Greenhouse Gas Assessment of Bush Control and Biomass Utilization in Namibia

Final Report

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Client

Gesellschaft für internationale Zusammenarbeit (GIZ) GmbH

Authors

Matthias Seebauer (UNIQUE, Germany)

Alexander Pinkwart (UNIQUE, Germany)

Benjamin Schwarz (UNIQUE, Germany)

Carter Hartz (NNF, Namibia)

Date: 22.05.2019

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LIST OF ABBREVIATIONS

AGB	Aboveground biomass
BCBU	Bush Control and Biomass Utilization
BGB	Belowground biomass
DEA	Division of Environmental Affairs
DPM/RPM	Decomposable Plant Matter / Resistant Plant Matter
GHG	Greenhouse Gas
GIZ	Gesellschaft für internationale Zusammenarbeit
GWP	Global Warming Potential
Ha	Hectare
INDC	Intended Nationally Determined Contributions
Kg	Kilogram
LDN	Land Degradation Neutrality
LU	Land Use
LSU	Large Stock Unit
MAP	Mean Annual Precipitation
MAWF	Ministry of Agriculture, Water and Forestry
MET	Namibian Ministry of Environment and Tourism
MW	Megawatt
NAP	National Adaptation Plan
NC	National Communication
NDC	Nationally Determined Contributions
NIR	National Inventory Report
NNF	Namibia Nature Foundation
OWL	Other Wood Land
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
tC	tonne Carbon
tCO_2e	tonnes CO_2 equivalents
TE	Tree equivalent
TNC	Third National Communication
VCS	Verified Carbon Standard
WUE	Water Use Efficiency

EXECUTIVE SUMMARY

Land degradation by bush encroachment

Invasion and encroachment of woody plants into grassland is a global driver of land degradation and a widespread phenomenon in African savannas with significant negative economic and environmental impacts. It decreases landscape heterogeneity, alters vulnerable habitats and reduces biodiversity (de Klerk, 2004; Sirami et al. 2009; Smit and Prins 2015), and it impacts carbon sequestration and water budgets (Woodward & Lomas 2004; Mitchard & Flintrop 2013). Changing the habitats towards more xerophytic, less productive, palatable, nutritious and resilient grass species, encroachment can reduce the "grazing capacity" to less than 10%.

In Namibia, bush encroachment is a major problem: the bush vegetation covers already an estimated 45 million ha of the country's savannas and reduces livestock productivity significantly (SAIEA 2016). The National Rangeland Management Policy and Strategy estimates the resulting direct economic losses at N$1.4 bn[1] each year. Thus, bush control presents economic opportunities: Restoring encroached areas by sustainably removing and utilizing woody plants will result in improved grass production and enhance the grazing capacity. Targeted management and preventing bush encroachment would provide benefits outweighing by far the costs of management and control: Stafford et al. (2017) estimate the annual value of ecosystem services and tangible benefits from the restoration of bush encroachment in Namibia to USD 5.8 billion.

The Government of Namibia has recognized the importance of the topic for different economic and environmental objectives. Due to the dimension, the management of bush land use will have significant impacts on the country's GHG emission profile. Active reduction of bush encroachment and restoration can provide meaningfully to Namibia's Nationally Determined Contributions under the Paris Agreement and enhance the resilience to climate change impacts.

Study objective and design

The objective of this study is to analyze and quantify the mitigation impacts of

- large-scale bush thinning on Namibian farmland,
- land use or productivity changes after bush thinning, and
- the utilization of the resulting bush biomass.

The Namibian region of Otjozondjupa was selected as a suitable and representative study area: it has 8.6 Mio ha of encroached areas and represents about 19% of the total encroached area in Namibia. The study examines ecosystem impacts of bush control and likely future impacts after harvesting, e.g. due to increased livestock stocking, and carbon stock changes in the bush biomass pool (considering aftercare) and in soil organic carbon. An Excel-based bush control accounting model allows to flexibly define utilization options and bush system strata, and to compare carbon stocks, carbon stock changes and GHG impacts. Study and model follow the 2006 IPCC Guidelines for the AFOLU sector in National GHG Inventories.

The study consists of three assessments:

[1] 97.1 Mio USD

1. A land use impact analysis with an assessment of bush carbon stocks and expected carbon stock changes in the different carbon pools after thinning/ harvesting of bush biomass.

2. A value chain GHG assessment of bush utilization from harvesting, processing to the final product for specific value chains related to thermal or energy use (e.g. charcoal, electricity, etc.).

3. A synthesis of the two assessments to develop pre-defined bush management scenarios.

Results

In total, bushland in the study area results in 123.9 Mio t of carbon (tC) sequestered corresponding to an average of 14.5 t C/ha (30.81 t dm/ha expressed in biomass). Additionally, 146.4 Mio tC are stored as soil organic carbon, resulting in an average 17.1 t C/ha. These figures are average values for encroached bushland. The results of the study and the accounting model also quantifies carbon stocks for all defined strata allowing to assess other encroached areas in Namibia with known conditions of lower bush biomass compared to the study region.

Bush control and utilization scenarios

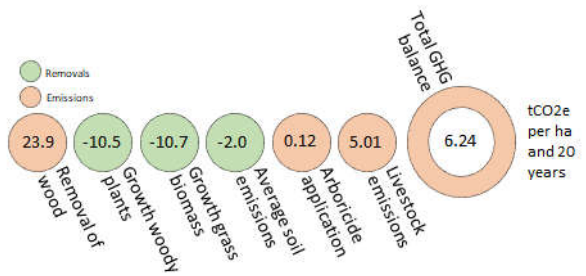
The study defined five harvesting and utilization scenarios that reflect existing and future bush value chains. The scenarios calculate all emissions in the value chain as footprint (at the time of bush extraction and utilization) and as a long-term impact over a default IPCC period of 20 years:

- GHG scenario 0: Bush chemically controlled, with livestock and increased stocking rate
- GHG scenario 1: Rangeland restoration & bushblok, bush-to-feed or pellet production
- GHG scenario 2: Bush farming & bushblok production
- GHG Scenario 3: Medium-scale charcoal production
- GHG Scenario 4: Use of fire wood
- GHG Scenario 5: Large-scale bush harvesting for electricity generation

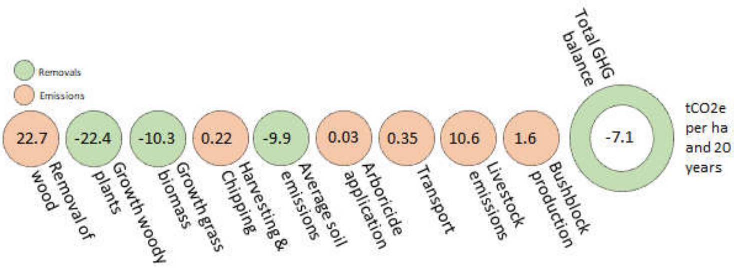
All removals, i.e. sequestration of carbon as well as emission reductions are indicated with a negative value throughout this report

Scenario 0: Bush chemically controlled with subsequent livestock & increased stocking rate

This scenario represents the baseline conditions of chemically controlled bush systems in Namibia. The removal of bush biomass and loss of carbon takes place over time as the standing dead wood is slowly decomposing. Significant carbon sequestration occurs in grass biomass and soil organic carbon.



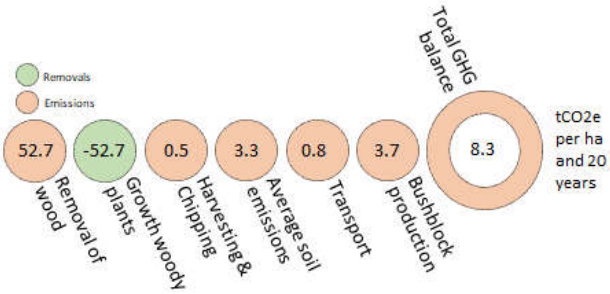
Scenario 1: Rangeland restoration & bushblok, bush-to-feed or pellet production



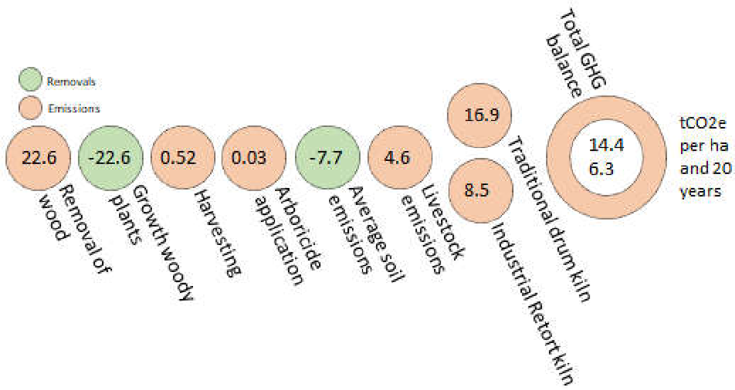
In the savanna restoration scenario bush biomass is used for bushblok, bush-to-feed or pellet production as well as left on-site as additional organic inputs to the soil. Aftercare takes place, but no aerial application of chemicals. This is a plausible restoration scenario for farmers and would have an estimated impact of -7.1 tCO_2e per ha over 20 years. The thinning opens up enough area for grasses to re-establish; the organic inputs from various sources, including trash lines of some of the harvested bush biomass, will increase site fertility over time.

Scenario 2: Bush farming and bushblok production

This scenario offers farmers to shift towards becoming “biomass-energy farmers”. In contrast to the previous two scenarios, the main objective of this scenario is sustainable production (2 harvesting events) and use of bush biomass. Given the environmental impacts of bush encroachment in view of climate change this option should only be considered in combination with other restoration-focused scenarios.



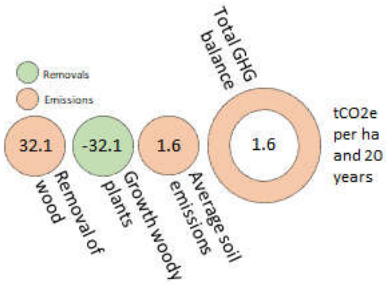
Scenario 3: Medium-scale charcoal production



Namibia could export charcoal on a larger scale if advanced kiln technologies replace the traditional steel drum kilns currently used. The charcoal industry is already well established and the sector is growing. This scenario assumes a shift to stationary industrial retort kilns. This could cut the GHG balance over 20 years by more than half: traditional kiln results in 2.83 tCO_2e per ton charcoal over the 20-year period, while retort kilns reduce the emission intensity in the range of 1.87 to 0.85 tCO_2e per ton (emissions from burning charcoal are not considered).

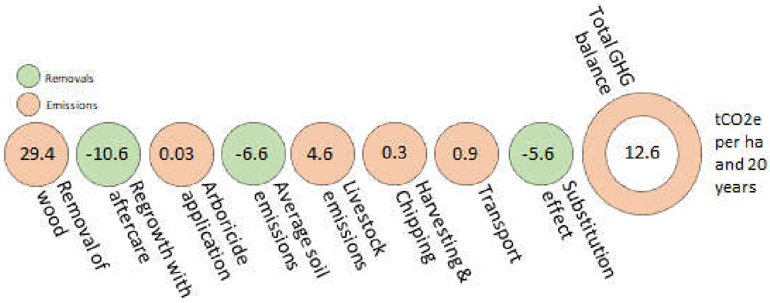
Scenario 4: Use of fire wood

In this scenario, the bush is harvested for fire wood use, especially on community lands subject to smallholder based utilization. This scenario represents a near neutral GHG balance over 20 years. Firewood might be one of the biggest uses for bush biomass. Aftercare is unrealistic because smallholders would most likely use bush biomass as a cheap resource and not want to invest into such measures. However, firewood harvesting is not a strategic control measure against large-scale bush encroachment.



Scenario 5: Electricity generation

A promising project in Namibia is utilization of bush biomass as substitution for imported electricity from the Southern African Power Pool. This would reduce Namibia's energy import dependency and enable investment into renewable energies as part of the national climate action agenda.



Based on the Namibian power mix in 2010, the strong substitution effect could even be further enhanced if Namibia expands its biomass power production and exports electricity to the Southern African Power Pool (SAPP). According to the UNFCCC (2018) this would result in an emission reduction of ca -12 tCO_2e/ha over 20 years as compared to -5.6 tCO_2e. A 20 MW biomass power plant would require 106,500 t dry biomass per year (Cirrus Capital 2018). According to the biomass densities in this study, an area of 6,932 ha would need to be harvested every year. For the 20-year period this would amount to 138,645 ha of bush encroached land.

Table: Summary of ha-based GHG bush control scenarios

	scenario 0: Bush chemically controlled	scenario 1: restoration, bushblok, bush-to-feed / pellet	scenario 2: Bush farming & bushblok production	Scenario 3: Medium-scale charcoal production	Scenario 4: Use of firewood	Scenario 5: Bush harvesting for electricity generation
Total emissions over 20 yrs. (tCO2e/ha/20 years)	**6.24**	**-7.10**	**8.26**	**14.36 / 6.32**	**1.56**	**12.57**

The GHG balances in this study end at the factory gate. Some scenarios would change if the analysis was extended to the post-gate life cycle. However, the export of bush biomass products and the resulting substitution effects in other countries will not be accounted for in Namibia's carbon balance according to the IPCC 2006 logic on national GHG inventories.

National baseline and bush utilization scenarios

The results were used to estimate GHG emissions and removals at the national level under current (baseline) conditions of bush control and for selected future utilization scenarios over the 20-year period. Carbon sequestration due to new encroachment is accounted for, based on an annual encroachment rate of 0.43 Mio ha until 2035 and an assumed growth rate of 0.61 tCO_2e/ha/year. As no further growth of already encroached bush areas is assumed, this is a conservative estimate of the sequestration capacity. The baseline scenario assumes an annual implementation of bush control on 198,510 ha.

