellifera	2,522	680,335	50%	340,167	2.0	680,335
8	Terminalia prunioides	12,510	312,849	0%	0	25.0	0
9	Acacia mellifera, Terminalia cericea	1,765	548,916	20%	109,783	4.0	439,133
10	Acacia mellifera, Terminalia cericea	9,457	432,499	10%	43,250	13.0	562,249
11	Acacia mellifera, Terminalia prunioides	9,557	509,133	0%	0	24.0	0
12	Acacia mellifera, Terminalia cericea	5,958	110,477	0%	0	8.5	0
13	Terminalia cericea	1,786	1,258,116	0%	0	1.2	0
14	Terminalia cericea, Acacia mellifera	12,058	298,047	0%	0	11.4	0
15	Terminalia cericea, Acacia mellifera	6,850	271,529	0%	0	7.0	0
16	Terminalia cericea	19,038	185,472	0%	0	20.7	0
17	Terminalia cericea	1,486	175,155	0%	0	0.0	0
18	Dichrostachys cinerea, Acacia mellifera	1,844	600,779	30%	180,234	1.0	180,234
19	Acacia mellifera	2,180	424,024	30%	127,207	1.4	178,090
20	Terminalia cericea	11,570	171,348	20%	34,270	3.0	102,809
21	Acacia mellifera, Terminalia cericea	2,585	799,614	30%	239,884	4.0	959,536
22	Acacia mellifera	10,514	276,172	0%	0	18.0	0
TOTAL			**10,520,723**	**13%**	**1,381,879**		**9,135,596**

*commercial

Source: N-BiG

Table 21.5: Area suitable for semi-mechanical and manual harvesting and potential biomass yield

Area	Main encroacher species	Average density (bushes/ha)	Area (ha)	Area suitable (%)	Area suitable (ha)	Removable biomass (t/ha)	Total potential biomass yield* (t)
1	Acacia mellifera	1,580	1,856,773	20%	371,355	1.0	371,355
2	Acacia mellifera	14,350	109,282	0%	0	41.0	0
3	Acacia mellifera	7,703	620,177	0%	0	19.0	0
4	Acacia mellifera	14,288	474,894	0%	0	35.0	0
5	Terminalia cericea	2,496	228,993	20%	45,799	3.5	160,295
6	Acacia mellifera, Dichrostachys cinerea	2,255	176,140	20%	35,228	4.0	140,912
7	Acacia mellifera	2,522	680,335	20%	136,067	2.0	272,134
8	Terminalia prunioides	12,510	312,849	0%	0	25.0	0
9	Acacia mellifera, Terminalia cericea	1,765	548,916	20%	109,783	4.0	439,133
10	Acacia mellifera, Terminalia cericea	9,457	432,499	20%	86,500	13.0	1,124,499
11	Acacia mellifera, Terminalia prunioides	9,557	509,133	0%	0	24.0	0
12	Acacia mellifera, Terminalia cericea	5,958	110,477	20%	22,095	8.5	187,810
13	Terminalia cericea	1,786	1,258,116	20%	251,623	1.2	301,948
14	Terminalia cericea, Acacia mellifera	12,058	298,047	20%	59,609	11.4	679,548
15	Terminalia cericea, Acacia mellifera	6,850	271,529	20%	54,306	7.0	380,140
16	Terminalia cericea	19,038	185,472	20%	37,094	20.7	767,855
17	Terminalia cericea	1,486	175,155	20%	35,031	0.0	0
18	Dichrostachys cinerea, Acacia mellifera	1,844	600,779	20%	120,156	1.0	120,156
19	Acacia mellifera	2,180	424,024	20%	84,805	1.4	118,727
20	Terminalia cericea	11,570	171,348	20%	34,270	3.0	102,809
21	Acacia mellifera, Terminalia cericea	2,585	799,614	20%	159,923	4.0	639,691
22	Acacia mellifera	10,514	276,172	0%	0	18.0	0
TOTAL			**10,520,723**	**16%**	**1,643,643**		**5,807,010**

*non-commercial

Source: N-BiG

Table 21.6: Area suitable for manual application of arboricides

Area	Main encroacher species	Average density (bushes/ha)	Area (ha)	Area suitable (%)	Area suitable (ha)
1	Acacia mellifera	1,580	1,856,773	80%	1,485,418
2	Acacia mellifera	14,350	109,282	0%	0
3	Acacia mellifera	7,703	620,177	0%	0
4	Acacia mellifera	14,288	474,894	0%	0
5	Terminalia cericea	2,496	228,993	80%	183,194
6	Acacia mellifera, Dichrostachys cinerea	2,255	176,140	30%	52,842
7	Acacia mellifera	2,522	680,335	30%	204,100
8	Terminalia prunioides	12,510	312,849	0%	0
9	Acacia mellifera, Terminalia cericea	1,765	548,916	60%	329,350
10	Acacia mellifera, Terminalia cericea	9,457	432,499	20%	86,500
11	Acacia mellifera, Terminalia prunioides	9,557	509,133	0%	0
12	Acacia mellifera, Terminalia cericea	5,958	110,477	80%	88,381
13	Terminalia cericea	1,786	1,258,116	80%	1,006,492
14	Terminalia cericea, Acacia mellifera	12,058	298,047	80%	238,438
15	Terminalia cericea, Acacia mellifera	6,850	271,529	80%	217,223
16	Terminalia cericea	19,038	185,472	80%	148,378
17	Terminalia cericea	1,486	175,155	80%	140,124
18	Dichrostachys cinerea, Acacia mellifera	1,844	600,779	50%	300,389
19	Acacia mellifera	2,180	424,024	50%	212,012
20	Terminalia cericea	11,570	171,348	60%	102,809
21	Acacia mellifera, Terminalia cericea	2,585	799,614	50%	399,807
22	Acacia mellifera	10,514	276,172	0%	0
TOTAL			**10,520,723**	**49%**	**5,195,457**

Source: N-BiG

Finally, it was assumed that 60% (6.3 million hectares) of Otjozondjupa would be targeted for de-bushing. It is not specified which areas would be de-bushed. Some areas may not be de-bushed due to their remoteness, terrain restrictions, lack of economic incentives, or the potential damage that de-bushing may have on the environment (e.g. fragile soils). The potential production from an initial round of de-bushing over 20 years, according to the above assumptions, would therefore be 42.0 million tonnes, where 38.5 million tonnes would be available for commercial use.

Table 21.7: Production from initial round of de-bushing

Type of de-bushing	Target area (ha)	Total biomass (m tonnes)	Biomass yield (tonnes/ha)
Large-scale mechanical	1,379,846	33.0	23.9
Small-to-medium-scale mechanical	829,127	5.5	6.6
Semi-mechanical and manual	986,186	3.5	3.5
Manual application of arboricides	3,117,274		
TOTAL	**6,312,434**	**42.0**	

Source: N-BiG

21.1.2 Cost of initial round of de-bushing

N-BiG's estimates on capex, opex, and capacity per set by type of de-bushing operation are presented in Table 21.8.

Table 21.8: Cost and capacity by type of de-bushing operation

Type of de-bushing	Capex (N$/ha/year)	Equipment lifetime (years)	Opex (N$/ha)	Capacity per set (ha/year)	Capacity per set (tonnes/year)
Large-scale mechanical	1,313	6-8	3,597	4,500	45,500
Small-to-medium-scale mechanical	2,450	4-5	2,940	1,000	10,500
Semi-mechanical and manual	80	2-3	1,298	175	
Manual application of arboricides	12	0.25-0.5	725	775	

Source: N-BiG

Over the initial round of de-bushing across 20 years, this results in a required total capex of N$4.0 billion, a total opex of N$10.9 billion, and a total cost of N$14.9 billion (2015 prices, undiscounted), if the 60% de-bushing assumption is to be met. This is equal to N$745 million per annum (N$198 million worth of capex and N$547 million worth of opex).

Table 21.9: Costs of initial round of de-bushing (2015 prices, undiscounted)

Type of de-bushing	Total capex (N$m, 2015 prices)	Total opex (N$m, 2015 prices)	Total cost (N$m, 2015 prices)
Large-scale mechanical	1,811	4,963	6,774
Small-to-medium-scale mechanical	2,031	2,438	4,469
Semi-mechanical and manual	79	1,280	1,358
Manual application of arboricides	37	2,260	2,297
TOTAL	**3,959**	**10,940**	**14,899**

Source: N-BiG, de Wet 2015

21.1.3 Follow ups and after care

Hengari (2016) recommends aftercare and SAIEA (2016, p29) states that:

> "… the idea of a bush-thinned area being allowed to re-thicken to enable a new wave of harvesting (i.e. bush farming), is contrary to the objectives of the Rangeland Management Policy since it narrows the provision of ecosystem services to only the harvesting of bush biomass… the aim of bush thinning should be to restore ecosystem health of rangelands, so that the area provides a broad range of ecosystem services on a sustained basis (i.e. groundwater recharge, soil health, habitats for biodiversity, and livestock production)."

It is therefore necessary to undertake follow up and after care activities to manage the regrowth of bush. Honsbein et. al. (2009) provides estimates of the timing, production, and cost factors associated with follow up and after care, presented in Table 21.10.

Table 21.10: Production and cost factors and timing of follow up and aftercare treatments

Type of harvest	Timing (years after initial harvest)	Production factor (% of initial harvest)	Cost factor (% of initial harvest)
First follow up	5	55.0	50.0
Second follow up	10	30.3	12.5
First aftercare	20	10.0	23.3
Second aftercare	30	5.0	10.0

Source: Honsbein 2009

This results in additional production of follow ups and aftercare of 33.7 million tonnes over 25 years (see Table 21.11) and additional costs of N$9.7 billion (2015 prices, undiscounted) over 25 years (see Table 21.12).

Table 21.11: Production from follow ups and aftercare

Type of de-bushing	Total biomass (m tonnes)
Large-scale mechanical	26.5
Small-to-medium-scale mechanical	4.4
Semi-mechanical and manual	2.8
Manual application of arboricides	
TOTAL	**33.7**

Source: N-BiG, Honsbein 2009

Table 21.12: Costs of follow ups and aftercare (2015 prices, undiscounted)

Type of de-bushing	Total cost (N$m, 2015 prices)
Large-scale mechanical	4,417
Small-to-medium-scale mechanical	2,914
Semi-mechanical and manual	886
Manual application of arboricides	1,498
TOTAL	**9,715**

Source: N-BiG, de Wet 2015, Honsbein 2009

21.1.4 Total production and cost

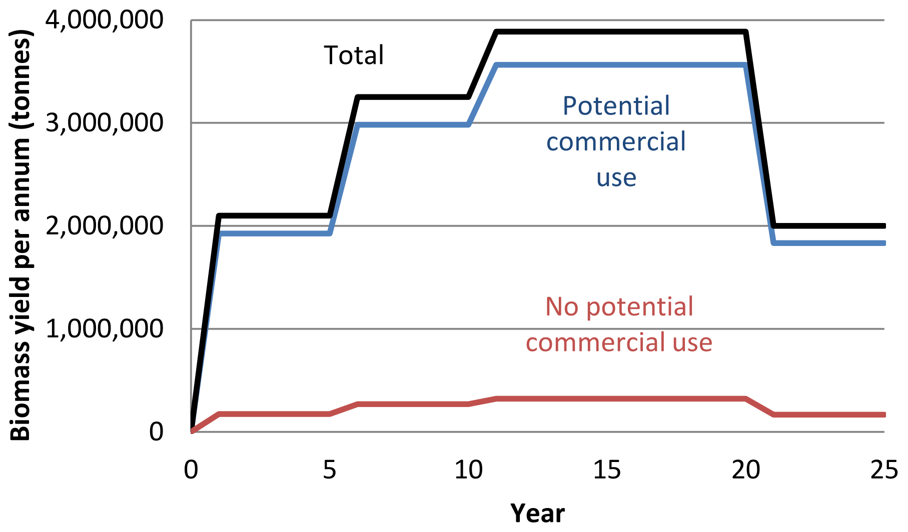
Adding production from the initial, follow up and after care rounds of de-bushing results in total production of 75.6 million tonnes over 25 years (see Table 21.13), where 69.4 million tonnes of this is suitable for commercial use.

Table 21.13: Total production from de-bushing over 25 years

Type of de-bushing	Total biomass (m tonnes)
Large-scale mechanical	59.5
Small-to-medium-scale mechanical	9.9
Semi-mechanical and manual	6.3
Manual application of arboricides	
TOTAL	**75.6**

Source: N-BiG, Honsbein 2009

Chart 21.1: Biomass yield



Adding costs from the initial, follow up and after care rounds of de-bushing results in a total cost of N$24.6 million (2015 prices, undiscounted) over 25 years (see Table 21.14).

Table 21.14: Total costs of de-bushing over 25 years (2015 prices, undiscounted)

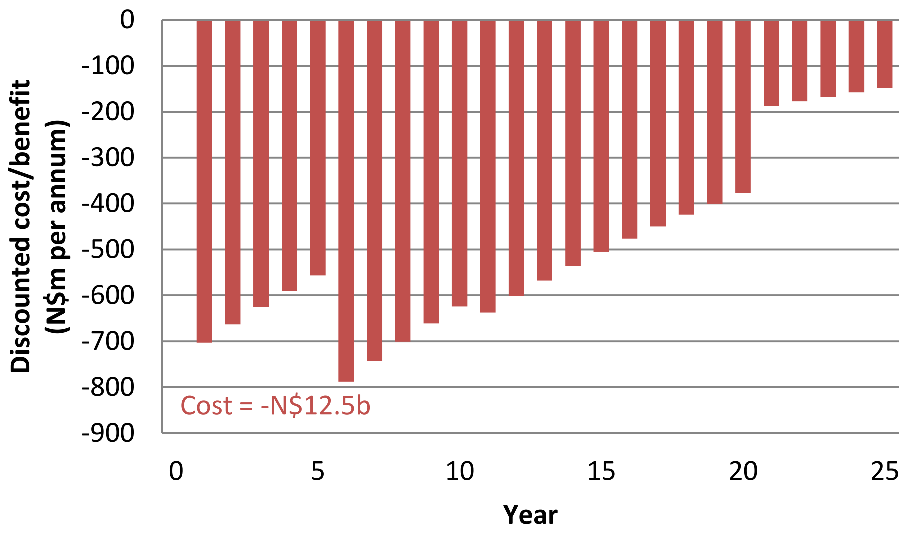
Type of de-bushing	Total cost (N$m, 2015 prices)
Large-scale mechanical	11,191
Small-to-medium-scale mechanical	7,383
Semi-mechanical and manual	2,244
Manual application of arboricides	3,796
TOTAL	**24,614**

Source: N-BiG, de Wet 2015, Honsbein 2009

The analysis showed that the initial round of de-bushing would cost around N$745 million per annum (undiscounted, 2015 prices) and that the follow ups and after care would add between N$372 million and N$639 million per annum, depending on the point in the cycle.

Once discounted at a rate of 6% (see Section 3.5.3), the total discounted cost was estimated at **N$12.5 billion** over the 25 year horizon.

Chart 21.2: Cost of de-bushing[21]



21.2 Sensitivity analysis

If the cost of de-bushing operations was 20% higher, the total cost is estimated to increase by almost N$2.5 billion to N$15.0 billion. If the cost of de-bushing was 20% lower, perhaps due to economies of scale, new technology, and optimisation of processes, then the estimated total cost could be as low as N$10.0 billion.

Table 21.15: Sensitivity analysis for de-bushing costs

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**12,469.9**	**0.0**	**-12,469.9**
Cost			
+20%	14,963.9	0.0	-14,963.9
-20%	9,976.0	0.0	-9,976.0

1: 2015 prices, discounted by 6% p.a.

21.3 Limitations and risks

The continued widespread availability of arboricides in Namibia is uncertain. Recently, MAWF imposed a quantitative restriction on the importation of arboricides on the Meat Board, due to uncertainty around long term effects, which has temporarily slowed the sale and affected the availability of arboricides from the Meat Board specifically. Separate from this, Agra recently halted sales of certain arboricides due to a conflict with the EPA framework which bans the trade of certain substances, including some commercial arboricides such as tebuthiron. However, this has not stopped Agra from selling all arboricides. Our analysis assumes the use of arboricides across almost

[21] The year-to-year fluctuations can be explained by discounting and timing of follow ups and aftercare. For example, the cost decreases between Year 1 and Year 5 because it is being discounted. It then increases in Year 6 because the first follow up round has begun, in addition to the initial round of de-bushing.

half of the area targeted for de-bushing. If arboricide use were to be significantly affected, this would have substantial ramifications for the cost of de-bushing, as arboricides are the lowest cost method of de-bushing (per hectare).

This study does not specify which methods should be used in which locations, depending on resources (e.g. labour), ecosystems and environmental context, bush species, individual land-owner preferences, and potential uses of the biomass. These should be investigated, as the costs and benefits could vary considerably by location depending on which methods are used.

There is a risk that the initial growth of the harvesting industry will be slow, as it goes hand-in-hand with the growth of the local biomass industry as a whole, which is still in its infancy. This would mean slower improvement in other sectors, such as livestock production and groundwater recharge, but it would not necessarily alter the costs of de-bushing.

22 Appendix V: Soil organic carbon

22.1 Existing evidence

Studies assessing the impact on carbon sequestration of changes in land cover relating to bush encroachment have largely focused on changes from grassland or savannah to bush cover. However, evidence from these studies is mixed. Studies presented by Wessman et al. (2004) illustrated that the response of the storage of soil organic carbon (SOC) ranged from decreases to significant increases when moving from grassland to bush cover, while Hudak et al. (2003) found evidence of non-monotonic responses based on the level of bush cover.