As shown in the baseline figure below the chemically controlled bush and charcoal production using traditional kiln technology represent significant sources of emissions in a 20-year baseline scenario, with annual emissions of 0.42 Mio tCO_2e and 1.75 Mio tCO_2e respectively. Ongoing bush encroachment currently results in an annual net sink of -2.1 Mio tCO_2e, respectively and -42.2 Mio tCO_2e of net removals after 20 years.

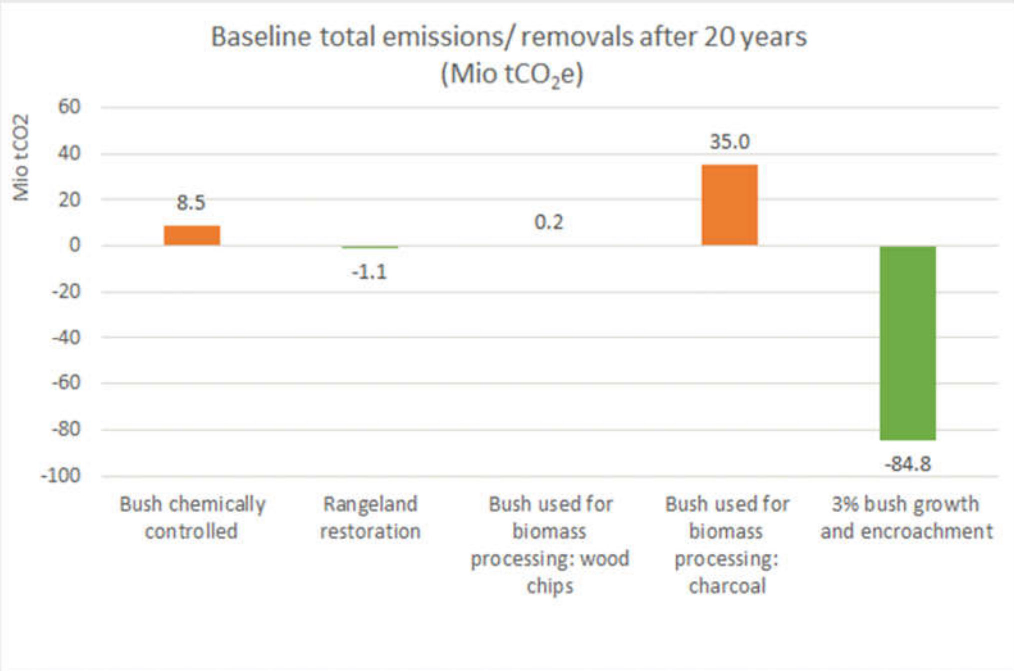


Figure: Baseline of emissions and removals after 20 years (in Mio tCO_2e)

To compare the baseline emission of bush control, we calculated the average annual emissions of the different baseline activities (i.e. removal of biomass and biomass utilization processes). For this, we used the activity data of the latest NIR 3 report and combined it with the accounting tool developed for this study. In total, the average annual emissions of the different baseline activities amount to 7.4 Mio t CO_2e – significantly above the annualized emissions in the baseline scenario that also considers biomass regrowth and sequestration in soils over this timeframe.

A significant mitigation potential exists if chemical bush control is replaced by rangeland restoration: Implemented on 68,000 ha annually provides a mitigation potential of 9.7 Mio tCO_2e over 20 years. Increased soil organic carbon contributes also to climate change adaptation as the soils will be more resilient and productive. In addition, the establishment of a 20 MW power plant is also considered under this future scenario, which requires annually 6,932 ha for biomass supply.

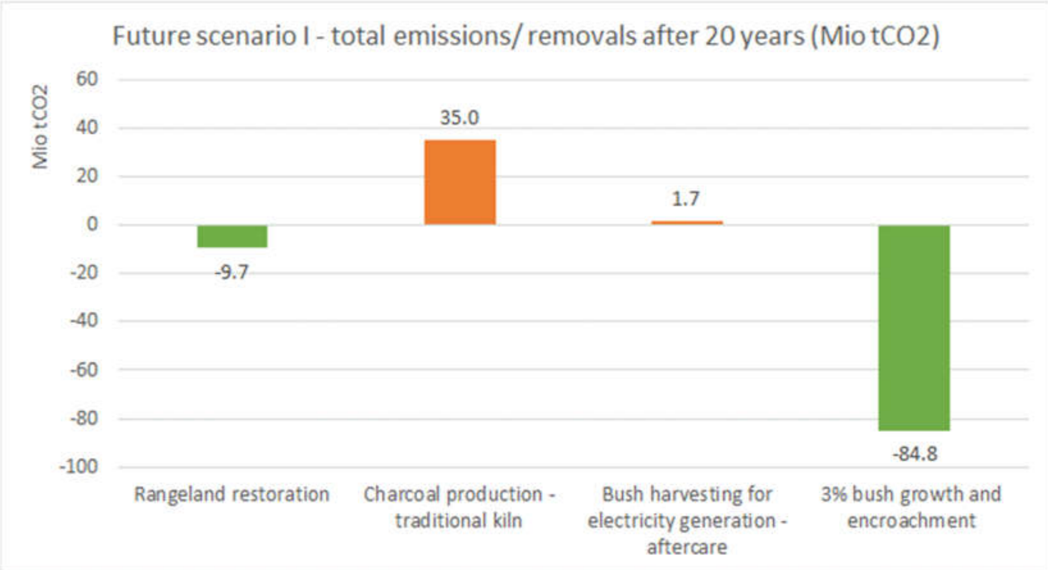


Figure: Future scenario I emissions and removals in a range restoration scenario after 20 yrs.

Finally, an alternative future scenario is presented for up-scaled large-scale bush control expecting an increase in charcoal production to 320,000 ha per annum of which 270,000 ha of bush are utilized with the traditional kiln technology while another 50,000 ha is implemented with an advanced stationary retort kiln technology. 130,000 ha annually are successfully restored by consequently implementing aftercare. The biomass is used for different uses, such as production of bushbloks, bush-to-feed applications and, if realistic, pellet production. In order to show options for future developments the requirements and impacts of 170 MW extra biomass power (based on Stafford et al. 2016) are modelled here, using the assumption to use 58,924 ha annually.

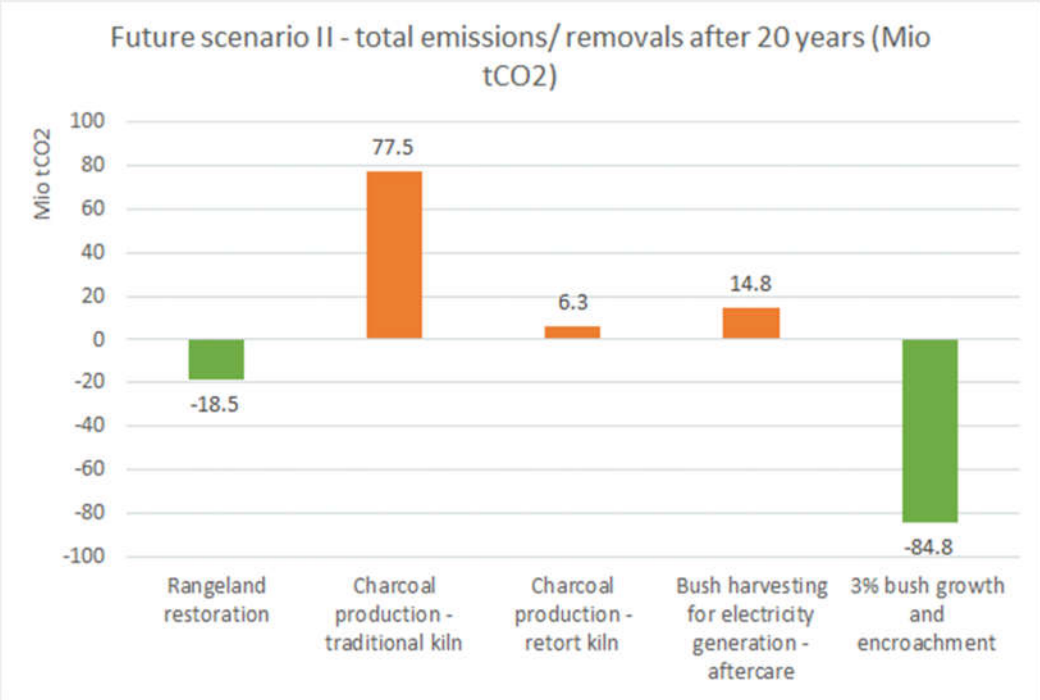


Figure: Future scenario II emissions and removals of bush control activities after 20 yrs.

In total, all utilizations and harvest options in the future scenario would require the biomass of around 0.5 Mio ha per year. The largest emission source would still be the traditional charcoal sector followed by electricity generation and charcoal produced with advanced kiln technology.

Factoring in the 3% bush growth and encroachment, the net GHG result of this scenario would almost result in a carbon neutral situation with a sink of annually -0.2 Mio tCO_2e. Electricity generation, even though it represents an emission scenario in total, would also include a substitution (mitigation) effect of -6.6 Mio tCO_2e over 20 years or -0.3 Mio tCO_2e annually.

Conclusions

The GHG balances show potential mitigation options. When directly comparing the bush control scenarios over a default period of 20 years, it can be concluded that the highest emissions are caused in charcoal production when using a traditional Namibian steel drum kiln. If charcoal is produced in industrial retort kilns, emissions drop to levels below the ones of bush farming. Despite the substitution effect of electricity generation from bush biomass, this scenario also results in GHG emissions over 20 years.

One of the most important factors considering bush encroachment and bush control is the effect on soil organic carbon, which is closely linked to soil fertility, due to the ability of SOC and SOM (soil organic matter) to bind water and nutrients. Increased bush biomass creates sufficient organic inputs, but alters soil microbial communities and therefore reduces decomposition ratios. With reduced decomposition rates SOC and ultimately soil fertility in bush encroached areas consequently drop as well (Buyer et al., 2016). Due to the expected reduced rainfall and strong bush growth, SOC and fertility are expected to decrease in the future; soil erosion is expected to increase due to bare areas between bushes, which are prone to wind erosion (Manjoro et al., 2012).

Bush control can have various impacts on soil fertility. Harvesting intensity and aftercare are key management tools. They determine restoration success or failure, due to the amount of bare areas or the successful re-introduction of a grass layer. If no sustainable management is implemented the areas will further degrade, with lower biomass growth (wood) and no establishment of perennial and palatable grasses (Zimmermann et al., 2017). The soil modelling confirms that only under the assumption of aftercare and savanna restoration success SOC is increasing (sequestration), and the highest SOC increase is under a moderate harvesting of 50% bush biomass leading to 0.44 tCO_2e sequestered per year and ha.

Water provision is a vital ecosystem service, in particular for very arid conditions as those in Namibia. Bush encroachment impacts all water related ecosystem services due to interception: interception is increasing; climate change and changing rainfall patterns with high interception rates will reduce groundwater recharge as well as overall soil moisture. Less bush reduces interception, and more water can percolate and contribute to groundwater recharge. As under climate change precipitation is expected to decrease, groundwater may not necessarily benefit – even if rangelands are restored – but impacts will be less negative compared to bush farming or even encroachment. The water use efficiency under a rangeland restoration scenario is increased while under encroachment water gets scarce. Rangeland restoration has also positive impacts on biodiversity.

In general, all bush control scenarios which actively increase soil fertility through soil carbon sequestration should be promoted on a national level. This should be combined with wetland restoration to establish more diverse conditions in favor of grasses. It can be concluded that despite uncertainties rangeland restoration at landscape scale will increase the adaptive capacity of the ecosystem as well as benefit biodiversity, groundwater, and soil fertility. Bush-to-feed systems should be assessed more in terms of potential emission reductions of the livestock sector.

Given the importance of the topic the authors see a strong need for a national paradigm shift in the bush management sector and propose the following measures as next steps:

- The accounting logic of this study should be combined with the bush information system study to develop a National Bush Management and Information System. This system should allow to combine spatial information on bush encroachment on a national level with activity data on bush control activities and emission factors along their different value chains.
- The mitigation potential of shifting from chemical bush control to rangeland restoration should be further assessed regarding a carbon crediting scheme for the voluntary carbon market. The VCS (Verra) Standard for example allows accounting for emission reductions in agricultural landscapes (bush systems in Namibia are not defined as forests).
- With a view to the high vulnerability of Namibia and the importance of the bush sector, a detailed climate change adaptation study should assess the vulnerability and impacts, in line with the IPCC Climate Risk and Vulnerability Assessment Framework.
- The study findings should be further scrutinized in a thorough economic assessment.

The closing of these knowledge gaps and the monitoring data allow for developing tailored measures at different jurisdictional levels. It enables the sector to be 'ready' to integrate the accounting in the wider national GHG inventory (as well as other national reporting requirements) and the future enhanced transparency framework under the UNFCCC. Beyond mitigation, this system could also be used for monitoring other ecosystem and biodiversity.

1 INTRODUCTION

Invasion or the expansion of woody plants into grassland and savannas is a global problem and has received growing attention during past decades (Eldridge et al. 2011). The changing balances in the proportion of trees and shrubs relative to grasses and herbs is considered as a form of land degradation (Oldeland et al. 2010) and has been described as one of the dominant ecological changes in the last two centuries (Polley et al. 1997).

Over the past 60 years, growing evidence suggests that savannas throughout the world are being altered by this phenomenon, also known as 'woody encroachment' (Adamoli et al. 1990; Archer et al. 1995; Moleele et al. 2002). African savannas which cover approximately 13.5 Mio km² (Riggio et al., 2013) and woody encroachment is a widespread phenomenon. It has been documented since the early 20th century (Bews, 1917) but has become increasingly prevalent over the last several decades (Archer et al., 2000; Wigley et al., 2010; O'Connor et al., 2014). The shift from grasslands to shrub-encroached grasslands is often irreversible. It decreases landscape heterogeneity and reduces the diversity of invertebrates, birds, and large mammals (Sirami et al. 2009; Smit and Prins 2015). Large-scale vegetation change also has consequences for energy, carbon, and water budgets (Woodward and Lomas 2004; Mitchard and Flintrop 2013). Impacts on carbon sequestration are significant, in particular for soil organic carbon (SOC) and the regional carbon balance (Li et al. 2016).

Bush encroachment can reduce the grass-based carrying capacity ("grazing capacity") to less than 10%, consequently resulting in severe losses to individual ranchers and the nation as a whole. With nearly 20% of the world's population living in savanna regions woody encroachment has important ecological and economic implications. Changes in the composition of savannas are particularly important in Africa, which hosts a large and rapidly growing proportion of the world's human population, many of whom are pastoralists (Scholes and Archer 1997). The loss of grazing capacity is due to overwhelming bush competition that reduces grass yield per se as well as changing the botanical composition of the grass sward towards more xerophytic, less productive, palatable, nutritious, and resilient grass species.

Bush encroachment in Namibia

Bush encroachment already occurred in Namibia during pre-colonial times. Since the 1940's it accelerated quickly to the landscape level, as a result of technological advances in land use practices, and it was recognized as a problem of national dimension in the 1960's (GIZ 2014). Until today, it constitutes a major problem for agriculture in Namibia: the bush vegetation covers approximately 45 million hectares of the country's savannas, and reduces livestock productivity significantly (SAIEA 2016). Without harvesting and other interventions, and a bush encroachment rate of 3.18% all livestock production areas in the country (app. 51.5 Mio ha) could be covered with bush by 2035 (Honsbein 2016).

Drivers of woody encroachment in African savannas are widely discussed in academic literature (Archer et al. 1995; Wigley et al. 2010). Most studies focus on areas that are being encroached and ignore areas that are not. However, a study by Mitchard and Flintrop (2013) examined both, woody encroachment and woodland degradation in sub- Saharan Africa. They demonstrated that woody encroachment was as prevalent as woodland degradation, thus showing that a bias in the literature towards woody encroachment is unlikely. Drivers for woody encroachment are local and global. A number of studies have elucidated the drivers of woody encroachment at specific locations (e.g., Bond et al. 2003; Goheen et al. 2004; Higgins et al. 2007; Wigley et al. 2010); other studies have examined the determinants of woody cover from savanna sites across Africa (e.g. Sankaran et al. 2005, 2008).

The environmental and indirect economic impacts of bush encroachment in Namibia are well-documented descriptively (e.g. De Klerk 2004), however the quantification of these impacts is still debated in research. For example, bush encroachment reduces groundwater reserves and limits groundwater recharge and extraction rates – a critical consequence for a very arid country like Namibia. Bush encroachment and the associated pioneer-stage herbaceous layer are a reliable indicator that the landscape has become drier. Therefore, artificial drought events ("man-made droughts") will become more frequent and resilience to withstand harsh natural events (e.g. drought, out-of-season wildfires, termites, locusts and climate change events) decreases (GIZ 2014). Less measurable is the impact of bush encroachment on the tourism industry. Bush invasion reduces biodiversity and visibility of, for example, game animals in protected areas and thus changes the wide, open landscape which attracts tourists (GIZ 2014).

Most bush-encroached areas are highly productive and fairly stable ecosystems that offer plentiful feed to browsers and protect themselves from fierce fires. Due to bush encroachment's detrimental effect on the grazing capacity of agriculturally productive land, productivity has declined in Namibia, often to such an extent that many previously productive livestock farms are now no longer economically viable.

The newly-formulated National Rangeland Management Policy and Strategy puts the direct losses due to the bush encroachment/weakened grass sward complex at N$1.4 billion each year (updated to N$1.6 billion in the STEAG study of 2013). In a country where more than 70% of the population depends on agricultural (mainly livestock) production, this is a significant cause of rural poverty (GIZ 2014). With this, bush encroachment is considered the single most important obstacle for the development of the country's meat industry. The former Honorable Minister of Agriculture John Mutorwa even described bush encroachment as a national disaster (National Rangeland Policy 2012).

Bush control and its impacts

Approaches for addressing the problem exist: bush control presents economic opportunities through sustainable harvest and utilization of the bush biomass. Restoring bush encroached areas through the sustainable removal of some of the woody plants to yield a more balanced rangeland ecosystem will result in an improvement in grass production and therefore also the grazing capacity. The resulting biomass provides ample economic opportunities, in support of various national policies. Bush thinning of Namibia's affected rangelands will lead to a more productive, ecologically diverse, and balanced state. The abundance of undesirable woody biomass, coupled with the need for local value addition and for electricity generation creates a socio-economic development opportunity. The management of invasive alien plants and bush encroachment can deliver signi cant ecosystem services bene ts, whose value outweighs the cost of management and control (Stafford et al. 2017). The same study concluded that in Namibia, the estimated value of ecosystem services from the restoration was US$5.8 billion.

Academic studies furthermore allude to the positive mitigation impacts of bush control. Stafford et al. (2017) show that the use of biomass for electricity can deliver notable carbon emission reductions through the replacement of coal, and biomass co- ring is noted as an important greenhouse gas abatement opportunity (McKinsey and Co. 2010). In addition, various wood products (fence posts, poles) could also reduce net carbon emissions by increasing carbon stocks in harvested wood product pools (Stafford et al. 2017).

However, these positive impacts are contrasted by negative carbon flows: a change from bush encroachment to the natural vegetation result in a net loss in terrestrial carbon stocks, due to the loss of rapidly growing woody biomass. In addition, there may also be carbon emissions from the land-use practice that follows the clearing of plant invasions and control of bush encroachment such as increased emissions from livestock. Last but not least, there is still uncertainty about the impact of bush control on changes and notably losses of soil organic carbon.

Almost 70% of the estimated value of ecosystem services from bush control (Stafford et al. 2017) are water benefits (mainly water recharge). Bearing in mind that Namibia is highly exposed to climate variability and the effects of climate change, which are expected to worsen in coming decades clearly indicates that bush control might have significant impacts on climate change adaptation. This knowledge is relevant for various efforts, which the Namibian government is committed to – such as the United Nations Framework Convention on Climate Change and the corresponding Nationally Determined Contributions (NDC 2015), Convention on Biological Diversity, and the United Nations Convention to Combat Desertification, and the National Development Plan 5 (NDP 5).

Objective and overview of the study

The Government of Namibia seeks to mobilize international climate finance to address the problem as part of its climate change mitigation actions. The German Development Cooperation implemented by GIZ is supporting the Namibian government through the Ministry of Agriculture, Water and Forestry (MAWF) in the Bush Control and Biomass Utilization (BCBU) project. The project aims to counter bush encroachment, to promote restoration of degraded lands, and economically utilize the bush-based biomass resource. It explores and encourages the utilization of and value addition to encroacher bush wood in various value chains, and bush harvest on farms (commercial and communal) in an ecologically sensible manner that leads to improved rangeland condition, increased animal productivity and enhances eco-tourism. Against this background, GIZ commissioned this study, which analyzes and substantiates the climate change mitigation and related impacts of bush control and resulting biomass utilization.

The objective of this greenhouse gas assessment of Bush Control and Biomass Utilization is to analyze and quantify the mitigation impact of large-scale bush thinning in Namibia.

More specifically, this study assesses in detail the GHG impacts of

- large-scale bush thinning on Namibian farmland,
- the changes in land use or its productivity after bush thinning, and

- the utilization of the resulting bush biomass.

Consequences of bush control in terms of ecosystems impacts are also examined as well as the potential future impacts after the harvesting related to GHGs emissions (e.g. due to increased livestock stocking) and carbon stock changes in the bush biomass pool (considering aftercare) as well as soil organic carbon.

For the removed bush woody biomass, GHG emissions are analyzed for different utilization scenarios, including different charcoal production systems (from traditional to improved kiln technologies) and biomass (wood chips) electricity generation. The focus of the analysis is mainly on energetic uses of bush biomass, excluding handicraft or other wood products.

This report starts with a short policy analysis, which summarizes the climate change mitigation and to some extend adaptation frameworks with relevance to bush control and biomass use in a national as well as broader African context (Chapter 2). Chapter 3 outlines the methodological approach used in this study to a analyze and quantify the climate change mitigation impact of large-scale bush thinning in Namibia using datasets of one particular representative region (Otjozondjupa). Being merely a desk-based study combined with field consultations in Namibia, the analysis is based on available datasets, bush control studies and peer-reviewed literature. Chapter 4 presents the results of this study, starting with setting the frame in terms of current bush control activities in Namibia. This is followed by the presentation of the carbon stock analysis of the bush systems in the study region. Then, pre-defined bush management and utilization scenarios are presented on one-ha-level, which are subsequently applied to assess the national baseline GHG balances of different bush control activities, as well as for a potential future up-scaling bush control scenario. In addition, a qualitative assessment of bush control on different ecosystem services is presented based on an extensive literature review. Chapter 5 summarizes the key findings and conclusions.

2 POLICY FRAMEWORK REVIEW AND ANALYSIS

The scope of work for this consultancy includes an analysis of international and national policy frameworks on climate change mitigation and adaptation with relevance to bush control and biomass utilization in Namibia. In addition to this desk-based review, a meeting was held on 12 March 2019 at the office of Mr. Reagan Chunga of the Namibian Ministry of Environment and Tourism (MET), Division of Environmental Affairs (DEA), Subdivision of Climate Change to get his views and additional input on the policy framework.

In 1994, Namibia became a party to the United Nations Framework Convention on Climate Change (UNFCCC). In 2015, Namibia became a signatory to the Paris Agreement. As a non-Annex 1-country, Namibia is required to submit a National Communication (NC) report to the UNFCCC every four years, a Biennial Update Report every two years, and a revised version of its Nationally Determined Contribution (NDC) report every five years. The latest available versions of these reports have been reviewed and are discussed below.

Several of the policy documents reviewed do not have bush encroachment or climate change as their central focus, but do include important statements that directly or indirectly influence how bush control and biomass utilization is carried out in Namibia. Therefore they have relevance in the context of climate change mitigation and adaptation in Namibia. Since many analyzed policy documents are not explicit parts of Namibia's climate change policy framework, their review has been included at the end of this report in the annex section.

The current and key elements of Namibia's policy framework on climate change mitigation and adaptation include:

- the National Policy on Climate Change for Namibia (MET, 2011)
- the National Climate Change Strategy & Action Plan: 2013 – 2020 (MET, 2013)
- the 3rd National Communication to the UNFCCC (MET, 2015a)
- Intended Nationally Determined Contributions (INDC) of the Republic of Namibia to the United Nations Framework Convention on Climate Change (MET, 2015b)
- the 2nd Biennial Update Report (BUR2) of the Republic of Namibia (2016)

According to Mr. Reagan Chunga of MET, Namibia's 4th National Communication will be submitted to the UNFCCC in 2019, and the 2nd NDC report will be submitted in 2020.

2.1 National Policy Frameworks

National Policy on Climate Change for Namibia (2011)

Bush control and biomass use are mentioned in the *National Policy on Climate Change for Namibia* (2011), but do not feature prominently. Bush encroachment is referred to in a sentence of the *Forward* section as part of Namibia's wealth of renewable energy sources; and is again referred to in the *Introduction* as having a suffocating impact on livestock production. It is also referred to indirectly in *Objective 2*, where the enhancement of GHG sinks is identified as one of Namibia's mitigation strategies; the bush encroachment area is Namibia's largest GHG sink. *Objective 3* of the *Policy* is also relevant to bush control and biomass use. It points out that the cross-cutting nature of climate change and calls for other ministries, divisions and subdivision, not just MET's Climate Change Subdivision, to incorporate it into their policies and plans. This is particularly relevant to the Ministry of Agriculture, Water & Forestry (MAWF), which has a strong focus on bush control due to the devastating impact of bush encroachment on livestock productivity. It is also relevant to the Biodiversity and Sustainable Land Management Subdivision of MET, since bush encroachment is a form of land degradation that adversely affects biodiversity. It should be noted that Mr. Chunga of MET also places great importance on the need for other government ministries, divisions and subdivisions to coordinate and participate in planning and actions for climate change mitigation and adaptation.

National Climate Change Strategy & Action Plan: 2013 – 2020 (2013)

Bush control and biomass use are also touched on in the *National Climate Change Strategy & Action Plan: 2013 – 2020*, but again do not play a dominant role. In Chapter 2, bush encroachment is mentioned as contributing to a large uptake of carbon dioxide making Namibia a net GHG sink. However, in Chapter 6, Namibia's Climate Change Action Plan Framework for adaptation, mitigation and cross-cutting issues, bush control and biomass use are not mentioned at all. This is an important shortcoming of the *National Climate Strategy & Action Plan,* given the large GHG sink capacity of the bush encroachment area that has been reported on in Namibia's *National Communications* and the importance of bush control and biomass use have in the mitigation plans of Namibia's *Intended Nationally Determined Contributions* (see below). This shortcoming would be a key topic to address in any future update/revision of the *Strategy & Action Plan*. The update/revision would ideally include statements about the importance of bush control and biomass utilization and how they generally fit in with Namibia's goals for climate change mitigation and adaptation. Such important statements would then support coordination of bush control and biomass utilization policies and plans between MAWF and MET.