A recent paper by Blaser et al. (2014) assessed results from 15 studies across 21 different locations mostly in the US, and found a range of changes in carbon sequestration in soil following woody encroachment of between -80gC/m^2 per annum to 239gC/m^2 per annum, with an average of 21gC/m^2 per annum. In their own analysis of soil samples from Zambia, they found a response of between 12 and 16gC/m^2 per annum. The evidence seems to indicate that there is a broadly positive impact from bush encroachment on soil carbon sequestration, but that it is likely to be location and context-specific.

Hengari (2016) conducted soil analysis and found the SOC in Otjozondjupa to be very low at between 0.1% to 0.4% per 100g soil). The average SOC of savanna soils can be up to 1% per 100g soil (Du Preez, Van Huyssteen and Mnkeni, 2011). However, no analysis has yet been done on the data to estimate how SOC is affected by varying degrees of bush density. If this analysis is carried out in the future, it would provide a more accurate reflection of the Namibian context.

An attempt is made to value the impact of the change in carbon sequestration as a result of de-bushing in Namibia. The values presented should be taken as only broadly indicative given the assumptions that need to be made to elicit a value, and the location- and context-specific nature of the rate of carbon sequestration.

22.2 Economic valuation of carbon sequestration from de-bushing

Several different values have been attached to carbon. The US Environmental Protection Agency (EPA) uses the Social Cost of Carbon (SCC) as an estimate of the economic damages associated with a small increase in carbon dioxide (CO_2) emissions (US EPA, 2015). The central estimate of the SCC of a tonne of CO_2 emitted in 2015 is approximately US$40 in 2014 prices (US$40.1 in 2015 prices), rising to US$77 by 2050. The *State of Voluntary Carbon Markets*[22] indicates that the average prices of voluntary carbon offsets traded in markets in 2014 was US$3.8/t$CO_2$e. The average carbon market price under the EU Emissions Trading Scheme (ETS) in 2015 was €7.8/ tCO_2e.

We have chosen to use a value of N$60/t$CO_2$e which is currently being used for the National Integrated Resource Plan review. This is the only available value currently used in the Namibian context. Although it is not based on an actual market, this value is very close to the average price of voluntary carbon offsets traded in markets (US$3.8/t$CO_2$e), which gives it a measure of robustness.

[22] http://forest-trends.org/releases/uploads/SOVCM2015_FullReport.pdf

In order to estimate a value for carbon sequestration from de-bushing, the impacts have to be expressed in tonnes of CO_2 per year[23].

The starting point is provided by the average of the Blaser et al. (2014) range of impacts in terms of the change in grams of carbon per m^2 per year. We make two key assumptions here. Firstly, due to Namibia's relatively low levels of soil organic carbon, we assume that the capacity of the soil to sequester carbon is only reduced in the year of de-bushing, rather than annually. Secondly, we assume that the inverse of these estimates can be applied as an approximation of the reduction in carbon sequestered when encroacher bush is removed. The impacts are then transformed into tonnes of CO_2 per hectare sequestered. The resulting estimate is a reduction of 0.771 tonnes of CO_2 sequestered per hectare per year (see Table 22.1).

Table 22.1: Estimate of carbon sequestration impacts from de-bushing

	Carbon sequestration	Source
(1) Change in carbon sequestered from grassland to bush ($gC/m^2/yr$)	21	Blaser et al. (2014)
(2) Invert to estimate impact of debushing	-1	Assumption
(3) Convert to CO_2 from C	3.67 units CO_2 = 1 unit of C	-
(4) Convert to tonnes from grams	1000000 grams = 1 tonnes	-
(5) Convert to ha from m^2	10000 m^2 = 1 ha	-
(6) Change in CO2 sequestered from debushing ($tCO_2/ha/yr$)	**-0.771**	**Calculation: (1)*(2)*(3)*(5)/(4)**

To generate an estimate of the real economic costs or benefits of de-bushing in terms of carbon sequestration, the impacts estimated in Table 22.1 are multiplied by the Namibian offset value of N$60 for a given year and the total hectares of land de-bushed in Otjozondjupa by the end of that year. Table 22.2 presents the calculation for the (undiscounted) cost of de-bushing in Year 1, assuming that 5% (315,622ha) of bush encroached land is de-bushed to by a weighted average of 38.5%. This represents an (undiscounted) cost of N$5.6 million in 2015 prices.

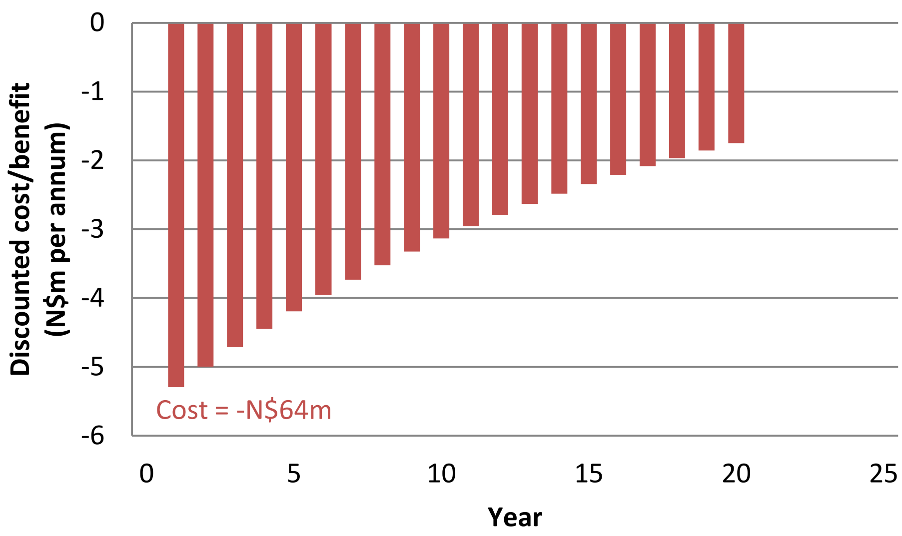
[23] 3.67 units of CO_2 = 1 unit of C

Table 22.2: Estimate of costs of reduced carbon sequestration as a result of de-bushing in Year 1

	Carbon sequestration	Source
(1) Change in CO_2 sequestered from debushing (tCO_2/ha/yr)	-0.771	Table 7.1
(2) Theoretical carbon price in Namibia (N$)	60	NIRP (2015)
(3) Total de-bushed land in Year 1 (ha)	315,622	
(4) Average decrease in bush density	38.5%	N-BiG
(5) Economic costs of loss of SOC in Year 1 in 2015 prices (N$m)	**5.6**	**Calculation: (1)*(2)*(3)*(4)/1000000**

Over the 25 year time horizon used for this study, it is possible to calculate the net present value (NPV) of carbon sequestration. This assumes that the same area of land is de-bushed each year, the real Namibian carbon offset value remains constant, and a real discount rate of 6% is applied consistently across the time period. Based on the estimate of a change in -0.771 tCO_2/ha per annum, the NPV represents a cost of N$64.4 million in 2015 prices.

Chart 22.1: Cost of loss of SOC



There will be further impacts on net carbon sequestration in Otjozondjupa based on how the de-bushed material and/or land are used. Two key issues are the use of de-bushed material to generate power for industry and electricity (see Sections 26.4 and 26.5), and the exploitation of the anticipated increased carrying capacity of land to farm more cattle (see Section 24).

22.3 Sensitivity analysis

The cost estimates in Section 22.2 use the Namibian carbon offset value of N$60 to generate a monetary value for CO_2 emissions, but there are alternative values. The Social Cost of Carbon (SCC) puts a particularly large value on CO_2 emissions as it is based on the potential cost of damages; other market-based values are currently significantly lower. Namibia does not appear to have clear guidance on how to value carbon emissions for policy appraisal at a domestic level.

As discussed above, in the absence of clear guidance at a domestic level, we have chosen to use a value of N$60/t$CO_2$e, which is currently being used for the National Integrated Resource Plan review. However, if the full economic and environmental costs are taken into account, then the adoption of the US SCC likely represents best practice.

Table 22.3 illustrates how the costs vary depending on the carbon value used. The central case, using the Namibian offset value, would result in a net cost of N$64.4 million over the 25-year horizon. Using the SCC, the net cost would be almost eleven times that, at N$695.9 billion.

Table 22.3: Sensitivity analysis for SOC

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**64.4**	**0.0**	**-64.4**
SCC	695.9	0.0	-695.9

1: 2015 prices, discounted by 6% p.a.

22.4 Limitations and risks

There are a number of assumptions in the above calculations which are particularly strong. The simple inversion of sequestration estimates undertaken in (2) of Table 22.1 is necessary given the lack of evidence going in the other direction, and may well overstate the true change in carbon sequestration. Furthermore, the estimates of changes in carbon sequestration taken from Blaser et. al. (2014) do not make clear the underlying level of bush density, and whether it is representative of the situation in Otjozondjupa. The assumption undertaken in (4) of Table 22.2 that because only a proportion of the bush is cleared the impacts can be scaled by the proportion that is cleared, is also very strong; there may be non-linear or threshold effects at work. Finally, only a point estimate is presented above, although as discussed in Section 22.1, the existing evidence presents a range of estimates of the impact on carbon sequestration from moving bush encroachment on grassland.

23 Appendix VI: Groundwater

Namibia is the most arid country in Sub-Saharan Africa and is highly dependent on groundwater. Bush encroachment increases the rate of evapotranspiration, reducing groundwater recharge rates compared with grassland. Bushes intercept some rainwater before it reaches the ground which then evaporates into the atmosphere. They also compete with grasses to take up significant amounts of water from the soil through their root systems. Transpiration, the process of water being carried from roots to leaves and evaporating, is where the main loss of water occurs. De-bushing would reduce the amount of water used by encroacher bushes, increasing recharge (Christian et. al. 2010).

23.1 Benefit for increased groundwater recharge/sustainable water supply

A two-step process was undertaken to estimate the potential benefit to groundwater recharge and sustainable water supply from de-bushing (compared with no de-bushing).

1. Estimate the change in groundwater recharge (Section 23.1.1)
2. Estimate the value of the additional sustainable water supply from groundwater each year (Section 23.1.2)

23.1.1 Estimating the increase in groundwater recharge

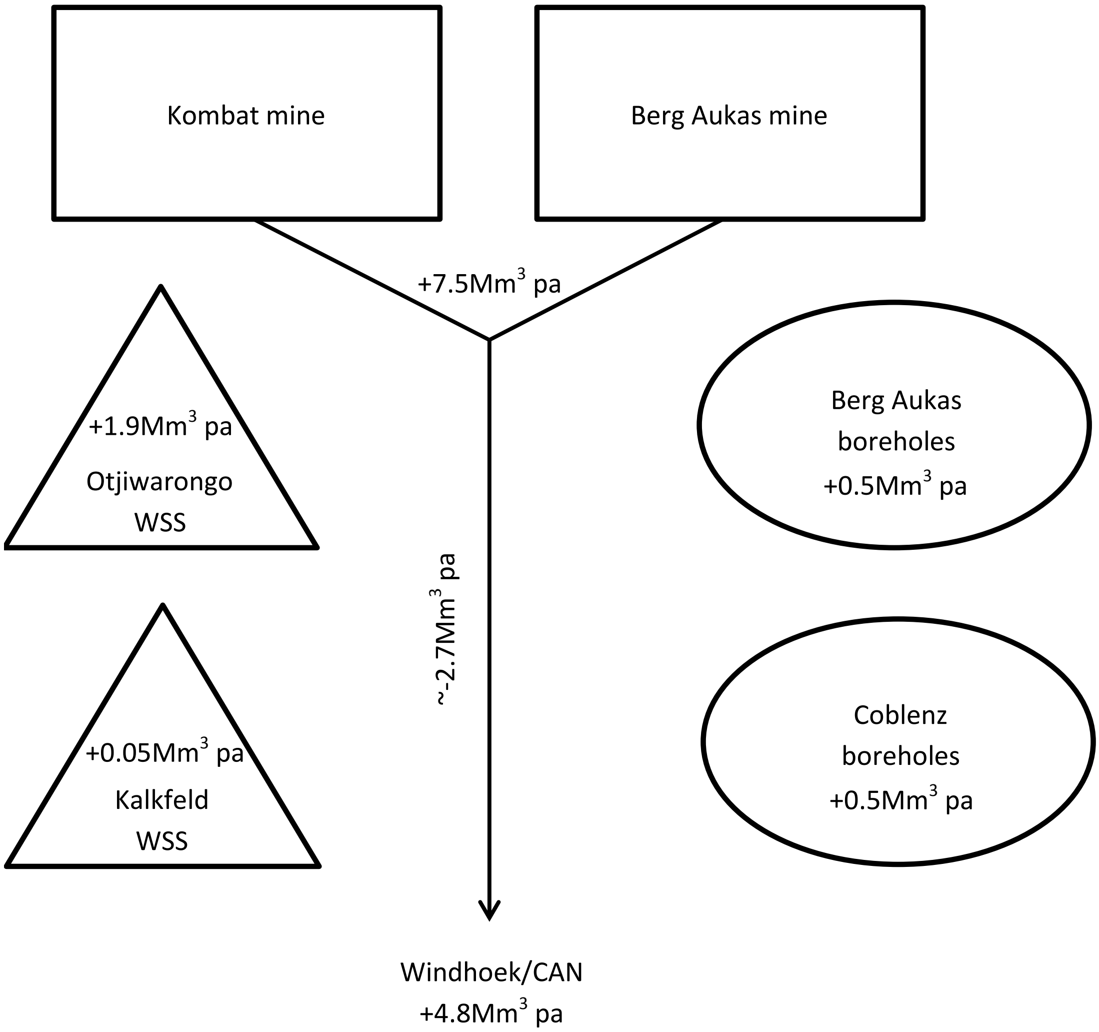
NamWater's current groundwater extraction and supply infrastructure in Otjozondjupa is presented in Figure 23.1. The aquifers under the Kombat and Berg Aukas mines supply water to Windhoek whereas the Berg Aukas and Coblenz boreholes and the Otjiwarongo and Kalkfeld water supply schemes (WSSs) supply water locally.

Sustainable extraction of 7.5 million m^3 per annum is permitted from the mines[24]. As it is transported to Windhoek, an estimated 36% (2.7Mm^3) of the water is lost through evaporation and leaks. The Berg Aukas and Coblenz boreholes yield a sustainable volume of 1.0 million m^3 per annum while the Kalkfeld and Otjiwarongo WSSs yield a sustainable volume of 1.95 million m^3 per annum.

Total extraction is therefore 10.45 million m^3 per annum while 7.72 million m^3 actually reaches users.

[24] Currently, water is being extracted at above the sustainable rate to make up for reduced water supply from other sources due to the drought. However, we take the current sustainable rate of extraction as the base.

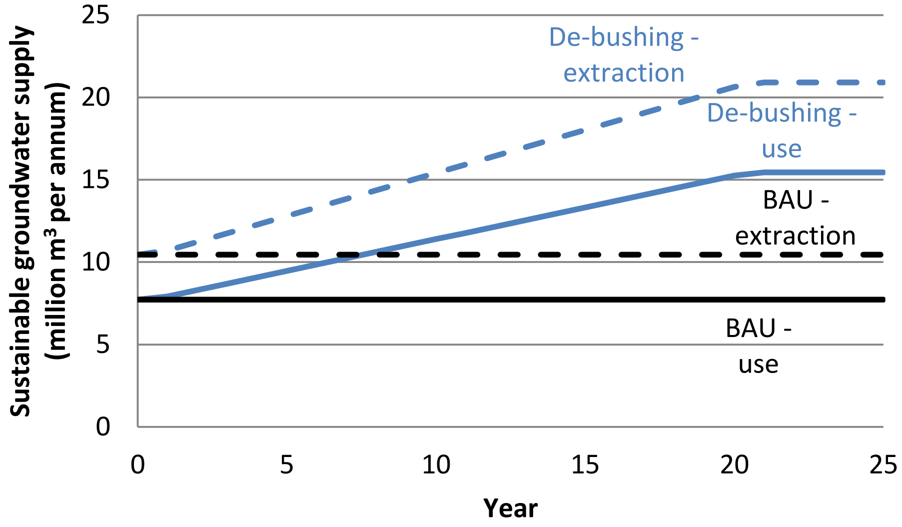
Figure 23.1: NamWater groundwater extraction and supply infrastructure in Otjozondjupa



Data on responses by groundwater recharge rates to de-bushing are limited. Christian et. al. (2010) cite a highly localised study of the Platveld Aquifer, where the recharge rate was estimated to improve to 8% in a de-bushed area. However, it should be noted that this estimate was based on a single rainfall event and is therefore not very robust. A more realistic estimate for the Platveld area was thought to be 4%. The authors also cite estimates of recharge rates of 6% observed in the Otavi Mountain Lands in the 1970s (before significant bush encroachment), which compares with a recharge rate of 1% in the late 1990s (under significant bush encroachment conditions).

We took a conservative estimate of a rise in the recharge rate from 1% to 2% to be used in the central case. Assuming that 5% of the areas where groundwater infiltrate to these aquifers was de-bushed per annum, and assuming that groundwater recharge rates improved linearly, it was estimated that de-bushing could result in additional sustainable extraction of 10.45 million m^3 per annum using the current infrastructure after 21 years. This would result in an additional 7.72 million m^3 reaching users per annum. Over 25 years, this represents additional sustainable extraction of 156.8 million m^3 and additional sustainable use of 115.8 million m^3.