Third National Communication to the UNFCCC (2015)

The *Third National Communication (TNC) to the United Nations Framework Convention on Climate Change (UNFCCC)* is a status report covering Namibia's GHG emissions and removals, adaptation activities, and a vulnerability & adaptation study. National Communication reports are to be prepared and submitted to the UNFCCC every four years. The TNC sets out Namibia's plans for future adaptation and mitigation. Although the bush encroachment area has been widely recognized as a GHG sink for Namibia, it does not explicitly discuss it as such.

Furthermore, it indicates that Namibia's sink capacity is steadily reducing due to the loss of forest biomass, so that Namibia is predicted to no longer be a net GHG sink by year 2022. However, during the meeting with Mr. Chunga of MET on 12 March 2019, it was understood that the mapping used to support the calculations and the above conclusion may not have provided an accurate picture. It is therefore anticipated that a significantly revised calculation of Namibia's GHG sink status will be presented in the upcoming *Fourth National Communication*.

Given the massive scale of bush encroachment in Namibia, the TNC also fails to provide a clear and straight-forward discussion in its GHG inventory section regarding the impact of bush encroachment on GHG emissions and removals. The TNC also omits a discussion of how the huge bush encroachment area could fit into Namibia's GHG mitigation plans. Regarding adaptation, the TNC does identify bush thinning as an important climate change adaptation strategy as a means to improve livestock production. In future NCs, it should be expected that bush thinning will also be identified as an adaptation strategy to conserve groundwater resources, since studies recently implemented by the GIZ Bush Control and Biomass Utilization Project have concluded that bush encroachment significantly reduces groundwater recharge.

Namibia's Intended Nationally Determined Contributions (2015)

The INDC was submitted to the UNFCCC as part of Namibia's commitment to the UNFCCC Paris Agreement of 2015. It sets out Namibia's goals and plans for GHG mitigation and adaptation to be achieved by year 2030. Bush control and biomass use feature importantly in the INDC. Namibia's goal for GHG mitigation is to reduce emissions by 89% by year 2030 compared to what the GHG emissions would be with the business-as-usual scenario for year 2030. The INDC sets out a number of planned mitigation actions, including the following:

- The replacement of fossil fuel-based electricity generation, with a significant increase in renewable electricity generation, including a bush biomass combustion power plant.
- The creation of 15 million hectares of grassland through bush thinning, where the grassland has been assumed to be more effective at GHG removals through carbon sequestration.

NamPower's plan to establish a bush biomass combustion power plant is well known and likely to be implemented. However, the plan to establish 15 million ha of grassland through bush thinning by year 2030 appears to be unrealistic. Future revised NDCs should provide more details supported by calculations to explain how this target can be achieved, as it is an important component of Namibia's mitigation strategy and contributed 6% to the planned mitigation target.

In the adaptation section of the INDC, bush thinning is presented as an adaptation strategy as a means to increase livestock production and economic growth. The INDC could have mentioned improved recharge of groundwater resources as an additional adaptation-related benefit of bush thinning, as that was recently concluded in a study implemented by the GIZ Bush Control and Biomass Utilization Project.

Namibia's Second Biennial Update Report (2016)

BUR2 was submitted to the UNFCCC in 2016 as part of Namibia's responsibilities to report to the UNFCCC about GHG emissions and removals and its capacity to perform such monitoring and reporting. With respect to bush encroachment, BUR2 states that data regarding the rate of invasion by bush species was not available and bush density had to be estimated. Efforts are currently made to address this deficiency in future GHG inventories. There is no further discussion regarding the details of calculations for GHG removals due to bush encroachment. This is a serious shortcoming of the report, given the massive bush encroachment area has in rendering Namibia a net GHG sink.

2.2 International Policy Frameworks

The international policy framework review included documents prepared for Australia, South Africa, Zimbabwe and Botswana. The review has generated important insights from other countries with similar issues:

- The Australian government's policy framework supports controlled fires in bushy areas during the early dry season as a strategy to mitigate GHG emissions, preserve biodiversity, and contribute to agricultural productivity and food security (Australia govt., 2017). The Australian example of using controlled fires could serve as useful example for those academics and stakeholders in Namibia who see reduced veld fires as an important contributing factor to bush encroachment.
- The Australian policy framework also supports the production of biochar for use as a soil amendment that also serves as a carbon mitigation strategy. It does state that the effectiveness of biochar to improve soil quality in dryland areas is less certain than in wetter areas (Australia govt., 2013). The Australian biochar example may serve as a good example for Namibian academics and stakeholders who believe more study is needed regarding the potential benefits and applications of biochar in Namibia as both, GHG mitigation strategy and a beneficial end-product for harvested encroacher bush.
- South Africa's *Third Annual National Communication to the UNFCCC* (*TNC*) identifies biomass energy and biochar as two options for GHG mitigation to be further developed in South Africa (RSA, 2018). The restoration of thickets, woodlands and forests is also mentioned as a strategy to increase carbon sequestration. This further supports the idea that the potential benefits of biochar as a GHG mitigation strategy and end-product for encroacher bush should be studied in Namibia and supported in the national policy framework if the studies support that.
- *Zimbabwe's National Climate Change Response Strategy* identifies the use of biomass for household cooking and heating as one of the country's most serious sources of air pollution and a significant source of GHG emissions (Zimbabwe govt., 2018). Fuelwood accounts for 60% of the country's energy supply. The *Response Strategy* calls for the promotion and use of cleaner cooking technologies. Botswana's *Biomass Energy Strategy* states that approximately 53% of its rural households and 13% of its urban households rely on wood for daily cooking energy needs (Botswana govt., 2009). The *Strategy* recommends the promotion of fuel-efficient biomass cookstoves. Namibia's *TNC* indicates that 54% of Namibian households rely on biomass for cooking fuel, yet it does not identify the dissemination of fuel-efficient biomass cookers as a mitigation and adaption strategy. The potential GHG mitigation potential and cross-cutting benefits of using fuel-efficient biomass cookstoves instead of traditional fires for cooking may warrant that they receive more attention and support in Namibia's climate change policy framework. A new biomass cookstove strategy could also explore how bush encroachment-based biomass fuel could be incorporated into the strategy and action plans.

2.3 Conclusion and policy recommendations

A key element of Namibia's policy framework for addressing climate change, the *National Climate Change Strategy & Action Plan: 2013–2020*, so far contains only very little discussion of bush encroachment and does not yet incorporate it into concrete action plans. Given the national importance of the bush encroachment area as a GHG sink, it appears that the *Strategy & Action Plan* should be updated sometime in the future. It should be noted, that Mr. Reagan Chunga of MET believes the need to further develop Namibia's policy framework for climate change is less of a priority than improving coordination amongst government ministries to work better together in implementing climate change mitigation and adaptation plans and actions.

Due to its relevance for mitigation, the topic should receive more attention in future NCs, BURs and NDCs. Furthermore, the climate change mitigation targets in Namibia's NDC should include more details on their feasibility and how they could be achieved, because the goal to create 15 million ha of new grassland through bush thinning is a very ambitious goal. MET should also consider how the carbon model application that has been developed for this consultancy could be further developed so that it could be used for future GHG inventories and national reporting on the GHG removals and emissions of the bush encroachment area.

The review of international policies indicates that Namibia's policy framework could be enriched by new aspects and related topics that could be further explored by academics and stakeholders. Examples include

- the use of controlled bush fires in Australia as a means to reduce GHG emissions and control bush growth;
- the study and potential future roll-out of biochar programmes in Australia and South Africa as a means of GHG mitigation and soil improvement;
- programmes to promote fuel-efficient biomass cookstoves in off-grid areas as a means to reduce GHG emissions and improve health through reduced household pollution.

Finally, the meeting with Mr. Chunga of MET on 12 March 2019, put important emphasis on the need to not only develop the policy framework for climate change, but to also ensure effective coordination and cooperation amongst government ministries and other institutions in integrating and implementing climate change mitigation & adaptation plans and actions. With respect to bush control and biomass use, this would for example entail greater coordination between

1) MET and MAWF to ensure that climate change mitigation and adaptation plans are incorporated into MAWF's plans for rangeland restoration through bush thinning and aftercare
2) MET, MET, NamPower & MAWF to ensure that climate change mitigation and adaptation plans and sustainable rangeland restoration plans are incorporated into MME's and NamPower's plans to harvest use bush biomass fuel on a large-scale basis for electricity generation.

3 METHODOLGICAL APPROACH OF THE CARBON STUDY

This GHG study is assessing the impacts of bush control on the GHG emission balance of bush encroached land and its utilization impacts on GHGs as well as substitution effects with electricity generation. Methodologically, the study has carried out three major assessments:

1. A land use impact analysis: this is related to the assessment of bush carbon stocks within the landscape under assessment and the expected carbon stock changes of the different carbon pools after thinning/ harvesting of bush biomass.
2. A value chain GHG assessment of bush utilization from harvesting, processing to the final product of bush biomass for specific value chains related to thermal or energy use (e.g. charcoal, electricity, etc.) in Namibia.
3. A synthesis of the two assessments to develop pre-defined bush management scenarios that allow analyzing the overall GHG balance both from a foot printing perspective:
    a. A GHG balance of removed biomass and utilization at one point in time;
    b. a long-term perspective: a GHG balance over a default time period (20 years) factoring in also carbon stock changes and land use GHG impacts after the bush removal.

Figure 1 illustrates the main approach taken in this study by analyzing first the land use component – estimation of carbon stocks in existing bush encroached systems in Namibia (GHG sinks) and potential carbon losses from these systems as a results of different bush management and harvesting scenarios.

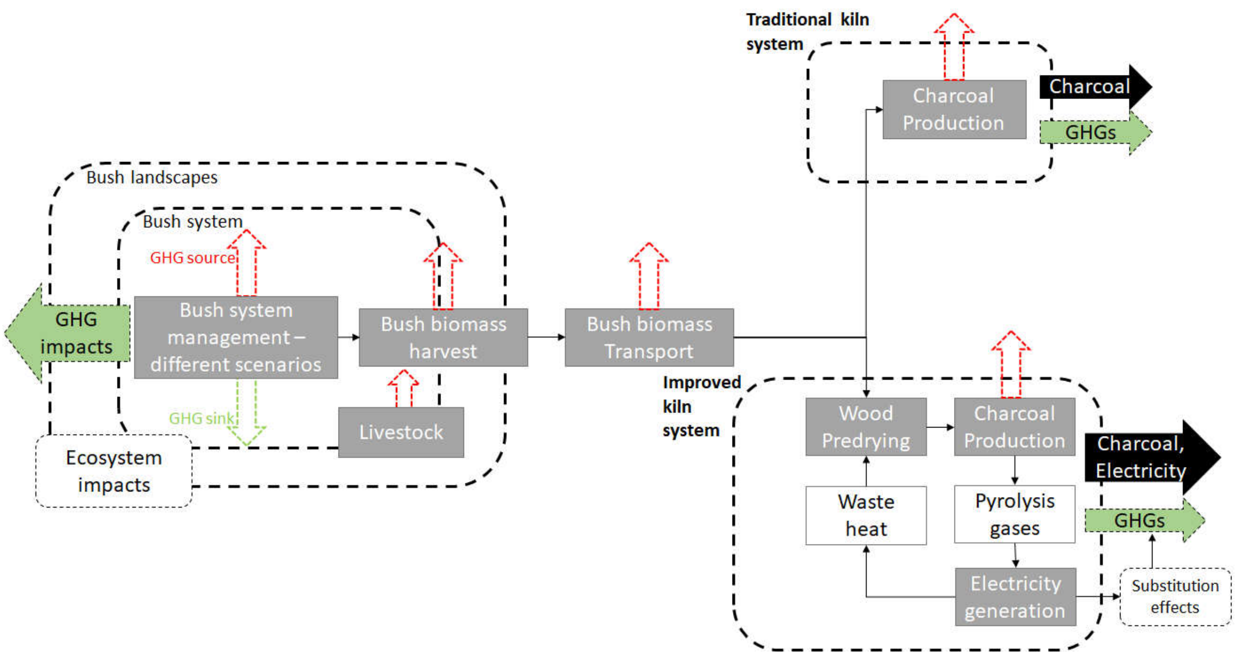


Figure 1 Schematic outline of the carbon and GHG study in view of bush control and utilization

The normative underlying accounting approach applied in this study follows the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, in particular the guidance provided for the

AFOLU sector in Volume 4. This approach quantifies carbon stock changes of different carbon pools in land use systems by combining information on the territorial area where activities such as bush control are conducted (activity data) and coefficients (emission factors) that quantify the emissions or removals per unit of activity (IPCC 2006). These factors are expressed as "t CO2 per ha and year". In this study, hectare-based emission factors have been derived for the different scenarios and components of the assessment.

The IPCC protocols follow a sector and component-based quantification approach ('silo' approach). The 1996 IPCC guidelines divided national GHG reporting into six different sectors, namely energy, industrial process, solvent and other product use, agriculture, land use and land use change and forestry, and waste. The revised 2006 guidelines merged the whole land-based accounting and reporting into one sector, the agriculture, forestry and other land use sector (AFOLU). Within this AFOLU sector, the GHG emissions sources and sinks are disaggregated into the following components:

- Non-CO_2 emissions: Enteric fermentation (CH_4), manure management (CH_4 and N_2O), rice cultivation (CH_4 and N_2O), agricultural soils (N_2O), burning of biomass (N_2O);
- CO_2 emissions or removals: Carbon stock changes in biomass (above- and belowground biomass, litter, deadwood, harvested wood products) and in soil organic carbon (SOC).

Further, fundamental to the IPCC guidelines is the concept of hierarchical tiers (Tiers 1, 2, 3) for estimating GHG emissions and removals. The three tiers are a function of methodological complexity, regional specificity of the emission factors, and the extent and spatial resolution of the activity data. The three tiers progress from least to greatest level of certainty (IPCC 2006). Moving from lower to higher tiers will usually require increasing investments in terms of baseline establishment and monitoring costs as well as institutional and technical capacities.