Chart 23.1: Sustainable groundwater extraction and use – de-bushing versus BAU



23.1.2 Valuing the increase in sustainable water supply

For valuation purposes, we had to first subtract the volume of additional groundwater that would be used for the increased number of cattle due to de-bushing, as the value of this is implicit in the value of the additional beef production (see Section 24). We also had to subtract the volume of additional groundwater that would be used for the new biomass power plants (see Section 26.4).

23.1.2.1 Groundwater used for additional livestock

To estimate the groundwater that would need to be allocated to the additional cattle, an estimate of the groundwater used per head of cattle was applied to the estimated numbers of additional cattle.

Christian et. al. (2010) cite the IWRM Plan Joint Venture Namibia (2010) which estimates that 61.3 million m^3 of groundwater was used for the livestock sector in 2009. It was assumed that 70% of this was used for cattle (42.9 million m^3) and the remaining 30% was used for other livestock. The livestock census for 2009 does not offer accurate data on total cattle numbers in Namibia, so the 2010 figure was used to approximate a volume of 18.0m^3 of groundwater consumed per head of cattle per annum.

This figure was then multiplied by the additional head of cattle per annum in Otjozondjupa (due to de-bushing) to derive the total volume of groundwater that would be used for the additional cattle per annum. This was subsequently subtracted from the annual estimates of additional groundwater supply. Over the 25-year horizon, this amounted to approximately 42.6 million m^3.

23.1.2.2 Groundwater used for additional electricity generation

This analysis includes a scenario where multiple power plants are constructed to use woody biomass for electricity generation (see Section 26.4). These plants will require water for their operations, likely supplied from groundwater. As the value of this water will be implicit in the benefit from additional electricity generation, this volume must be subtracted from the annual estimates of additional groundwater supply. Table 23.1 shows the water consumption of each type of envisaged power plant. The scenario allows for three 5MW plants and two of each type of 20MW plant to be constructed and operation over the 25 year horizon.

Table 23.1: Water consumption of biomass power plants

Type of plant	Water consumption (tonnes p.a.)
5MW grate (type 1)	2,606
20MW grate (type 2a)	8,584
20MW grate (type 2c)	8,584

Source: Theeboom 2012

Over the 25-year horizon, biomass plants would use an estimated 774,000 m^3 of groundwater.

23.1.2.3 Valuation

Net of groundwater used for additional livestock and electricity generation, there would be an estimated increase in sustainable groundwater use of 72.42 million m^3 over the 25 years.

To value this increase in sustainable groundwater use, we used an avoided cost approach. Data from NamWater revealed that a project in Kalkfeld to increase capacity by 300m^3 per day would incur capital costs of around N$64.6 million (in 2015 prices) over its 30 year lifetime (see Table 23.2). The Kalkfeld WSS is located in south-western Otjzondjupa. This includes reinstallments of power supply and machinery and equipment in Year 10 and Year 20, as they are only expected to have a ten year lifespan[25].

When adjusted to the 25-year horizon used in this analysis, and with the assumption of economies of scale of 10% (due to the extrapolation across the bush-encroached zones in Otjozondjupa), this represents an implicit cost of around N$14.7 million per million m^3 of water.

[25] NamWater pers. comm.

Table 23.2: Kalkfeld water supply project – capital costs

Activity	Cost (N$)[1]
Civil engineering	
Pipelines procurement & construction	33,800,000
Servitude and site clearance	4,800,000
Machinery and equipment engineering - initial	
Power supply	3,300,000
Machinery and equipment installations	5,120,000
Machinery and equipment engineering - after 10 years	
Power supply	3,300,000
Machinery and equipment installations	5,120,000
Machinery and equipment engineering - after 20 years	
Power supply	3,300,000
Machinery and equipment installations	5,120,000
Drilling and test pumping of boreholes	731,493
TOTAL	64,591,493

1: 2015 prices

Source: NamWater 2015

The implicit cost of water was then applied to the additional sustainable use volumes per annum to arrive at the estimated discounted benefit of **N$430.5 million** over the 25 year horizon.

23.2 Cost of additional groundwater extraction

According to NamWater, the only significant cost associated with extracting larger volumes of groundwater would be the energy used to pump the water from the aquifer to ground level. The following equation (provided by NamWater) was used to calculate the energy that would be required to pump the additional volume of water from the ground:

energy (watts) = density * g * quantity * head / n

Variable	Description	Value
density	density of water	$1000kg/m^3$
g	gravity	10N/kg
quantity	water extracted	x m^3
head	depth to groundwater	80m
n	efficiency	0.8

Source: NamWater

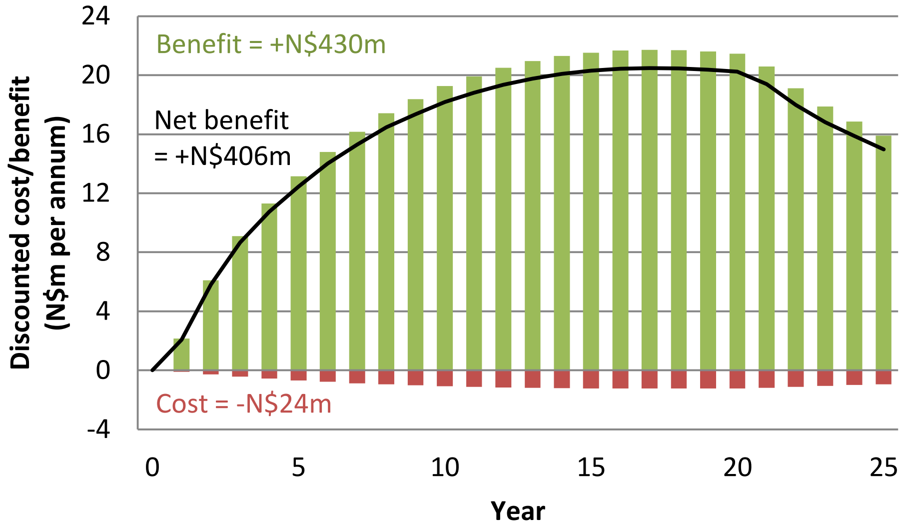
This equation was used to calculate the additional electricity required every year in watts, which was then converted to kWh. The industrial energy charge of N$1.39/kWh for the Okahandja municipality for standard time, averaged between high and low season, was then applied to calculate the cost of additional electricity every year.

Over the 25 years, it was estimated that it would cost **N$24.1 million** (2015 prices, discounted) to extract the additional groundwater.

23.3 Net benefit

The net benefit for additional sustainable extraction and use of groundwater was estimated at **N$406.4 million** (2015 prices, discounted).

Chart 23.2: Benefit, cost, and net benefit of increased sustainable groundwater use



23.4 Sensitivity analysis

Key variables, namely the change in recharge rate and the cost of electricity to pump water out of the ground, were varied in order to observe their impacts on the estimated cost, benefit, and net benefit. It was found that the estimated net benefit ranged from a low of N$83.9 million, when the groundwater recharge rate only increased to 1.5%, to a high of N$1.1 billion, when the recharge rate increased to 3%. Changes in the cost of electricity had a minor impact, with the estimated net benefit ranging from N$401.6 million, when the cost was 20% higher, to N$411.2 billion, when the cost was 20% lower.

Table 23.3: Sensitivity analysis for sustainable water supply from groundwater

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**24.1**	**430.5**	**406.4**
Recharge rate			
1.5%	12.0	95.9	83.9
3.0%	48.1	1,113.7	1,065.6
Cost of electricity			
+20%	28.9	430.5	401.6
-20%	19.2	430.5	411.2

1: 2015 prices, discounted by 6% p.a.

23.5 Limitations and risks

The impact of de-bushing on groundwater recharge rates needs to be further researched, as the current data is very constrained in terms of location and timing. Our central estimate of an increase in recharge from 1% to 2% of rainfall is conservative, but there is little data to support it. Furthermore, recharge rates would be highly variable in different locations, depending on morphology and geology.

The cost to increase capacity has been drawn from just one project (Kalkfeld WSS), as cost data for other projects were unavailable. The estimated value of water could be much higher if we calculated the avoided cost of importing water. Namibia has two feasible options for long-term water supply to the central area of Namibia (CAN): extraction from the Kavango River on the northern border and desalination at the coast. Both would require huge investment costs for infrastructure and energy to pump water to the CAN.

A key risk here is that if de-bushing is not carried out with good environmental management practices, it could increase soil erosion, which has the potential to increase vulnerability of groundwater resources.

24 Appendix VII: Livestock

Livestock farming, particularly cattle farming, is a significant land use, employer, and income generator in Otjozondjupa. In our analysis, we focus only on cattle farming, as this is the dominant type of farming. Between 2011 and 2015, Otjozondjupa accounted for an average of 16.9% of total cattle in Namibia, whereas the region accounted for just 3.7% of sheep and 5.6% of goats over the same period.

24.1 Benefit for increased livestock production

A three-step process was undertaken to estimate the potential benefit to cattle farming from de-bushing (compared with no de-bushing).

3. Estimate the change in cattle numbers (Section 24.1.1)
4. Estimate the value of the additional cattle that could be slaughtered each year (Section 24.1.2)
5. Estimate the option value of selling off the additional cattle at the end of the 25 years (to represent the change in wealth) (Section 24.6).

24.1.1 Estimating the increase in cattle numbers and beef production

Based on literature reviews and expert knowledge, the accepted rule of thumb is that a reduction in bush to an optimal density would at least double carrying capacity. As mentioned in Section 21, we are unable to calculate the optimal density, and different bush-encroached zones would be de-bushed at different rates (see Section 21.1). Therefore, changes in carrying capacity would be expected to differ by zone.

It was assumed that if total bush density (including encroacher and non-encroacher species) was reduced by less than 20%, there would be no change in carrying capacity. For a reduction of 20-40%, carrying capacity would increase by 50%, and for a reduction of 40-60%, carrying capacity would increase by 100%. This would result in an overall increase in carrying capacity of 59.7% across the de-bushed areas of Otjozondjupa. These assumptions were confirmed by NAU[26].

Livestock census data[27] were used to estimate head of cattle in each of the 22 bush-encroached zones of Otjozondjupa. In the absence of more detailed data, we assume that 60% (more than 284,000) of the total number of cattle would be located in areas targeted for de-bushing.

The latest data available were for 2015 and an average of the past 5 years was taken as a base, to take into account the effects of the current drought. These estimates of head of cattle were then split by land use: commercial, communal south of the veterinary cordon fence (S-VCF), and communal north of the veterinary cordon fence (N-VCF)[28]. This split assumed that cattle numbers were proportionate to the areas of commercial and communal land in each of the bush-encroached areas, as shown in Table 24.1.

[26] Pers. comm. 2016
[27] Directorate of Veterinary Services
[28] Breakouts of foot-and-mouth disease (FMD) sometimes occur in the north – the VCF prevents the spread of FMD.

Table 24.1: Cattle numbers in areas targeted for de-bushing, by bush-encroached zone

No. of area (map)[1]	Head of cattle			
	Commercial	Communal (S-VCF)	Communal (N-VCF)	Total
1	34,518	11,798	0	**46,316**
2	2,248	1,297	0	**3,545**
3	13,746	3,890	0	**17,636**
4	4,754	10,373	0	**15,127**
5	0	10,373	0	**10,373**
6	3,372	0	0	**3,372**
7	11,989	0	0	**11,989**
8	6,883	0	0	**6,883**
9	3,372	10,373	0	**13,745**
10	0	15,560	0	**15,560**
11	39,917	0	0	**39,917**
12	0	0	324	**324**
13	0	12,349	1,296	**13,645**
14	0	0	486	**486**
15	0	0	486	**486**
16	0	0	324	**324**
17	0	0	324	**324**
18	14,321	0	0	**14,321**
19	19,083	0	0	**19,083**
20	12,722	0	0	**12,722**
21	19,083	6,174	0	**25,258**
22	12,722	0	0	**12,722**
Total	**198,731**	**82,187**	**3,241**	**284,159**

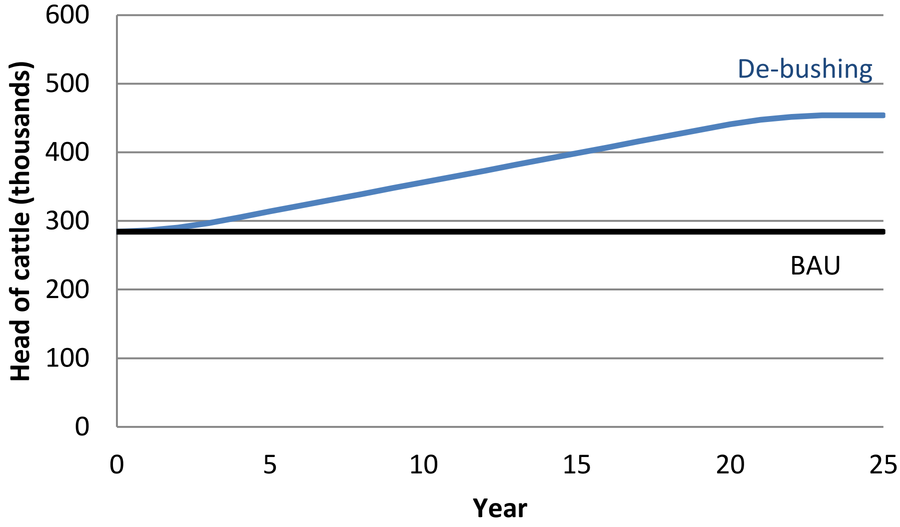
Source: Directorate of Veterinary Services 2015

1: Numbered bush-encroached zone (see Figure 2.2)

It was assumed that following de-bushing of an area, it would take four years to reach the new carrying capacity in that area. This was based on the personal experience of Hendrik Botha, a farmer in the Okahandja area, as presented during the Namibian Rangeland Forum (NRF) meeting in September 2015, and anecdotal evidence from other farmers. Consequently, there is a lag in the escalation of cattle over the time horizon. Based on our estimates, carrying capacity across the areas targeted for de-bushing in Otjozondjupa would have completed the overall increase of 59.7% by the end of Year 23 (see Chart 24.1). It is implicitly assumed that the current carrying capacity is being fully utilised[29].

[29] This was confirmed as a reasonable assumption by Roelie Venter from the Namibia Agricultural Union (NAU)

Chart 24.1: Head of cattle – de-bushing versus BAU



Offtake rates (the percentage of the herd that is slaughtered per annum) differ by land use and region (see Table 24.2). Commercial farms have the highest, at an average of 27.5%, while communal lands south of the VCF have an average of 16%. Part of the north-eastern section of Otjozondjupa is north of the veterinary cordon fence (VCF). Farmers north of the VCF are not allowed to export their meat and the average offtake rate is much lower here, at around 4%.

In order to utilise the increase in carrying capacity, offtake rates would need to be lowered to allow for natural growth in the herd. Using a model of herd dynamics from NAU, it was found that in areas where carrying capacity could be doubled, the overall offtake rate would have to be reduced by 3.6 per cent (until the new carrying capacity was reached in Year 23). In areas where carrying capacity could be increased by 50%, the overall offtake rate would have to be reduced by 6.1 per cent. These varying offtake rates were used to estimate the number of cattle slaughtered per annum.

Table 24.2: Off-take rates 2015

Land use/region	Offtake rates (%)	Average (%)
Commercial	25-30	27.5
Communal (S of fence)	15-17	16.0
Communal (N of fence)	3-5	4.0

Source: Meat Board of Namibia

A conversion factor of 246.9kg/head[30] was then applied to the number of cattle slaughtered to estimate meat production in kilograms.

[30] Namibian meat production data from the UN Food and Agriculture Organisation (FAO)

24.1.2 Valuing the increase in beef production

The year average beef producer price for 2015 of N$27.3/kg[31] was applied to the offtake (in kg) to estimate revenue for commercial and communal (both north and south of the red line) farmers in the 22 bush encroached zones. This was then summed to arrive at total revenue.

A BAU scenario for no de-bushing was also set up under which cattle numbers remained constant. The difference between the total revenue obtained in each of these two scenarios represents the benefits that would be gained from increased beef production due to de-bushing.

The analysis showed that de-bushing could result in an additional N$277 million per annum (undiscounted, 2015 prices). The discounted benefit was estimated at **N$1.1 billion** over the 25 year horizon.

24.2 Financial cost of increased livestock production

NAU provided data on the production costs of a cow-ox cattle production system for a typical cattle farm (see Table 24.3). For commercial farms, typical annual production costs amount to around N$914,000. On advice from the NAU, these costs were converted into representative costs for communal cattle farming, where annual production costs amount to around N$463,000. It should be noted that these cost estimates do not include interest payments and debt repayments.

Based on production of 68,713kg (live) for commercial farming and 40,719kg (live) for communal farming, the expenses per live kg produced were calculated as N$13.2/kg for commercial cattle farms and N$11.1/kg for communal cattle farming (see Table 24.3).

The additional offtake (carcass weight) per annum, calculated in Section 24.1.1, was then converted into live weight using NAU's methodology[32]. The cost per live kg was then applied to this additional offtake (in live kg).

[31] Meat Board of Namibia
[32] The NAU uses a standard factor of 0.53 to convert carcass weight into live weight.