Higher tier methodologies can be applied at fine spatial scales for land-based GHG accounting to facilitate decision-making in this sector. The latest National Inventory Report (NIR 3, 2018) of Namibia has compiled the AFOLU accounting with a mix of Tier 1 and Tier 2 levels. The latter has been applied for the categories falling under land as some of these were key sources in the last inventory. Most of the stock factors have been derived using data from past forest inventories and other available in-country information and resources.

This study follows a mix of Tier 2/3 level since it used spatially explicit information for the activity data (extent of areas under different bush systems in the study region - Tier 3) and compiled emission factors from mainly national and few international studies (Tier 2). This level allows to quantify the GHG balance of different bush control and utilization scenarios, and by changing different components along the bush value chain, to identify the main sensitivities of components in terms of the GHG impact. Following the life-cycle logic (Figure 1), GHG and utilization scenarios can be derived, allowing to compare the impacts on mitigation, and to estimate fossil fuel substitution effects.

Figure 2 below summarizes the overall step-wise approach of this study. First, available spatially explicit bush datasets from one particular representative region (Otjozondjupa) is analyzed with other existing spatial layers to derive a stratified bush system database. Using default values and assumptions from an extensive national and regional literature review, this database allows assessing different ha-based bush systems concerning their carbon stocks and impacts related to different pre-defined bush management scenarios. Next, the GHG impacts of different options for bush biomass utilization are assessed, using available default emission factors. Most of these factors are national or regional (Tier 2 approach according to the IPCC accounting logic).

In addition to this study, the team developed an Excel-based **bush control accounting model**. It allows to flexibly set the different utilization options and bush system strata in order to compare the different results in terms of carbon stocks, carbon stock changes and GHG impacts. In the model, all the default emission factors and values used are listed together with calculations on how they were derived.

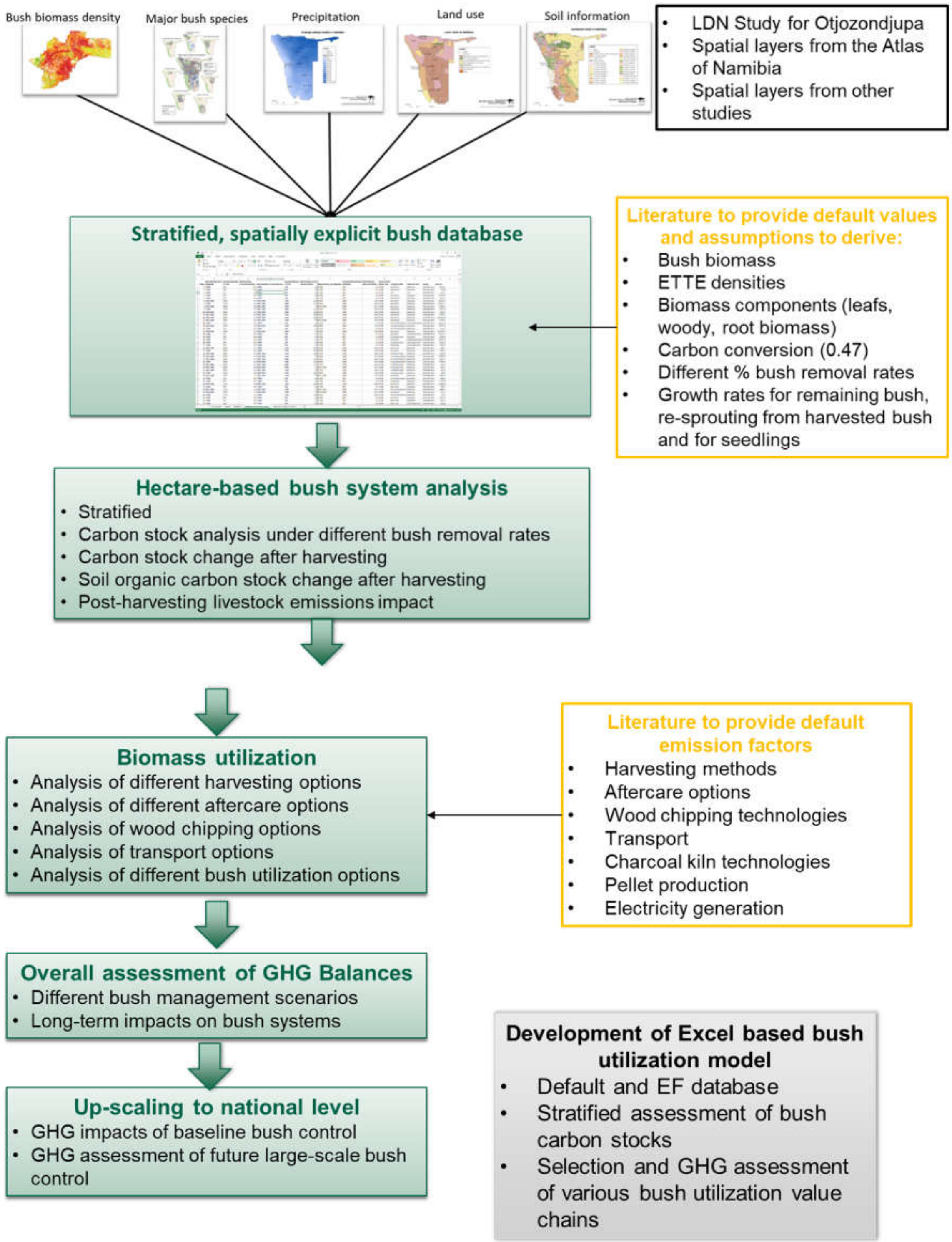


Figure 2: Methodological approach followed in this study

3.1 Land use impact analysis

The land use impact analysis defines the amount of biomass and thus the amount of carbon stored on a hectare basis, which can be later up scaled to a larger area of interest. The carbon pools addressed are bush aboveground (AGB) and belowground (BGB) biomass stratified into woody biomass and leaves, as well as soil organic matter (SOC) in the top soil (30 cm).

Deadwood and litter pools have been conservatively excluded from this study since only limited data is available directly related to the bush systems in Namibia. These carbon pools are subject to change under different harvesting scenarios (depending on their wood removal rates), as well as bush control and management scenarios which impact the harvested bush systems differently, for instance when applying aftercare measures. This will have an impact on the development of SOC, and thus productivity through soil fertility. The changes will be assessed based on pre-defined bush control and utilization scenarios in order to retrieve scenario-specific impacts.

Selection of representative bush area for this assessment

The study focuses on the Namibian region of Otjozondjupa (Figure 3). The region comprises app. 8.6 Mio ha of encroached areas and represents about 19% of the total encroached area in Namibia. Therefore, it is considered as being representative for the entire bush encroached areas in Namibia. Based on consulted literature and experts, Otjozondjupa is representative for most of the bush encroached landscapes in Namibia and has considerably large areas under bush encroachment (see Chapter 5.3 ‘Representativeness of the carbon results’). Furthermore, it is one of the most studied regions with regards to bush encroachment, including spatial information available on different bush strata as well as other indicators of interest such as soil organic carbon stocks. At the time of this study, this region represented the only area with spatially explicit information available in details, which was required for the assessment.

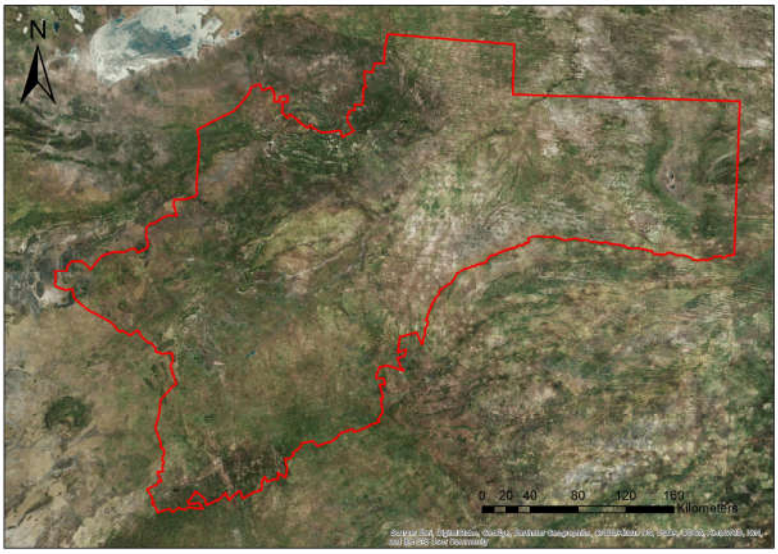


Figure 3: Aerial picture of Otjozondjupa,

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User community

Biomass stratification

The stratification of bush biomass is important, because many factors influence the occurrence of bush encroachment, such as climate (in Namibia mainly precipitation), soils, species distribution, SOC content, etc. In order to stratify, the available information of spatially explicit bush data, such as bush densities, SOC, etc. is merged into a database.

Stratified, spatially explicit bush database

Input data

The Land Degradation Neutrality Study (Nijbroek et al., 2017) investigated in the region of Otjozondjupa bush densities for bushes below 1.5 m and up to 3 m height, and also delivered spatial data on land uses in 2000 and 2016, as well as soil organic carbon content. The climate of this region does not differ much in temperature. However, rainfall varies depending on the distance from the sea, altitude and latitude. Bush growth is correlated with rainfall, therefore average annual rainfall from *worldclim.org* was used (Fick and Hijmans, 2017). Furthermore, the soil information from the Harmonized World Soil Database (HWSD) (FAO, 2009) and dominant plant species are used in the database. Species distribution of the most dominant bush species was provided as a spatial dataset by SAIEA (2016).

Procedure

The data was processed with ESRI ArcGIS 10.6. Every raster was projected to a suiting projection (including 30m resolution), and clipped to the area of interest. Individual steps were required for each raster, in order to suit it for a database compilation. The data from the LDN study such as bush density, LU, and SOC did not require any further processing steps. Precipitation data was provided as monthly average rainfall data, which had to be merged to average annual rainfall with the raster calculator in ArcGIS. The soil data from the HWSD did not need any further processing steps. However, the raster with the unique soil value was used for the stratification, while all other soil data were assigned to the strata layers. Dominant species were selected according to coverage data from SAIEA (2016). If more than one species occurred in the same region, mixtures were assigned with one species dominating the area after visual examination[2].

Every raster holding important information for a stratification was categorized and afterwards merged into one database, using the ArcGIS tool "Combine". The stratification is done by merging all pixels with the same value in a specific category in one stratum each. In the end, all possible combinations of categories from the former input rasters created a specific stratum, adding up to a specific area containing similar information. Finally, soil data from the HWSD was added to the already stratified database. The resulting database was exported in dBase format and further processed with MS Excel 2013.

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[2] The examination was not based on actual ground truthing, but on visual examination, given the shape files of species dominance and distribution (ArcGIS). Those shape files ultimately are based on ground truthing.

Bush biomass calculation

Biomass was calculated on the basis of available bush densities from the spatial database and per tree biomass (wood and leaf), given by Smit et al (2015). The biomass calculations encompass only trees with a height up to 3 m. Ultimately, root biomass and tree equivalents (ETTE) was calculated from these database figures. Root-to-shoot ratios were calculated from values given by Gobelle & Gure (2018) and verified with IPCC default ratios. The average regrowth of tree biomass for the different dominant species was calculated on the basis of values taken from Cunningham (2017) and projected with allometric equations by Guy (1980). In summary, the following default values are applied to the database:

Table 1: Biomass per plant (kg). Values are used to multiply with bush densities in the database

Bush height (m)	Wood biomass (kg/ plant)	Leaf biomass (kg/ plant)	Total biomass (kg/ plant)
< 1.5 m	0.67	0.26	0.93
1.5 – 3 m	7.04	1.31	8.35

Source: Smit et al. (2015) in GIZ BCUB 2015

Table 2: ETTE per plant per species group. Values are used to derive bush removal rates

Species	< 1.5 m height (ETTE per plant)	1.5 – 3 m height (ETTE per plant)
Acacia mellifera	0.8	4.7
Acacia reficiens	0.8	4.3
Terminalia sericea	0.7	3.8
Mix - A. mellifera	0.8	4.7
Mix - Colophospermum mopane	0.7	3.8
Mixed system	0.7	3.8

Source: Smit et al. (2015) in GIZ BCUB (2015)

Table 3: Root-to-shoot ratios used in this study for different bush conditions

Bush system condition	Root-to-shoot value
Bush encroached	0.23
Bush thinned site	0.297
Savanna system	0.302

Source: Gobelle and Gure (2018)

Table 4: Defaults and assumptions related to bush system growth used in this study

Species	Average age	Diameter growth (mm/ year)	Growth AGB/plant/year (kg)[3]	Re-growth after cutting	Seed-lings N/ha	Mortal-ity
Acacia mellifera	25.5	3.79	0.66	52%	866.6	61%
Acacia reficiens	35.7	3.40	0.36	45%		
Terminalia sericea	30	3.79	0.82	54%		
Mix - A. mellifera	25.5	3.79	0.66	52%		
Mix - Colophospermum mopane	29.8	3.59	0.71	51%		
Acacia mellifera	30	3.30	0.72	51%		

Source: Derived from Cunningham (2017); allomteric biomass equations applied from Guy (1980)

The default assumptions presented here reflect only the most important assumptions. For detailed listing and presentation of all values, please refer to the Excel accounting tool.

Reference savanna carbon stock estimation

Carbon stocks of savanna ecosystems are used to give a valuable reference to compare the estimation of current carbon stocks in encroached areas with the conditions under savanna ecosystems with a better balance of grass and woody biomass. Reference carbon stocks are calculated as averages from different savanna ecosystems in South Africa, taken from Grace et al. (2006). Shares of grass biomass from estimated total aboveground biomass estimates were calculated based on Moustakas et al. (2009) and Gobelle and Gure (2018). These values could not be stratified similar to the bush biomass due to lack of information, therefore an average value of total biomass is assumed as reference savanna ecosystem.