Table 24.3: Investment, operating, and maintenance costs for commercial and communal cattle farming

Type of expense	N$	
	Commercial	Communal
Buy in	60,000	20,000
Management	240,000	240,000
Labour	97,175	30,100
Fuel	88,703	40,000
Feeds	154,190	38,547
Electricity	32,000	0
Repairs and maintenance	57,100	11,420
Medicine and veterinary	48,238	24,119
Insurance and licences	29,880	0
Marketing	53,251	39,938
Sundries	43,300	8,660
TOTAL EXPENSES (N$)	**903,837**	**452,785**
Production (live kg)	68,713	40,719
TOTAL EXPENSES (N$/kg)	**13.2**	**11.1**

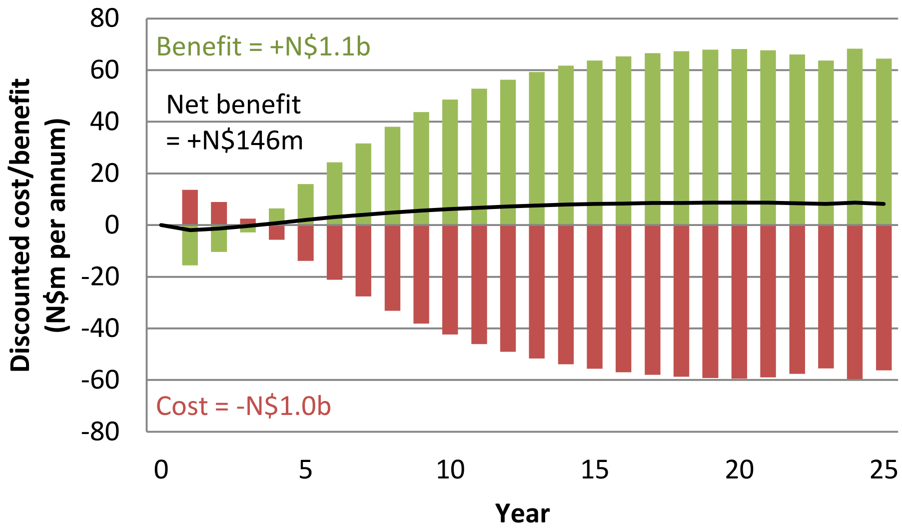
Source: NAU

The discounted cost was estimated at **N$1.0 billion** over the 25 year horizon.

24.3 Net benefit

The net benefit for additional cattle production was estimated at **N$146.0 million** (2015 prices, discounted).

Chart 24.2: Benefit, cost, and net benefit of increased cattle production



24.4 Sensitivity analysis

Key variables, namely the change in carrying capacity, price, and cost were varied in order to observe their impacts on the estimated cost, benefit, and net benefit. It was found that the estimated net benefit ranged from a low of -N$81.9 million, when price decreased by 20%, and a high of N$373.8 million, when price decreased by 20%. Changes in costs had a similar impact. When the carrying capacity increase was half that of the central case, the net benefit was estimated at N$58.5 million, but when the carrying capacity increase was double that of the central case, the net benefit was estimated at N$320.9 million.

Table 24.4: Sensitivity analysis for livestock production

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**993.3**	**1,139.3**	**146.0**
Carrying capacity increase			
half central case	399.2	457.7	58.5
double central case	2,181.6	2,502.4	320.9
Price			
+20%	993.3	1,367.1	373.8
-20%	993.3	911.4	-81.9
Cost			
+20%	1,192.0	1,139.3	-52.7
-20%	794.6	1,139.3	344.6

1: 2015 prices, discounted by 6% p.a.

Over recent years, cattle farming has become less profitable:

> "Over the past eight years, production costs on a cattle farm increased by 120%, while the beef price increased by only 73%. Subsequently, farmers without an additional source of income cannot afford to apply sustained bush control measures." (SAIEA 2016, p29).

It is likely that we will see the price increase, relative to the cost, in the near future, when the drought breaks and slaughter rates go down. In this case, the net benefit would be larger.

24.5 Limitations and risks

The relationship between carrying capacity and bush density was estimated using a rule of thumb, rather than robust data. The forecasts of cattle numbers do not allow for influences such as weather patterns (e.g. drought), social trends, and competing industries which cause variation – the forecasts should be taken as an average.

Increasing stocking rates by the estimated amount may result in overgrazing if good rangeland management is not practiced, encouraging bush encroachment and perpetuating the cycle. It is crucial that recommended rangeland management practices are undertaken. This may mean that in some areas, cattle numbers should not be increased by the estimated amount.

The price is held constant in real terms, which is unrealistic. There will be price fluctuations, which may put upward or downward pressure on stock and offtake rates. These tend to be linked to weather conditions.

24.6 Estimating the option value on the addition to the stock of cattle

We also need to take into account the increase in wealth represented by the additional cattle. We can do this by using an option value – at the end of the 25 year period, if the additional cattle were sold off, how much would this be worth?

In Section 24.1.1, it was estimated that almost 170,000 cattle could be added to the herd. Based on the NAU's model of herd dynamics, the expected breakdown could be represented by Table 24.5. NAU also provided guidance on the applicable weights and prices. Given the volatility of live auction prices, for some categories, carcass price (N$/kg) was applied to the live weight.

Table 24.5: Additional cattle, weights, and prices

Type	Additional head	Weight (kg/head)	Price (N$/kg)	Total value (N$m)
Bulls	2,725	440*	21.00	**25.2**
Productive cows	68,136	235*	21.00	**336.3**
Heif <12m	17,034	230	18.86	**73.9**
Heifers, 12-24m	17,034	350	18.13	**108.1**
Pregnant heifers	13,627	220*	26.50	**79.4**
Male <12m	17,034	250	18.86	**80.3**
Male 12-24m	17,034	370	18.13	**114.3**
Oxen	17,034	240*	26.50	**108.3**
Total	**169,659**			**925.8**

Source: NNF, NAU, Meat Board of Namibia

* carcass

The total option value was estimated at **N$215.7 million** (2015 prices, discounted).

24.7 Cost of additional emissions from livestock

Although de-bushing offers significant benefits in terms of additional rangeland carrying capacity and the associated increase in beef production, greater numbers of cattle will increase greenhouse gas (GHG) emissions; an additional kilogram live-weight of cattle is estimated to contribute an additional 11.93 kgCO_2e per annum[33].

Table 24.6 presents an estimate of the additional CO_2e emissions from the increased carrying capacity of rangeland in Year 1. Based on estimates of increased carrying capacity from de-bushing versus a business as usual (BAU) scenario (see Section 24.1.1), an additional 2,121 head of cattle are assumed to be present on Otjozondjupa rangeland. At an average live-weight of 297kg[34] per head,

[33] http://beefandlamb.ahdb.org.uk/news/livestock-and-the-environment/livestock-and-climate-change-the-facts/.
[34] Based on approx. 244 kg carcass weight: http://breedplan.une.edu.au/tips/Interpreting%20South%20African%20Simbra%20Selection%20Indexes.pdf

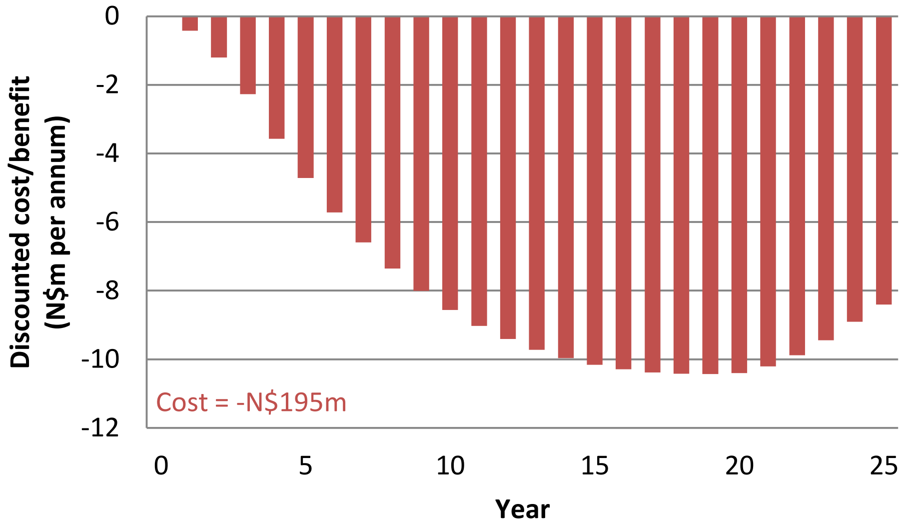
and with emissions of 11.93 kgCO_2e per kg live-weight, additional emissions of 7,514 tCO_2e in Year 1 are estimated. As the de-bushing and BAU scenarios further diverge over the 25 year study period, this would correspond to total additional emissions of 8.4 million tCO_2e.

Table 24.6: Estimate of CO_2e emissions from additional livestock carrying capacity in Year 1

		Source
(1) Additional head of cattle	2,121	Section 6.1.1
(2) Average liveweight (kg)	297	Venter (2015)
(3) Emissions per kg liveweight (kgCO2e)	11.93	Footnote 10
(4) Convert to tonnes from kg	1,000	
(5) Additional emissions (tCO_2e)	**7,514**	**Calculation: (1)*(2)*(3)/(4)**
(6) Theoretical carbon price in Namibia (N$)	60.00	NIRP (2015)
(7) Economic costs of additional livestock emissions in Year 1 (N$, 2015 prices)	**450,853**	**Calculation: (5)*(6)**

This can be valued using the Namibian carbon offset value as demonstrated in Section 22.2. The cost of additional CO_2e emissions in Year 1 is estimated at N$450,853 (2015 prices, undiscounted). Adopting a 6% real discount rate over the 25 year study period yields an estimate of the present value of costs of **N$195.5 million**.

Chart 24.3: Cost of additional emissions from cattle



24.7.1 Sensitivity analysis

If the SCC is used to value the additional emissions from livestock (see Section 22.3), the net cost would be N$2.4 billion over the 25 years, more than twelve times the net cost in the central case.

Table 24.7: Sensitivity analysis for additional emissions from livestock

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**195.5**	**0.0**	**-195.5**
SCC	2,390.9	0.0	-2,390.9

1: 2015 prices, discounted by 6% p.a.

25 Appendix VIII: Wildlife viewing, trophy hunting, and game products

Wildlife viewing is a significant tourism activity on private farms, in conservancies, and in protected areas in Otjozondjupa. Trophy hunting is also an important source of revenue for private farms and conservancies, and the use and sale of game meat brings in revenue and improves nutrition and food security in rural areas.

In Otjozondjupa, registered hunting farms cover approximately 1,248,300 ha. These also include mixed use farms, where livestock production and hunting of game both occur. Private game farms (no hunting) cover an estimated 183,000 ha and IUCN-listed protected areas cover an estimated 38,600 ha.

25.1 Wildlife viewing

This analysis takes a broad look at how wildlife viewing might be impacted by de-bushing on private land. Although wildlife viewing activities also take place in communal conservancies and protected areas in Otjozondjupa, there was not enough information or experience to get a clear idea of the impacts.

According to NACSO (2015), two conservancies in Otjozondjupa, Nyae Nyae, N=a Jaqna, reported returns from tourism, including wildlife viewing, in 2014. For N=a Jaqna, combined tourism returns equated to N$62,840, or 11% of total returns, while for Nyae Nyae, combined tourism returns were N$36,000, or 1% of total returns. Tourism returns are much lower than hunting returns (see Section 25.2).

It should be noted that even the analysis of the effects of de-bushing on wildlife viewing on private land is very general and some assumptions are informed by anecdotal evidence and data from individual farmers.

25.1.1 Benefit

The impacts of de-bushing on the value of wildlife viewing are very difficult to isolate. De-bushing has the potential to increase the carrying capacity of game and also to make animals easier to see for tourists, increasing success rates and satisfaction. However, there is very little literature on quantifying these effects. Gray and Bond (2013) looked at how woody plant encroachment impacts the visitor experience and economy of conservation areas. They found that "density of animals [was] much reduced in woody areas, suggesting that visibility is negatively impacted" and that "almost half of potential future visitors to the park may be lost if animals became more difficult to see" because of woody encroachment (p2).

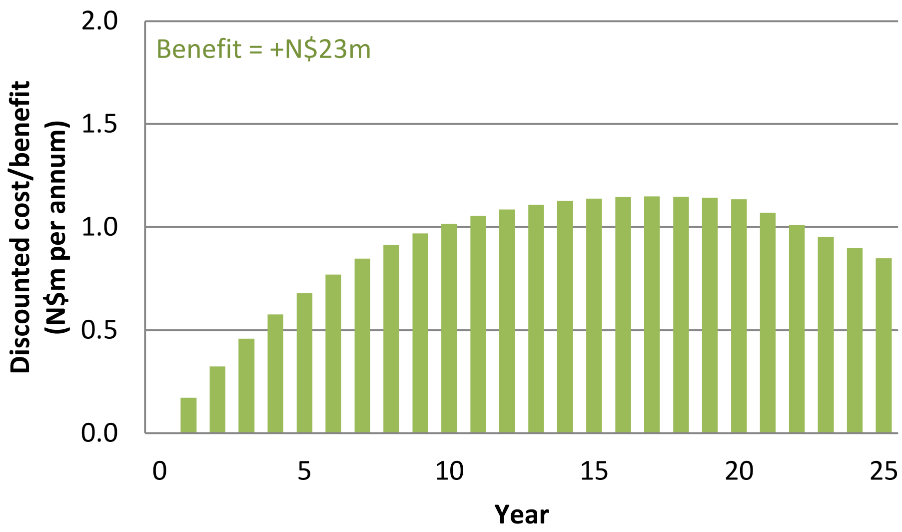
Okonjima Game Reserve covers around 22,000 hectares and is located off the B1 (main road) in Otjozondjupa. De-bushing has been carried out on about a third of its land there for several years. Wayne Hanssen from Okonjima estimates that game drives currently bring in an additional N$1.5 to N$2 million per annum since de-bushing began. He reports that success rates are much higher and that guests are willing to pay more for wildlife viewing.

However, part of this additional revenue would be attributable to factors other than de-bushing. For example, Okonjima hosts the Africat Foundation, which gets a lot of exposure and is an attraction for tourists. We assume that 25% of the additional revenue per annum from game drives, or N$437,500, is attributable to the higher success rates due to de-bushing. This is equivalent to N$19.9 in additional revenue per hectare.

If 5% of the 183,000 ha of private game farms (no hunting), or 9150 ha, is partially de-bushed per annum, we estimate that after 20 years of de-bushing, an additional N$3.6 million (2015 prices, undiscounted) could be realised per annum. No additional costs would be incurred as tourists would be willing to pay more for the same service.

Over 25 years, the discounted benefit for wildlife viewing was estimated at **N$22.7 million** (2015 prices).

Chart 25.1: Benefit for wildlife viewing



25.1.2 Limitations and risks

As mentioned above, this is a very general analysis, which assumes that visitors would be willing to pay more for the same product (e.g. a game drive) because the success rates would be higher. Practically, there could also be an increase in visitor numbers (depending on success of marketing) which would then incur additional costs (e.g. guide salaries, fuel, accommodation).

25.2 Trophy hunting and game products

In this analysis, we look at how trophy hunting, live game auctions, and game products on private game farms would be impacted by de-bushing. Hunting farms tend to only be partly de-bushed so that a variety of habitats exist (e.g. savannah, woodland, shrubland).

Trophy hunting and the use and sale of game products (mostly meat) are also important in communal conservancies in Otjozondjupa. Game meat is an important source of nutrition and food security for some rural communities. According to NACSO, three conservancies in Otjozondjupa have significant trophy hunting activities: Nyae Nyae, N=a Jaqna, and Ongjou, all in the eastern section of the region. Together they cover almost 2.7 million ha. NACSO audits from 2015 show that combined hunting returns to N=a Jaqna equated to N$352,120, or 59% of total returns, in 2014. For Nyae Nyae, combined hunting returns were N$2,747,210, or 91% of total returns.

However, the Nyae Nyae Development Foundation Namibia do not consider that bush encroachment is having a significant negative impact on their hunting operations and advised that de-bushing would not likely have a significant impact on stock of game. This is partly because game in conservancies is distributed over a much wider area than on private farms and can move more freely, and partly because water supply (from the pan structure, less so groundwater), and infrastructure is more of a constraining factor.

We therefore focus on the impacts of de-bushing on trophy hunting, live game auctions, and game products on private game farms.

25.2.1 Benefit

25.2.1.1 Established farms

Registered hunting farms cover approximately 1,248,300 ha in Otjozondjupa. Venter (2015) estimates that 15% of cattle farms are also hunting farms (i.e. mixed use). We assume that 75% of the land occupied by hunting farms is mixed use, while the remaining 25% is game only.

We spoke to a number of farmers who estimated that de-bushing had resulted in an increase in carrying capacity of stock on their land of at least 30% and up to 80%. We take an increase of 50% as a conservative average.

Venter (2015) profiles the revenue from hunting and game for three mixed use farms and one game only farm. The game only farm is located in Otjozondjupa (7,500 ha) while two mixed use farms are located in Khomas (7,500 ha and 10,000 ha) and one in Omaheke (7,500 ha). We assume that these are representative of mixed use farms in Otjozondjupa as well. The average revenue per hectare is then calculated in Table 25.1 as N$129.6/ha for mixed use farms and N$477.6/ha for game only farms.

Table 25.1: Revenue and area of identified mixed use and game only hunting farms

Type of revenue (N$/year[1])	Mixed use			Game only
	Witvlei	Windhoek	Khomas Hochland	Okahandja
Day rates	382,980	245,700	774,000	1,236,000
Trophies sold	800,220	292,500	600,960	1,788,000
Game meat	93,600	16,200	72,000	408,000
Live auctions				150,000
Total	**1,276,800**	**554,400**	**1,446,960**	**3,582,000**
Area (ha)	7,500	7,500	10,000	7,500
Revenue (N$/ha)	170.2	73.9	144.7	477.6
Average (N$/ha)		**129.6**		**477.6**
+50% (N$/ha)		194.4		716.4

1: 2015 prices Source: Venter 2015

Our model assumes that the sustainable offtake rate of game (for trophies and game products) remains the same. Therefore, as stock increases (by 50%), the sustainable offtake (in terms of number of animals) would increase correspondingly. This would result in a proportional increase in revenue, assuming that the proportions of revenue sourced from trophies, live auction, and game meat remained the same. As with cattle, it was assumed that following de-bushing, there would be a lag of four years before the new, increased carrying capacity was realised in that area.

We estimate that by the time that stock has increased by 50% across the entire area in Year 23, additional revenue of N$60.7 million per annum (2015 prices, undiscounted) would be generated by mixed use farms and N$74.5 million per annum by game only farms. This results in an additional N$135.2 million per annum for established hunting farms.

25.2.1.2 New farms

De-bushing could mean that such hunting operations become increasingly viable over a wider area of land as wildlife carrying capacities increase and the hunting experience is improved. Therefore, we can also look at the potential benefits from new mixed use and game only hunting farms on de-bushed land. This could include cattle farms adding hunting operations, cattle farms being converted to game only farms, or other de-bushed land being converted to game only farms.

We assume that land for mixed use farms and game only farms is expanded by 10%. This would equate to an additional 93,623ha of mixed use farms and 31,208ha of game only farms. If we assume that the average farm size was just over 7,800ha, there would be 12 new mixed use farms and 4 new game only farms. In terms of timing, we assume that a new mixed use farm would become operational every year between Year 2 and Year 13 and that a new game only farm would become operational in Years 2, 4, 6, and 8. We also assume that there would be a one year delay between de-bushing and the hunting operation commencing.

The revenue per hectare per annum when stock is increased by 50% (N$194.4/ha for mixed use and N$716.4/ha – see Table 25.1) was applied to new areas. We estimate that by the time that all 12 new mixed use farms were operational in Year 13, additional revenue of N$18.2 million per annum

(2015 prices, undiscounted) would be generated. When all 4 new game only farms became operational by Year 8, additional revenue of N$22.4 million per annum (2015 prices, undiscounted) would be generated. This results in an additional N$33.0 million per annum for new hunting farms.

25.2.1.3 Total

The discounted benefit for trophy hunting and game products for both new and established farms was estimated at **N$1.1 billion** (2015 prices).

25.2.2 Cost

Land costs are not included as they would be transferred within the system.

25.2.2.1 Established farms

We assume that operating and maintenance costs would increase for established farms in line with revenue and that the only additional investment cost would be buying in stock. Other new investments would be required whether stock had increased or not (although perhaps at a slower rate in the BAU case).

For the three mixed use and one game only farm identified above, Venter (2015) profiles the operating and maintenance costs, shown in Table 25.2. The opex were then calculated as a proportion of revenue.

Table 25.2: Opex of identified mixed use and game only hunting farms

Opex (N$/year[1])	Mixed use[2]			Game only
	Witvlei	Windhoek	Khomas Hochland	Okahandja
Labour	54,000	36,000	72,000	635,457
Marketing	156,000	83,160	414,632	431,440
Vehicle and fuel	64,800	21,600	60,000	261,630
Guest transport	26,000	18,000	42,000	317,900
Guest food, drink	140,400	72,800	130,000	
Electricity	10,000	5,000	12,000	144,000
Insurance	7,500	2,500	2,500	32,400
NAPHA m'ship	3,000	3,000	3,000	
MET permits			7,000	
Feed				287,913
Maintenance				49,100
Sundries				84,100
Total	**461,700**	**242,060**	**743,132**	**2,243,940**
Revenue (N$/ha)	1,276,800	554,400	1,446,960	3,582,000
Opex/revenue (%)	36.2	43.7	51.4	62.6
Average (%)	**43.7**			**62.6**

1: 2015 prices Source: Venter 2015
2: additional opex due to the game and hunting operation

When the opex as a proportion of revenue is applied to the additional revenue generated per annum, this results in additional opex costs of up to N$26.2 million per annum (2015 prices, undiscounted) for established mixed use farms and up to N$46.1 million per annum (2015 prices, undiscounted) for game only farms.

Venter (2015) provides estimates for the game stock value for the Witvlei mixed use farm and the Okahandja game only farm (Table 25.3). From this we calculate the current stock value per hectare and what the stock value per hectare would be if stock was increased by 50%.

Table 25.3: Stock value

Value (N$[1])	Mixed use	Game only
	Witvlei	Okahandja
Stock value (N$)	**3,165,500**	**5,603,000**
Area (ha)	7,500	7,500
Stock value (N$/ha)	**422.1**	**747.1**
+50% (N$/ha)	633.1	1,120.6

1: 2015 prices Source: Venter 2015

The stock value was then increased in line with the increase in carrying capacity, taking into account the four year lag, for both mixed use and game farms. This results in maximum buy in costs of N$15.7 million per annum between Years 4 and 20 for both mixed use and game only farms.

25.2.2.2 New farms

The above process for estimating operating and maintenance costs was also used for the new mixed use and game only farms, according to the escalation in revenue (see Section 25.2.1.2).

Investment costs, including buy in of stock, would obviously be larger for new farms. Venter (2015) lists the capex for each of the above identified farms in Table 25.4.

Table 25.4: Capex of identified mixed use and game only hunting farms

Type of capex (N$[1])	Mixed use			Game only
	Witvlei	Windhoek[2]	Khomas Hochland[2]	Okahandja
Accommodation	2,000,000	500,000	2,000,000	4,000,000
Fencing	2,625,000	0	0	2,625,000
Hunting vehicle(s)	400,000	400,000	400,000	800,000
Game stock	3,165,500			5,603,000

1: 2015 prices Source: Venter 2015
2: unfenced

We adapted these costs to get average capex by item for fenced mixed use farms, unfenced mixed use farms, and fenced game only farms (Table 25.5). We took a cost of N$2 million for accommodation on mixed use farms, both fenced and unfenced. We also increased the capex for the game stock by half, to fit in with our scenario of carrying capacity being increased by 50%.

Table 25.5: Adapted capex for mixed use (fenced and unfenced) and game only hunting farms

Type of capex (N$[1])	Mixed use		Game only
	Fenced	Unfenced	Fenced
Accommodation	2,000,000	2,000,000	4,000,000
Fencing	2,625,000	0	2,625,000
Hunting vehicle(s)	400,000	400,000	800,000
Game stock	4,748,250	4,748,250	8,404,500
Total	**9,773,250**	**7,148,250**	**15,829,500**

1: 2015 prices Source: Venter 2015

The capex for each type of farm was then added into the model a year prior to each new farm becoming operational. For mixed use farms, we assumed that 8 out of the 12 would be unfenced, and that these would become operational in Years 2, 3, 5, 6, 8, 9, 11, and 12. The four fenced mixed use farms would become operational in Years 4, 7, 10, and 13.

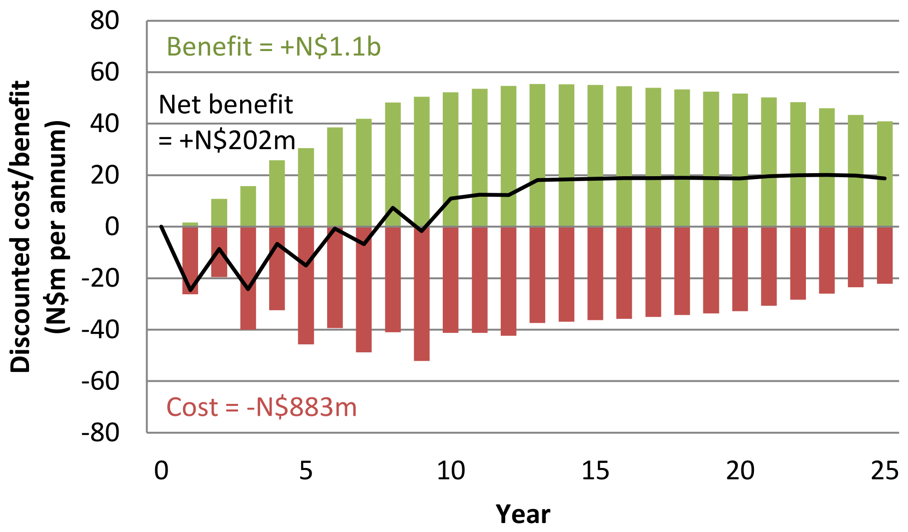
25.2.2.3 Total

Overall, the discounted cost for trophy hunting and game products for both new and established farms was estimated at **N$882.9 million** (2015 prices).

25.2.3 Net benefit

The discounted benefit for trophy hunting and game products was estimated at **N$202.0 million** (2015 prices).

Chart 25.2: Benefit, cost, and net benefit for trophy hunting and game products



25.2.4 Sensitivity analysis

When the carrying capacity increased by 30% instead of 50%, the net benefit was estimated at N$122.2 million, but when carrying capacity increased by 80%, the net benefit was estimated at N$321.6 million.

Table 25.6: Sensitivity analysis for trophy hunting and game products

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**882.9**	**1,084.9**	**202.0**
Carrying capacity			
+30%	622.6	744.8	122.2
+80%	1,273.4	1,595.0	321.6

1: 2015 prices, discounted by 6% p.a.

25.2.5 Limitations and risks

The increase in carrying capacity was not linked to a specific reduction in bush density, as the farmers we spoke to did not have estimates on this. Game stock may also vary year-to-year due to weather patterns (e.g. drought), social trends, and competing industries.

This analysis assumes that the hunting market is not saturated and that there is room for expansion. It also assumes that there is latent demand for hunting activities that could be unlocked with greater supply and more marketing. International ideas on the ethics of trophy hunting and influence on regulation on importing trophies also play a part in demand and willingness to pay for hunting activities in Namibia. Changes to attitudes or regulations could have a negative impact on hunting visitors and revenue.

The price is held constant in real terms, which is unrealistic. There will be price fluctuations, which may put upward or downward pressure on stock and offtake rates.

25.2.6 Estimating the option value on the addition to the stock of game

We also need to take into account the increase in wealth represented by the additional game. We can do this by using an option value – at the end of the 25 year period, if the additional game were sold off, how much would this be worth?

Although we have not used game population numbers, we do know the stock value. For established farms, we added the undiscounted value of the buy in over the 25 years to get the value of the additional stock. For new farms, we added the value of the buy in for each of the 12 farms.

The total option value was estimated at **N$94.3 million** (2015 prices, discounted).

26 Appendix IX: Utilisation of biomass

We calculate the costs and benefits for five uses of encroacher biomass: charcoal, firewood, and animal feed production, thermal power generation for industry, and electricity generation. We also calculate the benefit from leaving a proportion of the biomass on the ground, to protect the soil and return nutrients.

The cost of buying the biomass to use as an input is not included here as it is implicit in the cost of de-bushing. The cost to the purchasers of the biomass would exactly equal the payment (benefit) to the suppliers, so it cancels out within the system. Transport costs are not included as they would depend on distance and volume from biomass production hubs to points of use.

26.1 Charcoal production

The charcoal industry has been present in Namibia for the past thirty years, operating mainly on farmland in central and northern Namibia (NCA 2016).

26.1.1 Benefit

Between 2013 and 2015, Namibia exported around 120,000 tonnes of charcoal per annum and domestic demand was around 1,000 tonnes per annum, resulting in total national production of around 121,000 tonnes per annum. The Namibia Charcoal Association[35] estimated that 60% of this is produced in Otjozondjupa, around the hubs of Grootfontein, Otavi, Okahandja, and Otjiwarongo. This means that Otjozondjupa currently produces 72,000 tonnes for export and 600 tonnes for domestic demand per annum, for a total of 72,600 tonnes per annum.

We assume that this production would have been maintained without the specific programme of de-bushing in the bush-encroached zones. Therefore, the value of 72,600 tonnes of production each year cannot be considered a benefit of a new widespread de-bushing programme. However, if harvesting for charcoal production shifts from tree sources, overexploitation of bushes, or de-bushing in vulnerable areas, this would represent an avoided cost (i.e. benefit).

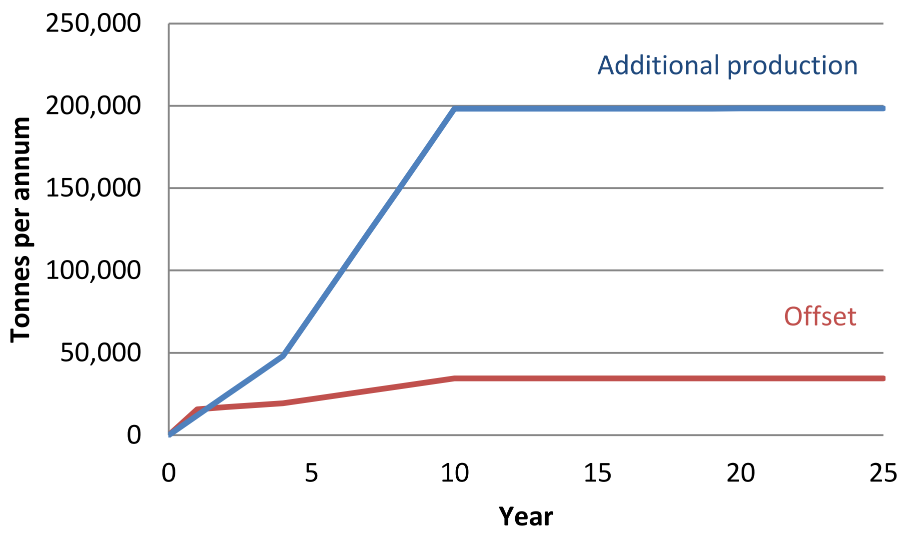
National production could potentially reach 400,000 tonnes within the next ten years[36]. We assume that production of charcoal in Otjozondjupa for export could increase to 270,000 tonnes by Year 10, or 67.5% of national potential production. This would represent an increase of 198,000 tonnes per annum compared with Year 0 and would be supported by the increased supply of woody biomass and overseas demand. We assume that production for export would then plateau after Year 10. We assume that domestic demand would increase in line with the current national population growth rate of 2.3%[37] for 2015.

In the absence of data or representative anecdotal evidence, we assume that 20% of original production and 10% of additional production would represent a shift from the use of non-encroacher bush and trees to encroacher bush.

[35] NCA 2016, pers. comm.
[36] https://www.newera.com.na/2016/09/27/charcoal-other-black-diamond-namibia/
[37] http://databank.worldbank.org/data/reports.aspx?source=2&country=NAM

By Year 25, we estimate that an additional 198,459 tonnes of charcoal could be produced per annum and that 34,366 tonnes would be produced using encroacher bush rather than non-encroacher bush and trees (see Chart 26.1).

Chart 26.1: Additional charcoal production and offset production from non-encroacher bush and trees due to de-bushing



The additional (non-offset) volumes of charcoal produced were then multiplied by the current real average wholesale price of charcoal of N$1,600 per tonne. The offset volumes were multiplied by N$100 per tonne, the approximate difference between fair trade and standard wholesale prices of firewood. The discounted benefit was estimated at **N$2.5 billion** (2015 prices) over the 25 year horizon.

26.1.2 Cost

NCA (2016) estimates the following capex and opex for charcoal production.

Table 26.1: Capex and opex for charcoal production

Type of cost	Cost
Capex	
Cost (N$/kiln)	2,500
Production (tonnes/kiln/year)	24
Opex	
Labour (N$/tonne)	650
Collection (N$/tonne)	50

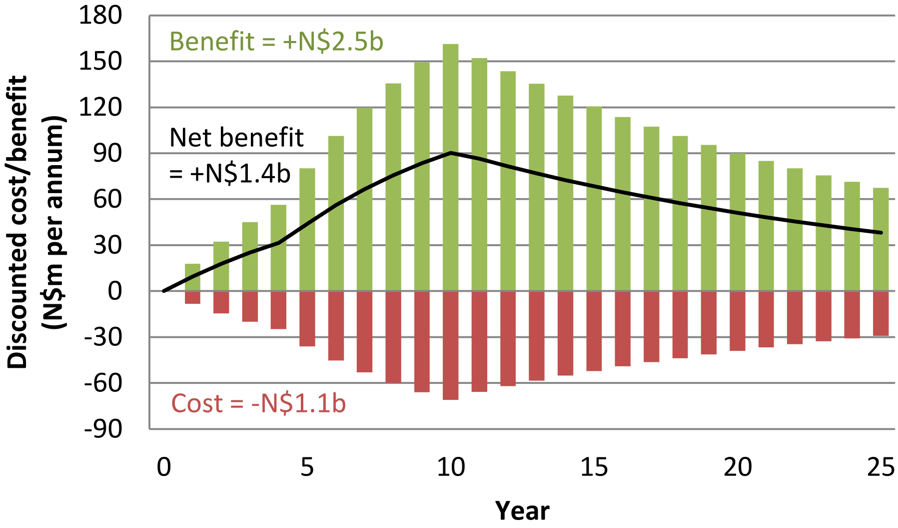
Source: NCA 2016

Every annual increase in additional production was divided by 24 to estimate the number of extra kilns required. The cost of a new kiln (N$2,500) was the applied for each extra kiln. Opex of N$700 per tonne was multiplied by the total additional tonnes produced per annum. Total cost increased from Years 1 to 10 before plateauing at around N$125 million per annum from Year 11 when additional production for export plateaus and only domestic demand is driving increased in production. The discounted cost was estimated at **N$1.1 billion** (2015 prices) over the 25 year horizon.