Bush harvesting scenarios

The utilization of bush biomass in terms of the removal rates is heavily debated. To estimate the correct amount of biomass to be harvested is difficult. Most consulted experts and available literature discuss the removed biomass as a function of tree equivalents per ha in bush systems in dependence of the mean annual rainfall. A tree equivalent (TE) is defined as a tree (shrub) measuring 1.5 m in height (Smit, 2001). The GIZ biomass assessment study (Smit 2015) uses Evapotranspiration Tree Equivalents (ETTE), where 1 ETTE is defined as the leaf volume equivalent of a 1.5 m single-stemmed tree. Since the equivalent height of 1.5 m is the same for both definitions, this study used the term ETTE as a standard even though some harvesting rules refer to TE and others to ETTE.

[3] This growth represents the growth under conditions where trees are growing from seeds. In the model growth from stumps after cutting has also been considered, plus growth from any new trees from seeds, therefore the growth after cutting is usually considered higher compared to the values given in the table. If aftercare is applied, this additional growth from tree stumps is inhibited.

From a legal point of view on harvesting bush, any activity requires a permit under the Forest Act (i.e. all wood harvesting and wood value-addition activities) and requires Environmental Clearance under the Environmental Management Act. However, compliance with this law is very poor (SAIEA 2016). General harvesting 2015 regulations and guidelines are listed below, extracted from SAIEA (2016):

- No one may harvest, transport, sell, market, transit, export or import forest produce without a valid license.
- Regarding bush encroachment control, a holder of a license for the removal of forest produce must report on the species and actual quantity of the forest produce removed when submitting the next license application or at the end of the financial year
- If the holder of a license intends clearing by burning, rehabilitating or planting, s/he must report on the area cleared by burning, rehabilitation or planted.
- The regulations specify the following seven key license conditions for bush control :
    1. No aerial application of herbicides.
    2. Herbicides are applied selectively on encroaching species.
    3. Only prescribed herbicides for bush control may be applied.
    4. Trees with stem diameter of more than 18 cm at ground level may not be removed unless special approval is granted.
    5. No protected species may be removed unless special permission is granted.
    6. The license owner must execute proper supervision over the operations.
    7. The harvesting license must be available at all times for inspection purposes.
- License conditions for charcoal production include :
    1. Trees with stem diameter of more than 18 cm at ground level may not be removed unless special approval is granted.
    2. An area of at least 15 m around the kiln for charcoal production must be cleared of any flammable material.
    3. No protected species may be removed unless special permission is granted.
    4. All employees/contractors must be treated according to all applicable laws in Namibia.
    5. The permit owner must explain the permit contents and conditions to all workers and contractors.
    6. Permit owner must execute proper supervision over the operations.
    7. Firefighting equipment must be on site at all times.
    8. All kilns must be guarded at all times.
    9. Burning of charcoal may not be done within 1 km of the nearest house or dwelling.
    10. The permit must be available at all times for inspection purposes.

The SAIEA report concludes that concise guidelines for harvesting are critical for the sustainable use of wood. The focus should be on bush thinning and not indiscriminate bush clearing. The guidelines should specify

- The harvestable dimensions per species,
- Bush thinning of smaller specimens and never complete clearing or the removal of large trees.
- Reduced thinning in areas where mopane and silver terminalia are dominant.
- Leaving 1-4 ha bush clumps within a diversity of habitats.
- That no harvesting should occur on slopes steeper than 12% and only partially on slopes from 5-12%.
- Limit or restrict harvesting on sensitive soils, especially sodic and duplex soils as they are highly erosive.
- Leaving fine material in the veld to improve soil organic matter and moisture, and nutrient levels.

The selected pre-defined harvesting scenarios for this study reflect this 'rule of thumb' and are mainly based on the tree equivalents per ha which should remain. The results differ as a result of the different strata in the database and the tree densities. The proposed harvesting scenarios are presented in Table 5 along with their sources.

Table 5: Harvesting scenarios according to different sources

Harvested and remaining biomass in % of the total available biomass are average values depending on the conducted climate stratification (MAP)

Harvesting rule	Harvested biomass	Remaining biomass	Source
Harvesting Scenario 1: Biomass remaining on the basis of ETTE per ha: 10x annual rainfall	63%	37%	Smit et al. (2015)
Harvesting Scenario 2: Biomass harvested: 60% of the theoretical maximum allowable ETTE/ha (from Scenario 1)	78%	22%	Smit et al. (2015)
Harvesting Scenario 3: Biomass remaining on the basis of ETTE per ha: 2x annual rainfall (ETTE/ha) below 450mm MAP and 3x annual rainfall above 450mm MAP	90%	10%	SAIEA, 2015
Harvesting Scenario 4: Biomass harvested: 50% of the total ETTE per ha	50%	50%	Personal communication during field consultations of this study

Source: UNIQUE, 2019

The percentage values of biomass harvested in this study relate to trees up to 3 m height, since the underlying dataset only provided information to this threshold. Since larger trees are excluded, it can be assumed that these trees will remain which is in line with current regulations and good practice guidance on bush harvesting. Therefore the rates shown above should be considered under this assumption.

Soil Carbon modelling

Impacts on SOC of different bush control scenarios was evaluated for Otjozondjupa by using a desk-based approach with triangulation of findings from the field visit and literature. The findings of the field visit were useful for cross validating the assumptions made in the modelling concerning type and timing of carbon input into the soil. The study uses a validated soil carbon accounting method which forms part of the validated SALM Methodology (link) under the VERRA Voluntary Carbon Standard. Soil Organic Carbon (SOC) changes in the topsoil are modelled using the RothC soil carbon turnover model. One of the advantages of RothC is that it uses a model instead of recurrent soil measurements to estimate soil carbon change (See Annex 2 for more information on the RothC model). We used an adapted Excel based version of the model, which has been already used for various carbon certification projects in Africa.

Data from the LDN study are used to determine the average soil carbon stock of the concerned area. The RothC soil model was then adapted from the original version for dryland soils to account for the soil status of Namibia. The model used is called "RothC10_N" and was originally developed by Farina et al (2013).

Calibration of models for Namibia

RothC10_N models were designed for each of the four specified precipitation strata of 200 mm, 350 mm, 450 mm, and 550 mm annual rainfall. The stratum-specific average monthly temperature, precipitation, PET, topsoil clay content, topsoil silt content, topsoil organic carbon content, topsoil reference bulk density was calculated and put into these models. An estimate on soil moisture in the wettest month (February) was derived from ESA and TUW (2012) and set to 0.175 m^3 per m^3.

Also a stratum-specific SOC stock (0-30cm) was calculated. The models were then calibrated through inverse modelling so that the specific SOC stock is split correctly into the different soil carbon pools. For the calibration a decomposition ratio, i.e. DPM/RPM-ratio of 0.25 was assumed for the bush encroached systems, which corresponds to the quality of incoming plant debris of tropical woodland. Assuming a lower DPM/RPM-ratio for the calibration accounts for the bush-encroached status of the concerned area. This approach follows the findings of Leitner et al (2018) who found that decomposition is much slower (almost only half as fast) in bush-encroached areas than in African savanna.

Furthermore, for the calibration it was assumed that only in February carbon inputs enter the soil from aboveground biomass (AGB) and belowground biomass (BGB). This simplifying assumption is valid because Farina et al (2013) and Janik et al (2002) show that the timing of when carbon enters the soil only minimally influences the modeling results. A root-to-shoot ratio of 0.48 was assumed[4]. No input from manure was assumed. The soil was assumed to be permanently covered with living plants which implies a reduced decomposition rate in the model.

[4] Please note: a ratio does not need a unit of measure because when both factors have the same unit, they get reduced in a fraction.

Modelling SOC turnover in different harvesting scenarios

The modelling period is set to be 20 years, which is a common timeframe in land use GHG modelling (Lal 2002, IPCC 2006). Carbon inputs to the soil are from litterfall of trees as AGB input. Dying roots are assumed to be BGB inputs in the model. We assumed that the current SOC stock is in equilibrium. Therefore, through inverse modelling using the *calibrated* models the current carbon input into the soil was calculated. This carbon input is assumed to be AGB input only. In the different harvesting scenarios, this carbon input from AGB (=current litter fall) must decrease after the harvest of bush. Thus a litterfall reduction factor is calculated as follows:

$$\text{Litterfall reduction factor} = \frac{\text{remaining biomass} + \text{growth over 20 years}}{\text{Initial biomass} + \text{growth over 20 years}}$$

A different litterfall reduction factor was calculated for scenarios with aftercare and without aftercare. Leaf carbon from harvested bush is assumed to stay on site and decompose linearly over 20 years. If there is no aftercare, we assumed that stumps and roots of harvested bush stay alive and therefore there is no BGB root carbon input. In the case of aftercare, we assumed that root carbon from harvested bush decomposes and enters the soil linearly over 20 years. All carbon inputs are assumed to enter the soil in February, which is the wettest month of the year. As mentioned above, simplifying the timing of when carbon enters the soil has only minor effects on the modeling results (Janik et al 2002, Farina et al 2013). Thus, this simplification is valid.

In the scenario where aftercare happens we assume that grass can successfully return to the site based on SAIEA (2016). Therefore, there are not only carbon inputs from tree litter fall but also from grasses. We assumed that carbon inputs from grasses are from BGB only because most of grass carbon input enters the soil via the extensive fine root system. In Southern Africa few data on carbon inputs from grasses exist as demonstrated in Grace et al (2006). Even fewer of this data seemed useful for this analysis. Therefore, we resolved to use the insights of Zhou et al (2012) who found a carbon input rate of 0.432 tC/ha/year for perennial grasses in northwestern China. We consider this as a conservative estimate for carbon inputs from grasses in African savanna systems. The productive savanna ecosystems of Southern Africa are most likely to have higher carbon inputs as suggested by various studies (Grunow et al 1980, Dunham 1989, Grace et al 2006). Therefore, the results of this study can be seen as conservative estimates.

Livestock

Rangelands are very extensive in Namibia, where large areas maintain comparatively small number of animals. Stocking rates are expressed in “large stock unit” (LSU). In Otjozondjupa most farmers keep cattle, and therefore the GHG assessment of livestock will focus on cattle, only. Livestock emissions are bound to the purpose of land management (rangeland restoration). Therefore, the amount of biomass harvested on the land and the projected availability of palatable grass define the possibility for higher livestock stocking rates and thus livestock emissions.

Many studies focusing on livestock stocking rates recovery with bush thinning and utilization expect an increase of doubling the livestock stocking rates after bush harvest (Stafford et al., 2017, Birch and Middleton, 2017). We assume an increase of 213% of stocking rates (in kg animal biomass) based on Honsbein (2016) and Van Eck & Swanepoel (2008). Based on this, the emission factor for this livestock increase results in 0.53 tCO_2e/ha/year reflecting an increase from 22 to 66 kg animal biomass per ha.

3.2 GHG assessment of bush biomass utilization

The second major assessment of this study is the quantification of GHGs of different bush control and utilization activities, which follows the logic of a lifecycle analysis. The lifecycle analysis takes the "cradle-to-gate" approach, i.e. GHG emissions/removals from harvesting of bush biomass to the production until the factory gate, before it is transported to the customer[5]. This includes the potential emissions of different harvesting options, transport, biomass processing, and biomass utilization. Typically, these emissions are linked to tons of biomass utilized, but the results will also be linked to the ha-based approach of the land use analysis.

Scope of the biomass utilization and GHG mitigation analysis

All emissions resulting from the harvest and transport operations are included if they are easily accountable, e.g. due to a simple fuel consumption per hour, hectare or kg calculation. Furthermore, the emissions resulting from other machinery along the value chains, e.g. wood chippers, feeders, kilns, etc. are also accounted as scope 1 emissions. For assessing a substitution effect coal is accounted as a major contributor for electricity production in Namibia. However, since most of the electricity is imported a general emission factor for the Namibian electricity mix of 2010 was used (WSP 2012).

Harvest technology

The GHG assessment of the harvesting technology used the fuel consumption as calculated in de Wet (2015). The costs of diesel fuel in Namibia in the year of de Wet's study were conservatively assumed to be N$11 per liter. This step was necessary to calculate fuel consumption in different harvesting scenarios. An emission factor of 2.68 $kgCO_2e$ per liter of diesel is assumed. For roller or bulldozer harvesting it was conservatively assumed that the emissions of these machines are similar to a heavy duty excavator used for large-scale bush harvesting. Fuel consumption per ton of woodchips of rollers and bulldozers are most likely lower due to the higher bush clearance rate of 5-8 ha per day for bulldozers and 5-15 ha per day for heavy rollers (Rothauge 2017).

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[5] For a "cradle to grave" analysis, which includes GHG emissions/removals up to end life (disposal/recycling), the data requirements could not be met in this study. In addition, the list of bush biomass utilisation categories in Namibia do not significantly stretch to the disposal/recycling life cycle stages.

Harvesting without any biomass use, e.g. Veldfire or chemical control also cause emission. Emission factors for these methods as well as for aftercare through arboricide are from IPCC (2006). The emission factor for Veldfire was calculated based on Tier 1 values for tropical shrubland (IPCC 2006).

$$GHG_{fire} = M_{Biomass} \times C_F \times G_{ef} \quad (1)$$

Where:

GHG_{fire} = amount of GHG from fire, kg of each GHG either CH_4 or N_2O

$M_{Biomass}$ = mass of fuel available for combustion in metric tons (AGB, BGB, litter)

C_F = combustion factor, for tropical shrubland: 0.72

G_{ef} = emission factor g kg^{-1} dry matter burnt, tropical shrubland: 6.8 for CH_4 and 0.2 for N_2O

From this equation, emissions of CH_4 and N_2O were calculated and transformed into a single emission factor of 0,209376 tCO_2e per ton of biomass using a Global Warming Potential (GWP) of 34 for CH_4 and 298 for N_2O.

Aftercare measures in the database consist of browsing by goats or the application of arboricide. Emission factors for these were found in du Toit et al (2013) and IPCC (2006).

Transport

Biomass transport emissions through fuel consumption were derived from the VTT study (2008). All bush biomass products are subject to transport emissions between the harvesting site and the point of utilization. This point of utilization may be the power plant, bushblok production plant, or charcoal plant (if kiln is stationary), etc. For fire wood no transportation emissions are assumed because most firewood is harvested and transported manually. Since transport vehicles will most likely return empty to the harvesting location the emission factor is multiplied by 2. Therefore, the activity data represents the distance from the harvesting location to the utilization location.

Processing technologies

Charcoal with different kiln technologies

Different emission factors for various kiln technologies were derived from Temmermann (2016) and cross-checked with the latest kiln emission testing study conducted by Demos Dracoulides (2018). From this study also the efficiency rates of wood utilized / charcoal produced were derived, i.e. Namibian traditional drum kiln 23%; retort kilns combined 33% efficiency.

Wood chips for electricity production

Data on fuel consumption by wood chippers, mechanized machine feeding and shuttling the biomass to the feeder is based on de Wet (2015). Price for diesel and emission per liter are the same as above. A conversion factor of 95% of wood to wood chips was assumed.

Fire wood

Fire wood is collected mostly manually and thus doesn't cause any emissions from harvesting. Burning firewood – although only releasing carbon that has been previously stored in the plant – causes emissions of powerful GHGs such as N_2O and CH_4. Therefore, an emission factor of 0.19 tCO_2e per ton of dry wood is assumed (IPCC 2006).

Fodder production (bush-to-feed)

Emissions from fodder production are mainly scope 1 emissions resulting from the fuel consumption of the chipper. This fuel consumption data stems from de Wet (2015). Price for diesel and emission per liter are the same as above.

Wood pellet production

Wood pellets are usually based on wood chips and thus cause emissions from wood chipping. Furthermore, an emission factor for wood pellet production through further drying, dusting and compressing was derived from Zhang et al (2009) and amounts to 0.133 tCO_2e per oven dry ton of pellets. This factor includes the transport to the plant. However, we assume that transport is not included in this factor to account for possible efficiency deficiencies in a Namibian pellet production plant as opposed to a foreign one. The literature suggests that such deficiencies existed in 2015, e.g. bushblok plants were not running (DECOSA 2015). A conversion factor of 90% of wood to wood pellets was assumed.

Substitution effects

It is assumed that electricity generated from biomass will substitute electricity generated in the Namibian Power matrix of 2010. This overall emission factor amounts to 0.4894 tCO_2e/MWh (WSP 2012). Table 6 shows the contribution of different providers to the Namibian energy mix in that year. The energy mix includes also hydropower and imported electricity. It makes sense to view substitution in a holistic way because it is more conservative. Assuming that only fossil fuels are substituted with biomass energy may overestimate benefits because much of Namibia's electricity is imported and Namibian legislation has only a limited effect on the power mix supplied by other countries.

Table 6: Emission factors in Namibian power mix in 2010 (WSP 2012)

Source	MWh / year (Net)	Weight (%)	Emissions Factor (tCO2e/MWh)	Overall Emissions Factor
Ruacana Power Station	1 312 069	34.5	0.00	0.00000
Van Eck Power Station	20 616	0.5	1.44	0.00782
Paratus Power Station	4 493	0.1	0.82	0.00097
Imports (ZESA)	891 00	23.5	0.35	0.08258
Imports (Eskom)	1 429 000	37.6	1.06	0.39836
Imports (EDM)	95 000	2.5	0.00	0.00000
Imports (Zesco)	47 000	1.2	0.002	0.00003
Total				**0.4898**

For a biomass power plant, additionally to the harvesting, chipping and transport emissions there are emissions of energy to run the plant and for handling of the woodchips. The latter two factors amount for emissions of 0.016 tCO_2e per MWh of electricity (WSP 2012).

3.3 Limitations of the study

Biomass

The biomass assessment was conducted on the basis of bush density numbers, calculated by Nijbroek et al. (2017) and biomass per tree values by Smit et al. (2015). Bush densities by the LDN study only incorporated bushes with a height of up to 3 m (Njibroek et al., 2017). Therefore, per hectare biomass assessments differ between Njibroek et al. (2017) and Smit et al. (2015). Furthermore, single tree biomass and species have been categorized according to encroacher bushes with higher and lower biomass (Smit et al. 2015). It can be concluded that the biomass assessment as well as the harvesting rates in this study can be considered conservative since it might underestimate the total biomass of the bush sites.

Database

The area selected for this study, the region of Otjozondjupa, is one of the Namibian regions with the strongest bush encroachment. However, although the region seems very representative for the problem of brush encroachment it does not encompass all different encroacher species or climate regions existing in Namibia. Therefore, the study will have representative character for the problem of bush encroachment in Namibia, but not resemble all of its details and facets.

The database has been compiled with data from different data-sources. Bush densities and SOC contents were taken from the LDN study by Nijbroek et al. (2017). The mean annual precipitation has been calculated from monthly average values, recorded from 1970-2000 (Fick and Hijmans, 2017). Dominant species data was taken from SAIEA (2016), based on the Tree Atlas of Namibia (Curtis et al., 2005). The database could only reflect the dominant species and therefore does not depict the entire range of different species of the study area. Because species presence was recorded in 2015/2016 and the record resolution is 26 km, certain areas might not show a species presence, however bush encroachment, and changes in the species distribution might have occurred. This will have some impact on the accurate biomass assessment. However, all dominant species occurring were part of the same higher biomass encroacher group, presented by Smit et al. (2015). Bush biomass accuracy is also influenced as a result of categorization of bush densities. Overall, representative categories have been assigned, according to the data distribution and histogram analysis.

Soil fertility and modelling RothC

SOC contents for the database were assessed by Nijbroek et al. (2017) by soil samples and spatial modelling. SOC modelling with models like RothC has its pitfalls due to static and abstract assumptions of carbon dynamics as discussed in Kleber (2010) and Schmidt et al (2011). However, alternative models that incorporate the newest findings in soil ecology do not exist yet. Therefore, Schmidt et al (2011) still points out the usefulness of SOC models like RothC in the short term. Modeling SOC is a useful and necessary step for future funding decisions considering its important role in climate change as shown by the "4 per 1000 initiative"[6].

For the modelling of SOC turnover several assumptions had to be made. Especially, the assumption that bush encroached land in the study region is in an equilibrium state is more an expert estimate than a scientific fact. However, this step was necessary to be able to conduct the modelling exercise in the data-sparse environment. Furthermore, since all models follow the same assumptions they are comparable to one another and are therefore helpful tools to guide further decision making. Reference carbon stocks from savanna ecosystems were taken as average from different studies and savanna ecosystems in South Africa (Grace et al. 2006; Moustakas et al., 2009, Ciais et al., 2011; House). This does not necessarily have to resemble conditions in Namibia, but assumes similar C stocks, due to comparability of climate zones and ecosystems.

The assumption on using February as the start month has no major implication on the SOC modeling as it only sets the starting month of the modeling year.

Livestock

Livestock emissions are accounted on the basis of rangeland restoration success, regaining rangeland fertility and therefore allowing a higher stocking density. The assumption of an increase from 22 to 66 kg animal biomass per ha lead to emission estimates being more conservative since it neglects current tendencies in the livestock sector to reduce herd sizes (personal observation during consultations).

Successful rangeland restoration, however depends upon many different factors, which cannot be evaluated in depth in this desk-based study. Furthermore, emissions from livestock are accounted emissions per kg live weight (Birch and Middleton, 2016). Although commonly applied, emissions might differ depending on the number of cows on the area. Not necessarily all cows have the same weight and therefore emissions might be different in reality.

Bush thinning impact evaluation

The impacts of large-scale bush thinning are manifold and complex. Although a wide range of different scientific studies have been considered, it is very difficult to assess especially long-term impacts. Many of the processes described in scientific literature and by experts are contradictory and impact the same ecosystem service or problem in opposite directions. Overall, the scientific debate about the impact of climate change in combination with bush control on certain ecosystem services is ongoing and more research is needed.

Emission factors

All emission factors are based on scientific studies or, if not available regionally, from IPCC Good Practice Guidelines. These studies are not always conducted in Namibia, but were selected according to reasons of representativeness and comparability to reflect similar bush and savanna ecosystems.

[6] https://www.4p1000.org/

4 RESULTS

4.1 Baseline - bush encroachment and bush control in Namibia

To compare potential future bush control management scenarios, it is first important to establish the baseline in terms of the total area under bush encroachment in Namibia as well as the current bush control activities occurring throughout the country. Rothauge (2014) states that at least 75% of Namibia's land surface (i.e. roughly 62 million ha) – consisting of all vegetation and land units that are not climatological deserts or saline deserts and all land uses (commercial farming, communal farming and conservation) – are subject to bush encroachment, albeit with varying intensity. This study further defines that every bush density (in bush equivalents/ha) exceeding twice the average annual rainfall (in mm) is considered "encroachment" (GIZ 2014).

The latest National Greenhouse Gas Inventory Report (NIR 3; 2018) 1994 – 2014 includes a major change in the reclassification of bush encroached grassland in previous NIR to form the Other Wood Land Class (OWL), which includes

- Woodlands where tree height of 5 m with a canopy cover between 10% and 20%
- Shrubland where trees and saplings are present as these have been invaded long ago
- Savanna grassland where bush invasion is occurring with an increase in woody biomass

According to this updated NIR 3, this OWL class extends over 58. 2 Mio ha with an annual increase of 289,361 ha and losses of 100,114 ha.

Another study revised the 'Bester map' using the field knowledge of recognized botanists and bush encroachment experts concluding that 45 million ha of Namibia are bush encroached (SAIEA 2016). This carbon study used this total area under encroachment.

In terms of areas under bush control activities in the baseline, this study refers to the updated data from the Baseline Assessment for the De-Bushing Programme in Namibia (GIZ 2014). Based on this, Table 7 summarizes the main bush control activities and their annual implementation areas.

Table 7: Bush control activities in the baseline

Bush control activities	Area implemented annually (ha)
Bush chemically controlled (no wood recovery)	68,000
Aftercare (does not contribute to utilization)	7,500
Bush used for biomass processing: charcoal	121,810
Bush used for biomass processing: wood chips	1,200
Total annual bush control	**198,510**

Source: GIZ, 2014

It has to be noted, that the use of chemicals for bush control is being discouraged by the authorities. This is especially relevant to the recent regulation (2015) that prohibits aerial spraying of chemicals for bush control.

4.2 Carbon in bush systems in Namibia

Our database results shows standing average biomass of 30.81 t dm/ha across all strata of a total bush assessment area of 8,554,517 ha in Otjozondjzupa. The dominant species are *Acacia mellifera*, *Acacia reficiens*, *Colophospermum mopane* and *Terminalia sericea*. The largest species group distribution is with ca. 63.6% mixed bush systems with *A. mellifera* as dominant species, followed by mixed systems (16.2%) and *T. sericea* bush (12.7%). Pure *A. mellifera* occurs only on 6.9% of the area (Figure 4). According to a classification by Smit et al. (2015) encroacher bush can be separated into desirable species, encroacher bush with low and high biomass growth. All the mentioned and present species belong to high biomass encroacher bush systems.

Encroached areas are characterized by high ETTE/ha, due to high number of stems in lower height- and thus diameter classes. This potential evapotranspiration represents a threat to groundwater recharge, due to the possibility of interception and possible evapotranspiration.

The major soil types in Otjozondjupa are Arenosols (47%), Cambisols (27%) and Leptosols (21%). Other occurring soil types occur on marginal areas and are therefore insignificant.

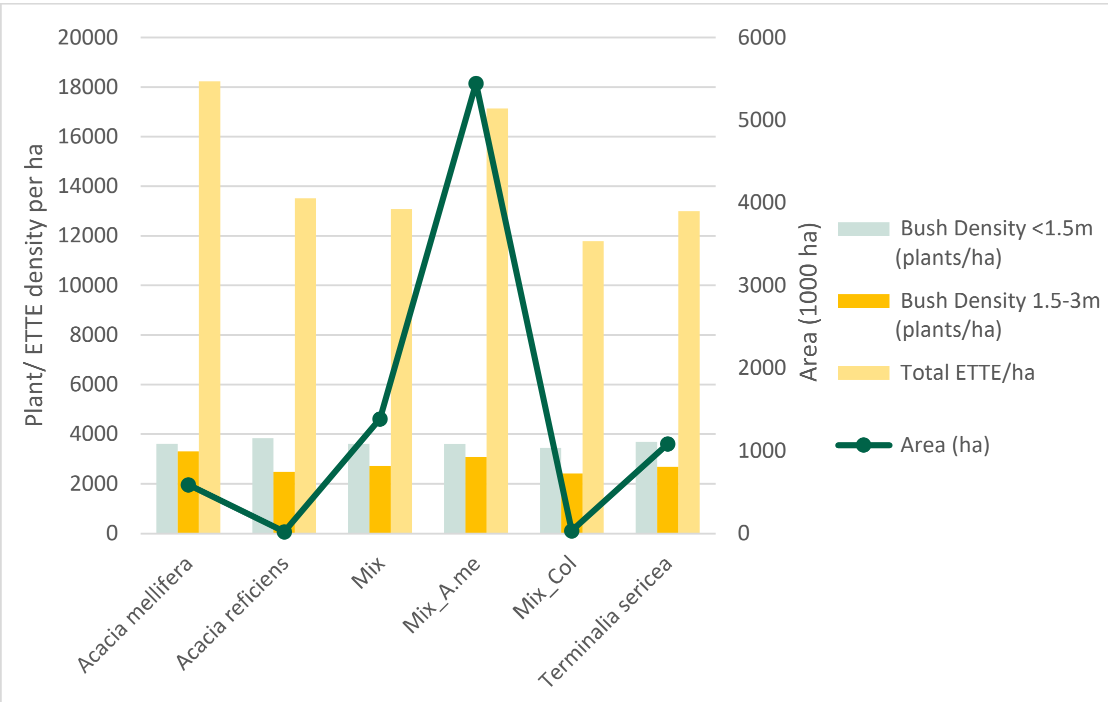

Figure 4 : Tree and ETTE density per ha according to existing tree species,

Mix – tree species mixture without a dominant species, Mix_A.me – Species mixture dominated by *Acacia mellifera*, Mix_Col –Species mixture dominated by *Colophospermum mopane,* ETTE: Evapotranspiration Tree equivalent is defined as the leaf volume equivalent of a 1.5m single stemmed woody plant

The mean annual precipitation (MAP) for the study area ranges from 78 - 618 mm/ year, with an average of 417mm/year in encroached areas. Approximately 66% of the area reach a MAP of 450mm/year and another 26% reach a MAP of 350mm/year, covering 92% of the entire encroached area of 8.6 Mio ha under assessment in this study.