26.1.3 Net benefit

The net benefit for charcoal production was estimated at **N$1.4 billion** (2015 prices, discounted).

Chart 26.2: Benefit, cost, and net benefit of increased charcoal production



26.1.4 Sensitivity analysis

The price of charcoal and cost of producing charcoal were varied in order to observe the impact on the estimated cost, benefit, and net benefit. It was found that the estimated net benefit ranged from a low of N$896.5 million, when the price was 20% lower, and a high of N$1.9 billion, when the price was 20% higher.

Table 26.2: Sensitivity analysis for charcoal production

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**1,076.5**	**2,466.3**	**1,389.7**
Price			
+20%	1,076.5	2,959.5	1,883.0
-20%	1,076.5	1,973.0	896.5
Cost			
+20%	1,291.8	2,466.3	1,174.4
-20%	861.2	2,466.3	1,605.1

1: 2015 prices, discounted by 6% p.a.

26.1.5 Limitations and risks

There are upside and downside risks to demand for charcoal. Namibia currently exports a significant proportion of its charcoal to Europe. Increases in demand from Europe, the expansion of Namibia's market share, or entry into new markets, such as the Middle East and Asia, may all put upward pressure on demand for Namibian charcoal, whereas competition from other sources may reduce it.

In terms of supply, charcoal producers may have to compete with other industries to secure supply. Fluctuations in supply and demand will affect prices, which we have held constant in real terms.

This analysis has estimated costs based on the standard, low-technology kilns that are widely used across Namibia. Cleaner and more efficient technology is available which would reduce emissions and ash and demand less biomass. New technology would likely increase the benefits and reduce the costs, particularly of woodchips.

26.2 Firewood

Firewood is the primary fuel source for many rural households and informal settlements in Namibia. Much of it is collected for own use or informally sold by roadsides and in markets, but some is retailed at supermarkets and petrol stations. It is thought that a significant amount of firewood is collected from non-encroacher bushes and trees, which can have negative environmental impacts.

26.2.1 Benefit

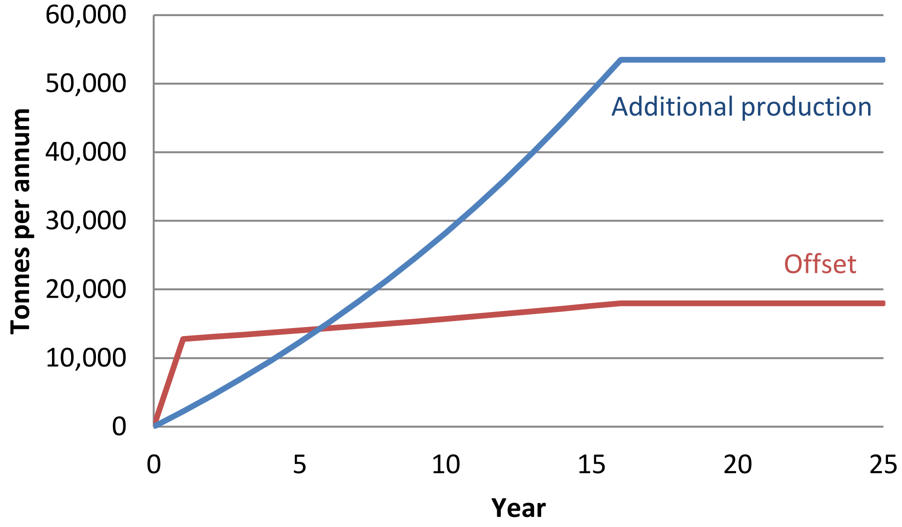
Current demand for firewood in Namibia is estimated at 550,000 tonnes per annum (Development Consultants for Southern Africa 2015b). The majority of firewood collection and use in Namibia is informal, so it is difficult to gauge how much actually originates in Otjozondjupa. Although the proportion of Namibia's population that lives in Otjozondjupa is around 6.4%, we assumed that the proportion of Namibia's firewood produced in Otjozondjupa was higher than this, given the abundant supply of wood. It was assumed that around 9%, or 50,000 tonnes, is currently produced in Otjozondjupa.

We assume that this production would have been maintained without the specific programme of de-bushing in the bush-encroached zones, but we also assume that the increased supply of firewood from encroacher bush would offset some of the firewood currently sourced from non-encroacher bush. As this offset may shift collection of wood from tree sources, overexploitation of bushes, or de-bushing in vulnerable areas, this would represent an avoided cost (i.e. benefit).

We assume that a quarter of the 50,000 tonnes currently produced in Otjozondjupa, or 12,500 tonnes, would represent an offset of non-encroacher firewood production in Year 1, with further offsets rising in line with Namibia's population growth of 2.3[38] per cent per annum. Total firewood production was estimated to increase by 5% per annum until it reaches 109,000 tonnes by Year 16, then plateaus.

[38] http://databank.worldbank.org/data/reports.aspx?source=2&country=NAM

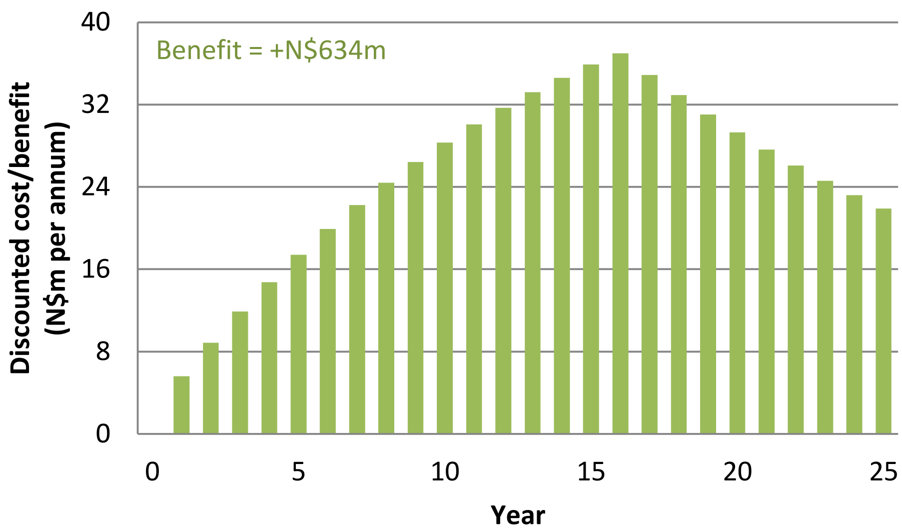
Chart 26.3: Additional and offsetting firewood production due to de-bushing



The additional volumes were multiplied by the current retail price of firewood of N$1,700 per tonne. To value the offset volumes, we applied the proportional difference between fair trade and non-fair trade prices for charcoal (also derived from woody plants) which is equal to around 10%, to the retail price of firewood. This resulted in an estimate of N$170 per tonne of firewood sourced from encroacher bush rather than non-encroacher bush or trees. By the time production plateaus in Year 16, benefits of almost N$94 million per annum (2015 prices, discounted) are estimated.

In total, the discounted benefit was estimated at **N$633.8 million** over the 25 year horizon.

Chart 26.4: Benefit of increased firewood production



26.2.2 Cost

The costs of additional firewood production were not calculated. There would be some additional transport costs and perhaps some labour costs. However, as mentioned above, it is thought that a significant proportion of firewood is collected informally and transported on foot. Overall, we believe that the additional costs would be relatively small.

26.2.3 Sensitivity analysis

The price of firewood was varied in order to observe the impact on the estimated benefit. It was found that the estimated benefit ranged from a low of N$507 million, when the price was 20% lower, and a high of N$760.5 million, when the price was 20% higher.

Table 26.3: Sensitivity analysis for firewood

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**0.0**	**633.8**	**633.8**
Price			
+20%	0.0	760.5	760.5
-20%	0.0	507.0	507.0

1: 2015 prices, discounted by 6% p.a.

26.2.4 Limitations and risks

The forecasts for escalation in demand for firewood (and hence production quantity) and the amount that would be offset are not backed up by robust data. The shift towards the use of encroacher bush would also need to be backed be tighter regulation and enforcement for it to be fully successful.

26.3 Animal feed

Biomass from encroacher bush can be used as an input into animal feed. Bush can make up between 50-85% of animal feed[39], with supplements such as molasses (to improve palatability and nutritional content), urea (for additional protein), polyethylene glycol (as a tannin binding agent), and sodium hydroxide (to aid digestibility) also being added (Pasiecznik 2016).

Although animal feed is an input into cattle production, we assume that in de-bushed areas, increased grass production would be sufficient and animal feed would not be required. Animal feed could be marketed to farms which haven't been included in the de-bushing programme within Otjozondjupa, or in different regions, and which don't have sufficient fodder. This avoids double-counting.

Given that feed production from encroacher bush is relatively new, and that pilot programmes are still underway to determine feasibility of expansion, nutritional content, and other factors, this analysis is very general and some assumptions are informed by anecdotal evidence and data from individual producers.

[39] Tambuti 2015, pers. comm.

26.3.1 Benefit

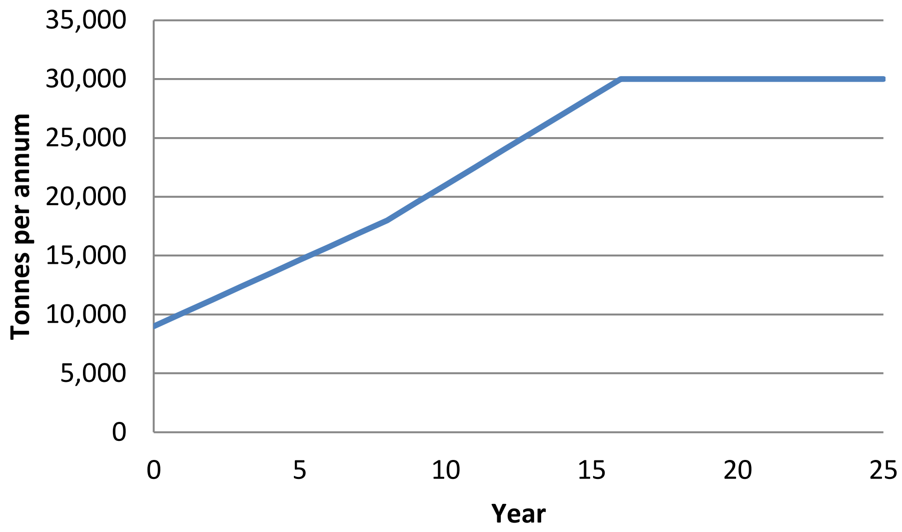
Tambuti, a mixed-use farm in the Otavi area, produces animal feed from de-bushed biomass on its property. Its current capacity is 45 tonnes per week, or 2250 tonnes per annum (based on 50 operational weeks per annum).

Currently, there are 15 identified farmers in Namibia producing animal feed from encroacher bush[40], including Tambuti. If another three of these are located in Otjozondjupa, and they are producing the same amount as Tambuti, 9,000 tonnes of animal feed from encroacher bush are currently being produced in Otjozondjupa per annum.

Tambuti is planning to increase capacity to 100 tonnes per week, or 5,000 tonnes per annum. Using this as a base, but taking into account that it would probably take some time for less established producers to escalate production and new producers to become operational, we assumed that production would be doubled to 18,000 tonnes per annum by Year 8. We then assumed that production would increase by another 67% to 30,000 tonnes per annum by Year 16 before plateauing.

We assume that this additional supply would be absorbed by demand. However, demand for animal feed production tends to fluctuate, largely based on weather conditions. Development Consultants for Southern Africa (2015a) quote figures for imports of feed as 2,000 tonnes in 2012, 14,600 tonnes in 2013, and 3,200 tonnes in 2014. Hence, these projections should be taken as averages.

Chart 26.5: Animal feed production



According to Larry Bussey from Tambuti, the 2015 market price for animal feed was between N$200 to N$325 per 40kg bag, depending on the recipe. On average, this equals N$6,562.50 per tonne. This price was applied to the additional production per annum to estimate the value.

[40] http://www.namibian.com.na/155009/archive-read/From-encroacher-bush-to-stock-feed

Once production reached its plateau of 30,000 tonnes per annum, we could expect to see benefits of almost N$128 million per annum (2015 prices, undiscounted). The discounted benefit was estimated at **N$952.3 million** (2015 prices) over the 25 year horizon.

26.3.2 Cost

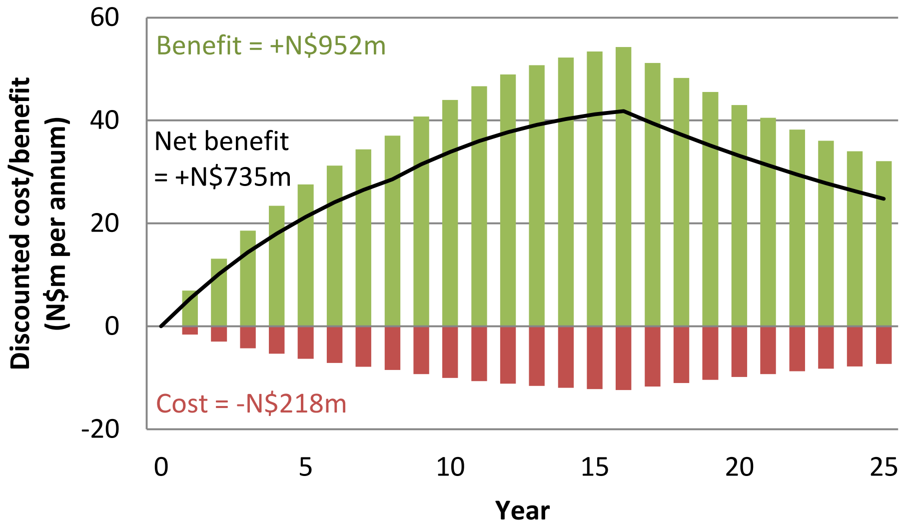
N-BiG provided figures for the combined capex and opex for animal feed production of between N$1.2 and N$1.8 per kilogram based on interviews with farmers. This equates to an average of N$1,500 per tonne. At Tambuti, the average operating cost is around N$1,600 per tonne, including the cost of additives, but this depends on the recipe. The cost of N$1,500 per tonne was applied to the additional production per annum.

Once production reached its plateau of 30,000 tonnes per annum, we could expect to see costs of around N$31.5 million per annum (2015 prices, undiscounted). The discounted cost was estimated at **N$217.7 million** (2015 prices) over the 25 year horizon.

26.3.3 Net benefit

The net benefit for animal feed was estimated at **N$734.7 million** (2015 prices, discounted).

Chart 26.6: Benefit, cost, and net benefit of increased animal feed production



26.3.4 Sensitivity analysis

The price of animal feed and cost of producing animal feed were varied in order to observe the impact on the estimated cost, benefit, and net benefit. It was found that the estimated net benefit ranged from a low of N$544.2 million, when the price was 20% lower, and a high of N$925.1 million, when the price was 20% higher.

Table 26.4: Sensitivity analysis for animal feed production

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**217.7**	**952.3**	**734.7**
Price			
+20%	217.7	1,142.8	925.1
-20%	217.7	761.9	544.2
Cost			
+20%	261.2	952.3	691.1
-20%	174.1	952.3	778.2

1: 2015 prices, discounted by 6% p.a.

26.3.5 Limitations and risks

Results from pilot projects and nutritional studies are pending – these will provide more data and information which could be used to more accurately project the results from an expanded roll out of animal feed production across Otjozondjupa.

26.4 Power for industry

We used two real life examples to analyse how de-bushing could impact power generation for industry:

3. Ohorongo cement – constrained supply of biomass
4. Replacing HFO use with a biomass boiler – Namibia Breweries (Windhoek) example

26.4.1 Ohorongo cement

Ohorongo is Namibia's only cement-producing company and the plant is located near Otavi in Otjozondjupa. Ohorongo invested in a kiln that can process wood chips as well as coal (at a 1:1.6 ratio of tonnes of coal to woodchips) to generate energy for cement production. It aims to replace 75% of coal with woodchips but is currently restricted to only 50% of this capacity due to supply constraints[41].

Current annual production of 700,000 tonnes of cement requires 80,000 tonnes of coal (if 100% of coal is used. Only 37.5% of coal, or 30,000 tonnes, is currently being replaced by woodchips (50% of aim of 70%). We assume that if a widespread de-bushing programme got underway, Ohorongo could reach its target of replacing 75% of coal, or 60,000 tonnes, annually by the fifth year by securing additional supply. This means that the use of coal could be reduced by an additional 30,000 tonnes per annum. If production and proportion of woodchips used remained constant over the rest of the forecast horizon, then the use of coal could be reduced by a total of 690,000 tonnes.

The average South African export price of coal in 2015 was ZAR723.3/tonne (N$723.3/tonne)[42]. When applied to the avoided use of coal, this represents an avoided cost of up to N$21.7 million per

[41] Ohorongo, pers. comm. 2016
[42] http://www.indexmundi.com/commodities/?commodity=coal-south-african&months=60&currency=zar

annum. This results in a discounted benefit of **N$238.7 million** (2015 prices) over the 25 year horizon.

As the investment has already been made and there would be no difference in operating and maintenance costs, there would be no additional costs. The costs of the woodchips are implicit in the costs of de-bushing.

26.4.2 Replacing HFO use with a biomass boiler

Namibia Breweries has invested in a biomass boiler worth N$50 million for its Windhoek plant[43]. This boiler will allow 3,100 tonnes of the current 3,600 tonnes of heavy fuel oil (HFO) used per year to be replaced by 7,500 tonnes of woodchips. This technology can be used in other industries, for example, in meat production.

We assumed that five similar conversions to biomass boilers could occur in Otjozondjupa, starting from Year 2 with a new conversion occurring every three years. This would result in a reduction in HFO use of up to 15,500 tonnes per annum.

The average international price of HFO in 2015 was US$291.25/tonne[44]. This would likely be higher when taking into account the cost of importing to Namibia. When converted to Namibian dollars using the average exchange rate for 2015 of N$12.75/US$[45], the price of HFO is N$3,714.2/tonne. When applied to the reduction in use of HFO, this represents an avoided cost of up to N$57.6 million per annum. This results in a discounted benefit of **N$434.2 million** (2015 prices) over the 25 year horizon.

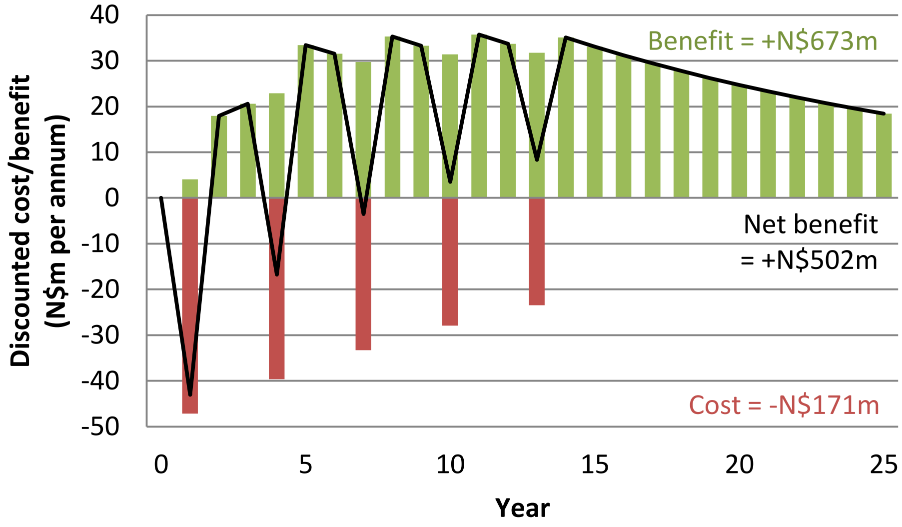
In terms of costs, the N$50 million of investment would be incurred in the year prior to each boiler becoming operational. We assume operating and maintenance costs would be the same compared with continued use of HFO.

26.4.3 Total benefit, cost, and net benefit

In total, replacing coal and HFO with woody biomass, according to the above examples, could result in a total discounted benefit of N$672.9 million and total discounted cost of N$171.4 million. Consequently, the net benefit biomass generated power for industry was estimated at **N$501.5 million** (2015 prices, discounted).

[43] http://www.namibian.com.na/index.php?page=archive-read&id=147980
[44] http://www.insee.fr/en/bases-de-donnees/bsweb/serie.asp?idbank=001642883
[45] https://www.oanda.com/currency/average

Chart 26.7: Benefit, cost, and net benefit of biomass generated power for industry



26.4.4 Sensitivity analysis

The capacity of industry power from biomass was varied by +/- 2 biomass boilers becoming operational. The net benefit ranged from a low of N$455.2 million to a high of N$514.9 million. The price of HFO (avoided cost) was also varied by +/- 20%. The net benefit ranged from a low of N$414.7 million to a high of N$588.4 million.

Table 26.5: Sensitivity analysis for power generation for industry

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**171.4**	**672.9**	**501.5**
Capacity			
+ 2 extra boilers	207.6	722.5	514.9
- 2 fewer boilers	120.0	565.2	445.2
HFO price			
+20%	171.4	759.8	588.4
-20%	171.4	586.1	414.7

1: 2015 prices, discounted by 6% p.a.

26.4.5 Limitations and risks

Other companies will likely be following with interest Namibia Breweries' experience with their new biomass boiler to ascertain how worthwhile a similar investment would be for them.

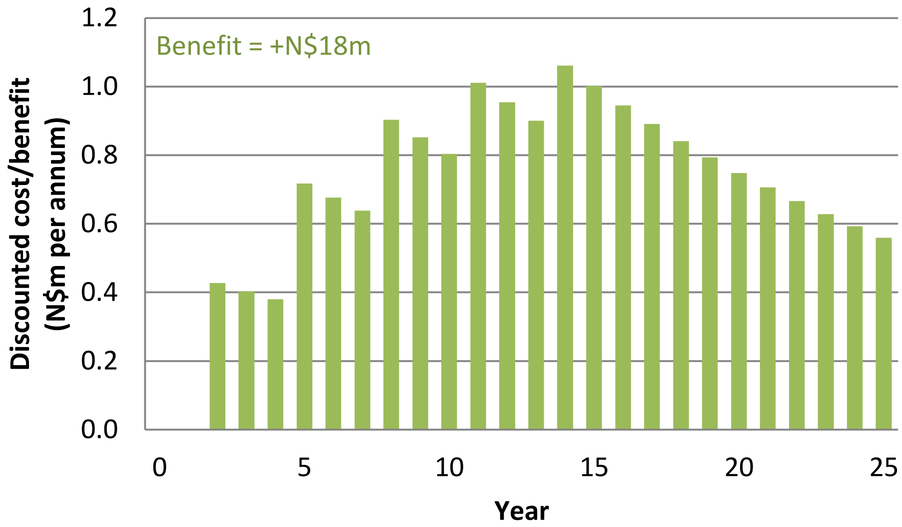
26.4.6 Benefit of emissions offsets

Ohorongo's emissions factor is confidential, so only the emissions offsets for using biomass boilers instead of HFO are calculated.

Namibia Breweries estimates that carbon emissions will be reduced by 8,000 tonnes per annum by replacing 80% of its use of HFO with woodchips. In Otjozondjupa, once all biomass boilers are operations, carbon emissions would be reduced by around 40,000 tonnes per annum. This represents a reduction of 720,000 tonnes over the 25 year horizon.

This reduction in emissions can be valued in the same way as in Section 22.2, i.e. using a carbon price of N$60/t$CO_2$e. An avoided cost of up to N$2.4 million (2015 prices, undiscounted) could be achieved per annum. Over the 25 year horizon, the discounted benefit was estimated at N$18.1 million (2015 prices).

Chart 26.8: Benefit of carbon offsets of biomass power generation for industry



26.4.6.1 Sensitivity analysis

If the SCC is used to value the offset emissions from power generation for industry (see Section 22.3), the net benefit would be N$215.8 million over the 25 years, almost twelve times the net benefit in the central case.

Table 26.6: Sensitivity analysis for offset emissions from power generation for industry

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**0.0**	**18.1**	**18.1**
SCC	0.0	215.8	215.8

1: 2015 prices, discounted by 6% p.a.

26.5 Electricity generation

Our analysis of the potential benefits and costs of electricity generation is based on scenarios outlined in WSP (2012a, 2012b, 2012c): *Prefeasibility Study for Biomass Power Plant, Namibia: Power Plant Technical Assessment; Commercial Assessment; and Preliminary Carbon Funding Analysis*. Updated and more robust feasibility studies are expected to get underway shortly.

26.5.1 Benefits of electricity generation from biomass

The development of three 5MW plants (type 1), two 20MW plants using grate combustion with steam turbine, with the additional energy input of heated air (type 2a), and two 20MW plants using grate combustion with steam turbine, with no additional energy input (type 2c) was envisaged.

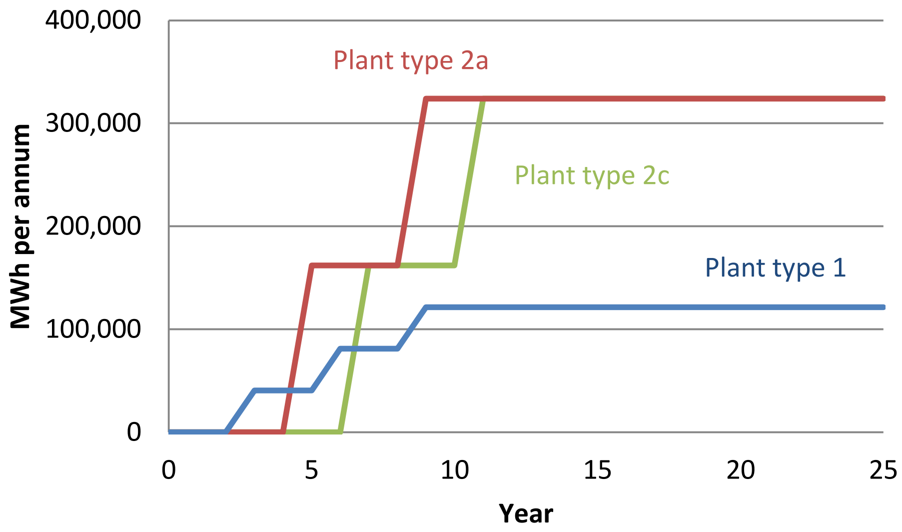
Table 26.7: Output and biomass consumption by type of power plant

Type of plant	Biomass consumption (tonnes p.a.)	Output (MW p.a.)
5MW grate (type 1)	45,247	40,500
20MW grate (type 2a)	147,226	162,000
20MW grate (type 2c)	154,386	162,000

Source: WSP 2012a

It was assumed that the first 5MW plant would enter production in Year 3, with additional 5MW plants entering production in Years 6, and 9, to total 15MW. It was assumed that the first 20MW (type 2a) plant would enter production in Year 5, with an additional plant entering production in Year 9, to total 40MW. It was assumed that the first 20MW (type 2c) plant would enter production in Year 7, with an additional plant entering production in Year 11, to total 40MW. On this schedule, capacity would reach 95MW by Year 11. The study assumes a total of 8100 operational hours per annum per plant.

Chart 26.9: Electricity generation from de-bushed biomass



The average price of electricity was taken as the 2015 average tariff of N$1.28/kWh and multiplied by the total output (in kWh) to estimate the total revenue from biomass-driven electricity production, according to the above assumptions. The discounted benefit was estimated at **N$7.4 billion** over the 25 year horizon.

26.5.2 Financial cost of electricity generation from biomass

The capex and opex according to WSP (2012a) are shown for each type of plant in Table 26.8.

Table 26.8: Biomass power plant capex and opex (€, 2012 prices)

Type of plant	Capex € (2012 prices)	Opex € p.a. (2012 prices)
5MW grate (type 1)	20,877,975	1,420,834
20MW grate (type 2a)	46,216,702	2,050,056
20MW grate (type 2c)	51,613,715	2,188,851

Source: WSP 2012a

To transform these costs into 2015 prices, they were inflated by the annual growth in CPI in the Eurozone[46] for 2013, 2014, and 2015, as presented in Table 26.9.

Table 26.9: Eurozone inflation

Year	CPI - annual growth (%)
2013	1.3
2014	0.4
2015	0.0

The costs in euros in 2015 prices were then converted to Namibian dollars using the average exchange rate for 2015 of 14.15N$/€[47]. The total capex and opex per annum for each type of plant in Namibian dollars (2015 prices) are presented in Table 26.10.

Table 26.10: Biomass power plant capex and opex (N$, 2015 prices)

Type of plant	Capex N$ (2015 prices)	Opex N$ p.a. (2015 prices)
5MW grate (type 1)	300,547,743	20,453,538
20MW grate (type 2a)	665,310,002	29,511,469
20MW grate (type 2c)	743,002,406	31,509,484

Source: WSP 2012a

The capex was distributed over the year(s) prior to the first year of production according to the construction period (see Table 26.11). The opex per annum was included for every year that a plant was in production.

[46] https://data.oecd.org/price/inflation-cpi.htm
[47] https://www.oanda.com/currency/average

Table 26.11: Biomass power plant construction period

Type of plant	Construction period (years)
5MW grate (type 1)	1.0
20MW grate (type 2a)	1.5
20MW grate (type 2c)	1.5

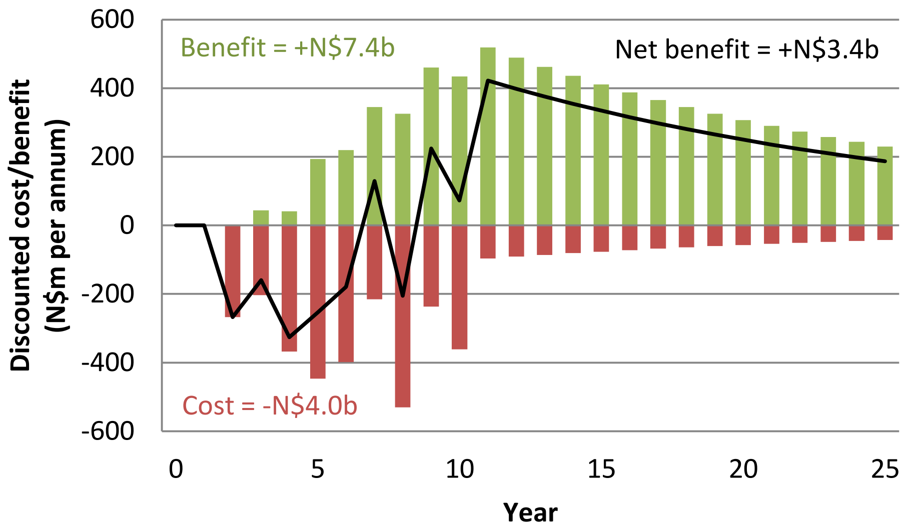
Source: WSP 2012a

This resulted in an estimated discounted cost of **N$4.0 billion** over the 25 year horizon.

26.5.3 Net benefit

The net benefit for biomass electricity generation was estimated at **N$3.4 billion** (2015 prices, discounted).

Chart 26.10: Benefit, cost, and net benefit of biomass electricity generation



26.5.4 Sensitivity analysis

The capacity, price, and cost of electricity generation were varied. An increase from 95MW to 140MW would result in an estimated net benefit of N$4.9 billion while a decrease to 50MW would result in an estimated net benefit of N$1.1 billion.

NamPower estimates that the breakeven price for biomass-fuelled electricity would be N$2.00 to N$2.20/kWh[48][49]. This would be significantly higher than the current electricity tariff of around N$1.28/kWh. It is therefore reasonable to expect that the government would have to subsidise

48 NamPower (pers. comm.)

49 Although this is higher than the current tariff of N$1.28, it is lower than the Kudu power plant's estimated breakeven price of N$2.55. This implies lower production costs for a biomass power plant compared with the Kudu plant proposal.

electricity to the tune of N$0.72/kWh, which represents a cost to society (see Section 26.5.5 for more information). Consequently, the net economic value of the additional electricity supply could be much lower. If the net economic value (price) was 20% lower, the net benefit is estimated at N$1.9 billion over the 25 year horizon, but it could be much lower than this.

When the cost of production was varied by +/-20%, the estimated net benefit ranged from N$2.6 billion to N$4.2 billion.

Table 26.12: Sensitivity analysis for electricity production

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**4,022.8**	**7,403.7**	**3,380.9**
Capacity			
+45MW	4,362.7	9,293.2	4,930.5
-45MW	3,523.5	4,575.3	1,051.8
Price			
+20%	4,022.8	8,884.5	4,861.6
-20%	4,022.8	5,923.0	1,900.1
Cost			
+20%	4,827.4	7,403.7	2,576.3
-20%	3,218.3	7,403.7	4,185.5

1: 2015 prices, discounted by 6% p.a.

26.5.5 Limitations and risks

There are a number of inherent assumptions in WSP (2012a,b,c) which may not be up to date or accurate; these have been carried across to this analysis. Updated and more robust feasibility studies are expected to get underway shortly.

There is a significant risk that the envisaged capacity will not be reached. It would require political support and significant investment by the private sector, as well as the government. The recent shift towards favouring renewables over developing the Kudu gas project is a good sign, but is no guarantee that there will be enough support and investment to reach the envisaged capacity of 95MW[50]. Changes in the plant technology or different types of plants may also alter the fuel requirements (woodchips).

The current electricity tariff of N$1.28/kWh is not a market price, so may not reflect the true economic value of the additional electricity. Furthermore, transmission costs are not included here. It is not clear whether/how they would differ from the current transmission costs and would likely depend on location of the plants.

26.5.6 Benefit of emissions offsets

The impact of electricity generation from biomass on net carbon sequestration in Otjozondjupa depends on whether this electricity generation is additional to or replaces other grid sources.

[50] http://allafrica.com/stories/201511051619.html

Table 26.13 presents an assessment of the total direct CO_2 emissions generated by the three different types of biomass power plant development in Otjozondjupa in a year of operation. Emissions are calculated based on assumptions in WSP (2012c), and the emissions factor includes the effects of both the supply chain and the combustion of biomass residues. As would be expected, the power plants that generate more energy also produce more emissions; they also have slightly higher emissions factors. These emissions can be valued in the same way as in Section 22.2, i.e. using a carbon price of N$60/$tCO_2$e.

Table 26.13: Emissions from a single biomass power plant of each type

Biomass powered	Power plant type			Source
	1	2a	2c	
(1) Size of power plant (MW)	5	20	20	WSP (2012a)
(2) Hours operational		8100		WSP (2012a)
(3) Electricity generated (MWh per annum)	40,500	162,000	162,000	Calculation: (1)*(2)
(4) Emissions generated (tCO_2/MWh)	0.026	0.031	0.032	WSP (2012c)
(5) Total emissions (tCO_2 per annum)	1,053	5,022	5,184	Calculation: (3)*(4)
(6) Theoretical carbon price in Namibia (N$/$tCO_2$)		60		NIRP (2015)
(7) Total cost of emissions (N$ per annum)[1]	**63,180**	**301,320**	**311,040**	**Calculation: (5)*(6)**

1: undiscounted

However this does not represent the net effect on CO_2 emissions in Namibia if it replaces other sources of electricity using the standard energy mix. While electricity generation from biomass sources would be unlikely to immediately displace grid energy, the development of such power plants would relieve pressure on supply and mean that more polluting sources could be avoided. The average emissions factor for electricity in Namibia is estimated at 0.4898 tCO_2/MWh (WSP 2012c). The emissions from each type of plant using a standard energy mix are presented in Table 26.14.

Table 26.14: Emissions from a standard power plant of each type

Grid energy	Power plant type			Source
	1	2a	2c	
(1) Size of power plant (MW)	5	20	20	WSP (2012a)
(2) Hours operational		8100		WSP (2012a)
(3) Electricity generated (MWh per annum)	40,500	162,000	162,000	Calculation: (1)*(2)
(4) Emissions generated (tCO_2/MWh)	0.4898	0.4898	0.4898	WSP (2012c)
(5) Total emissions (tCO_2 per annum)	19,837	79,348	79,348	Calculation: (3)*(4)
(6) Theoretical carbon price in Namibia (N$/$tCO_2$)		60		NIRP (2015)
(7) Total cost of emissions (N$ per annum)[1]	**1,190,214**	**4,760,856**	**4,760,856**	**Calculation: (5)*(6)**

1: undiscounted

Consequently, if these emissions are displaced, the net change in CO_2 emissions would be between -0.4638 and -0.4578 tCO_2/MWh or -18784 and -74,326 tCO_2 per annum. This would result in an avoided cost (benefit) of between N$1.1m and N$4.5m per annum (2015 prices, undiscounted) (see Table 26.15).

Table 26.15: Net change in emissions when electricity generation from biomass power plants displaces grid energy

Net change	Power plant type		
	1	2a	2c
Emissions generated (tCO_2/MWh)	-0.4638	-0.4588	-0.4578
Net emissions (tCO_2 per annum)	-18,784	-74,326	-74,164
Net cost of emissions (N$ per annum)[1]	-1,127,034	-4,459,536	-4,449,816

1: undiscounted

The total net CO_2e emissions and (undiscounted) avoided cost (benefit) over the 25 year lifetime of the project under the three different scenarios are presented in Table 26.16.

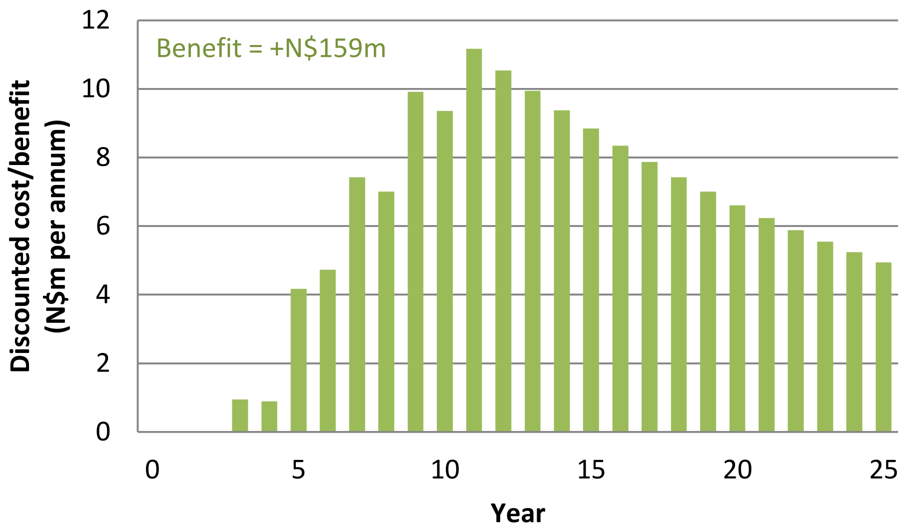
Table 26.16: Total net CO_2e emissions and benefit in Otjozondjupa from each type of biomass power plant development over the 25-year horizon

Net change	Power plant type			Total
	1	2a	2c	
Net emissions (tCO_2)	-1,127,034	-2,824,373	-2,521,562	-6,472,969
Benefit of avoided emissions (N$m)[1]	67.6	169.5	151.3	388.4

1: undiscounted

The discounted benefit was estimated at N$159.4 million (2015 prices) over 25 years.

Chart 26.11: Benefit of carbon offsets of electricity generation from biomass power plants



26.5.6.1 Sensitivity analysis

If the SCC is used to value the offset emissions from electricity generation (see Section 22.3), the net benefit would be N$1.9 billion over the 25 years, around twelve times the net benefit in the central case.

Table 26.17: Sensitivity analysis for offset emissions from electricity generation

Scenario	Cost (N$m)[1]	Benefit (N$m)[1]	Net benefit (N$m)[1]
Base case	**0.0**	**159.4**	**159.4**
SCC	0.0	1,917.7	1,917.7

1: 2015 prices, discounted by 6% p.a.

26.6 Residual biomass and bush banks

Most studies recommend that some of the de-bushed biomass be left on the land, rather all of it being removed, in order to return nutrients to the soil and provide some protection for new grasses coming through. Hengari (2016) recommends that all encroacher bushes be shredded and left on the ground to improve water and nutrient retention and protect the soil, to ultimately increase productivity. In financial terms, this would be unlikely to be feasible, as we find that utilisation of the biomass is key to offsetting the costs of de-bushing. However, we accept that it is vital to leave some of the de-bushed material on the land for the above reasons.

26.6.1 Benefit

Leaves and twigs are not considered useful for charcoal, electricity, and firewood production, so we suggest that these are left on the land. Smit et. al. (2015) provide estimates of leaf and twig mass to woody mass in different encroacher bushes. We take an estimate of 15% from here.

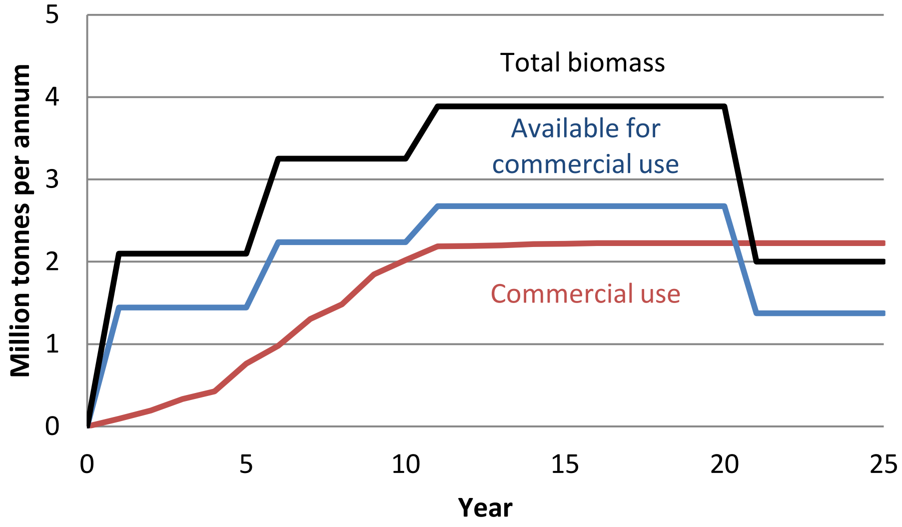
This means that for the commercially utilisable de-bushed biomass (i.e. produced by large scale and small-to-medium scale mechanical harvesting), 15% of all material de-bushed in the initial, follow up and aftercare rounds would be left on the land.

Furthermore, N-BiG recommends that biomass produced by semi-mechanical and manual de-bushing and by the manual application of arboricides are not suitable for large-scale commercial utilisation. We assume that all of the biomass produced by semi-mechanical and manual de-bushing would be left on the ground but disregarded the bushes treated by arboricides.

In total, this would equate to 16.7 million tonnes of biomass being left on the ground over the 25 years.

According to the analysis of the utilisation of biomass (Sections 26.1, 26.2, 26.3, 26.4, and 26.5), Otjozondjupa/Namibia would not have the capacity to utilise all of the produced biomass until Year 21, after the initial round of de-bushing has been completed. This is shown in Chart 26.12.

Chart 26.12: De-bushed biomass, biomass available for commercial use, and actual commercial use of biomass



This leaves two options:

3. Leave the residual amount on the ground
4. Store it for future use in a bush bank

We look at a scenario that includes both options.

De-bushed biomass cannot be stored indefinitely. If stockpiled in a bush bank, it is crucial that the biomass is very dry, otherwise it will mould and lose some favourable properties. Even dry, over years, it will deteriorate, reducing its value and its potential for commercial use.

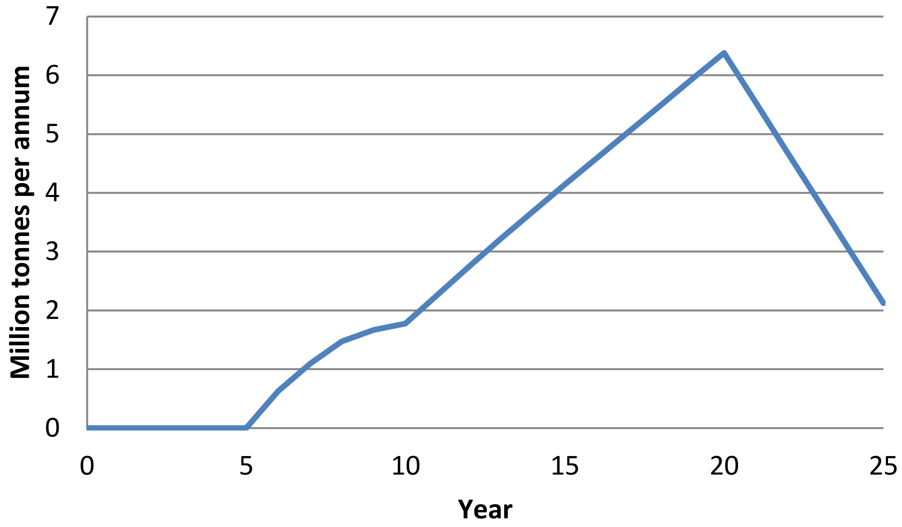
Therefore, as a surplus of biomass is not projected until Year 21, it does not make sense to invest in a bush bank too many years before this. Even so, once the bush bank has been established, the stockpiled biomass should be regularly turned over.

Ndilula, Kangombe, and Zireva (2016) propose the establishment of a bush bank and estimate total construction costs of N$188.4 million across three years. WML Consulting Engineers (2016) have drafted a concept for a "biomass value-adding and agri-industrial park" which would include storage of biomass. This concept involves four phases at a cost of N$421.7 million (although the authors note that these estimates are rudimentary). The plans allow for the addition of biomass power plants and other value-adding industries, so some of these costs would overlap with the costs that we have already estimated.

In our scenario, we take Ndilula, Kangombe, and Zireva's (2016) cost estimate, as it focusses just on the storage. We have already taken into account costs and benefits of value-adding industries in previous sections. We assume that construction on a bush bank would begin in Year 5, allowing biomass to be stored from Year 6. Construction costs would be distributed according to Ndilula, Kangombe, and Zireva's (2016): N$37.8 million in Year 5, N$81.6 million in Year 6, and N$69.0 million in Year 7. This results in a discounted total cost of **N$131.7 million**.

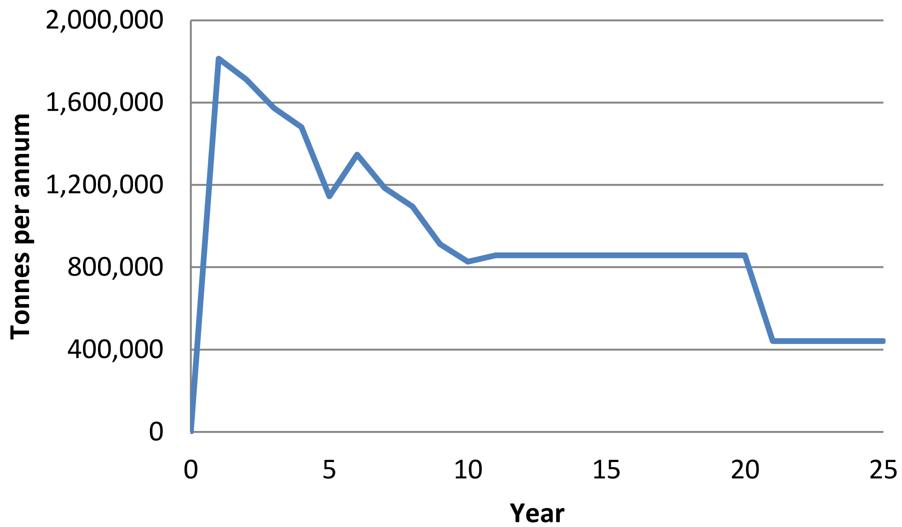
We assume that no surplus biomass would be stored in Years 1 to 5 – this would instead be left on the ground. We assume that 50% of surplus biomass would be stored in Years 6 to 10 – the other 50% would be left on the ground. We then assume that all surplus biomass from Years 11 to 20 would be stored for future use. The profile of stockpiled biomass is shown in Chart 26.13.

Chart 26.13: Biomass stored in bush bank



When we include the additional biomass to be left on the ground to the initial estimates above, this would result in a total of 23.9 million tonnes of biomass being left on the ground over the 25 years (Chart 26.14).

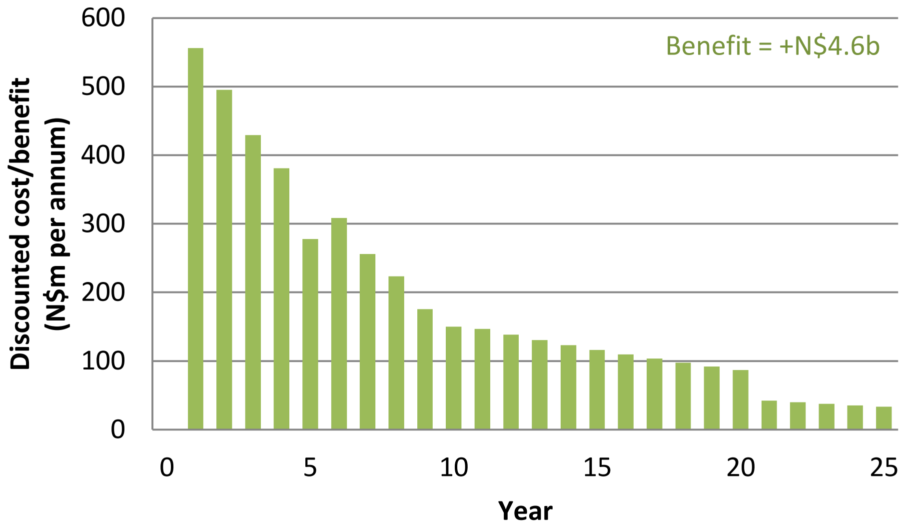
Chart 26.14: Residual biomass from de-bushing



To value the benefits of this residual biomass that is left on the ground, we take a price for mulch. For a cubic metre of mulch in South Africa, the price is R130 (=N$130)[51]. A weight-to-volume estimate of 400kg/m^3 was used to arrive at a price of N$325/tonne of residual biomass.

The volume of volume of biomass left on the ground after de-bushing was then multiplied by this price to estimate its value. The discounted benefit was estimated at **N$4.6 billion** over the 25 year horizon.

Chart 26.15: Benefit of leaving residual biomass on the land



26.6.2 Limitations and risks

There is a risk that de-bushing contractors could remove all of the biomass, rather than leaving the recommended 15% of total biomass on the ground. This would remove all of the nutrients locked up in the biomass from the land and come at a cost to the soil quality, while also removing protection that leaves, twigs, and small branches would provide for new grasses.

26.7 Other opportunities

The increased supply of woody biomass could also have other uses. Wooden crafts are traditionally made in Namibia, so de-bushing could support increases in production. Construction materials can also be produced from de-bushed biomass, including poles, wood cement, medium-density fibre boards, wood-plastic composites, and wooden frames. Poles are currently produced at an estimated 334,000m^2 per annum, but are also imported. The other materials appear to be either niche industries or currently not produced in Namibia at the moment. Increased supply of biomass could support growth in these industries.

There are many other uses of woody biomass that are widespread outside of Namibia, such as the production of wood-plastic composites. These represent further, and potentially profitable, opportunities for Namibia to utilise encroacher. WML Consulting Engineers' (2016) concept for a

[51] http://www.reliance.co.za/productpricelist.html

"biomass value-adding and agri-industrial park" would increase ease of access to wood, supporting growth in new production industries.