Species distribution looks slightly different along this gradient. While most species occur in all precipitation strata, certain species, especially single species systems show a preference for a certain precipitation stratum. Encroachment correlates strongly with higher precipitation rates (Ward, 2005). Most species occur only in strata with higher precipitation (Figure 4). Only *Acacia reficiens* occurs in larger areas also at 200 mm MAP.

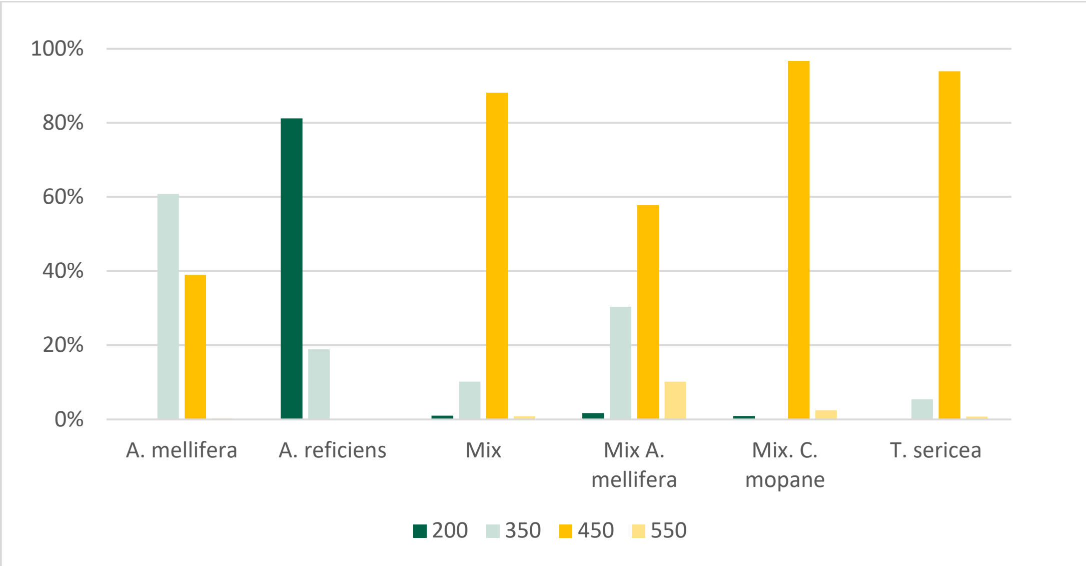

Figure 5 Species distribution according to Mean Annual Precipitation (MAP), mm/year

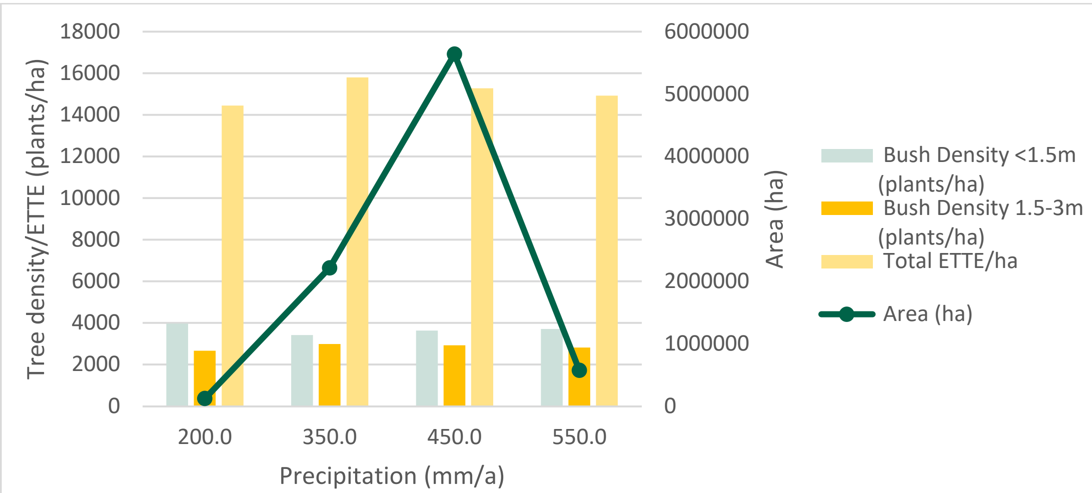

Figure 6: Bush density according to climate (precipitation) strata and distribution of area

In total, bushland in the study area results in 123.9 Mio t of carbon (tC) sequestered corresponding to 14.5 t C/ha. Additionally, 146.4 tC are stored as soil organic carbon, corresponding to 17.1 t C/ha. These figures are average values for encroached bushland.

Typical savanna ecosystems (not encroached) show similar amounts of total stored carbon (34.2 t C/ha), but differ in the allocation of carbon. Savannas store as SOC more than double the amount of carbon than stored in biomass (Figure 7) based on the average default values compiled from various studies. The biomass in savanna-like systems is around 10.9 t C/ha, while SOC ranges around 23.3 t C/ha.

Under the assumption that bush encroached areas in the study area have reached an equilibrium most changes regarding carbon happen through encroachment of new areas. Once an area is encroached, the SOC slowly decomposes, while in the same manner more biomass in the form of bushy vegetation is build up, resulting in a slight decrease of the total C stock. However, SOC decomposition will take several decades (IPCC, 2006).

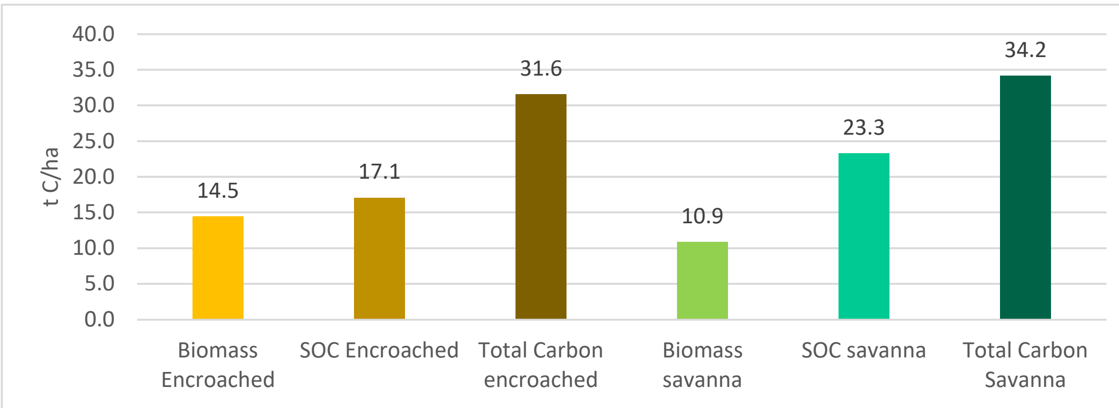

Figure 7: Overview Carbon stocks of encroached areas and reference savanna ecosystems

Source: UNIQUE database; SOC savanna Grace et al. (2006)

Representativeness of the carbon results

In order to use the results of this carbon study from a defined study area with available data (Otjozondjupa) for upscaling bush baseline as well as future bush utilization scenarios to a national level the standing biomass stocks of this study are compared to other studies.

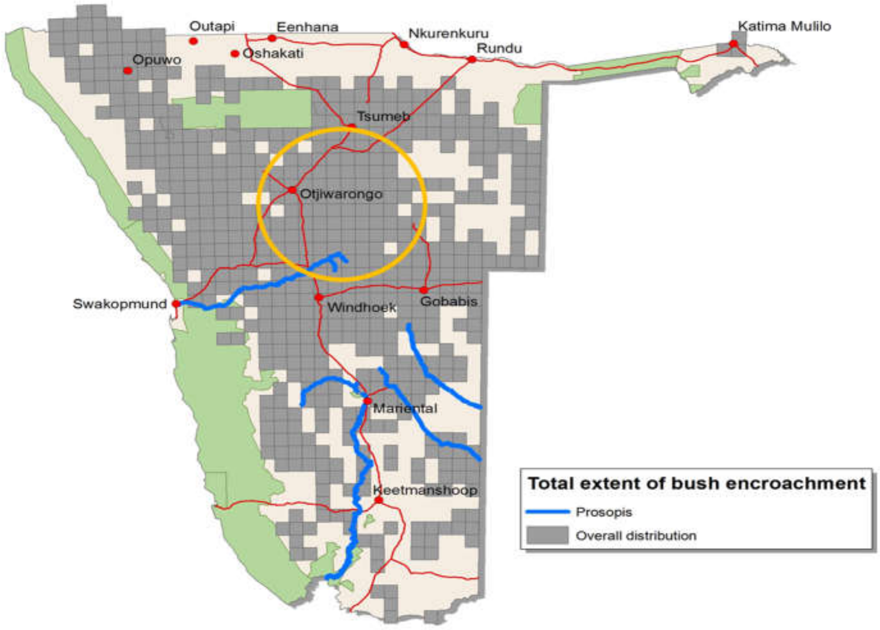

Figure 8: Study assessment area (yellow circle) and extent of bush encroached areas in Namibia

Source: SAIEA (2016)

The value applied in this study is comparably lower than other study results mainly from the same region: Our calculated standing average biomass of 30.81 t dm/ha is lower than the estimated 36.22 t dm/ha of a GIZ study (Smit et al., 2015) in the same region of Otjozondjupa. Another study in the same region results in a total biomass of 38.3 t dm/ha (Honsbein, 2016). The updated NIR3 report established a default value of 36.38 t dm/ha for the OWL class representing bush systems in Namibia. Assuming that this region is more representative for high-biomass encroacher species (see also Smit et al. 2015), a lower value is justified to be representative as a national value to include also areas of encroacher species with lower biomass stocks.

The results of the study and the accounting model also quantifies carbon stocks for all defined strata in contrast to the overall average results presented above. Therefore, to assess other encroached areas in Namibia with known conditions of lower bush biomass, average values from the following table can be used for further analysis.

Table 8: Stratified carbon stock averages

Species strata	Average biomass carbon stocks (tC/ ha)	Average soil carbon stocks (tC/ ha)
Acacia mellifera	17.2	17.1
Acacia reficiens	8.6	19.8
Mix	11.9	16.6
Mix dominated by *A. mellifera*	15.6	19.1
Mix dominated by *C. mopane*	9.5	22.2

Terminalia sericea	11.1	9.3
Overall weighted average	**14.5**	**17.1**

Source: UNIQUE

4.3 Hectare based bush control & utilization scenarios

Greenhouse Gas Balance for different bush control and utilization scenarios

The following chapter presents five different harvesting and utilization scenarios reflecting existing and future bush value chains. The scenarios calculate all emissions in the value chain as footprint (at the time of bush extraction and utilization) and as a long-term impact over a 20 year time period. This period is commonly used for GHG calculations in the land use sector as it accounts for the necessary time until carbon stocks reach a new equilibrium (Lal 2002).

All scenarios are calculated on a per hectare basis to make them comparable to one another and to easily upscale them. As a consequence, certain emission sources will show an uncommon unit, e.g. transport emissions are depicted in tCO_2e/ha. However, this refers to the amount of biomass harvested, transported and processed on one hectare.

In general, all scenarios assume that leaf biomass stays on site (as a results of the on-site drying commonly applied) and only carbon from wood biomass is removed from the system. It is further assumed that biomass can regrow after harvesting up to the average total biomass per hectare prior to the removal as calculated in the database.

The annual change of carbon stocks and emissions over 20 years for each of the scenarios are shown in Annex 1.

GHG scenario 0: Bush chemically controlled (no wood recovery) with subsequent agricultural use (Livestock ranging with increased stocking rate)

This scenario was selected to represent the baseline conditions of chemically controlled bush systems (currently around 68,000 ha) in Namibia. Based on the available literature and stakeholder consultations the following assumptions are applied for this scenario:

- 90% of total average bush biomass dies off (de Klerk 2004) which represents 27.7 t dm/ ha. Decomposition of the standing dead bush begins after 10 years.
- Aerial application of chemicals by manual broadcast, e.g. Molopo GGP200;
- One application with 5 kg active ingredient/ha, based on van Eck and Swanepol (2008)
- No emissions in application process (manual application)
- Increased livestock emissions due to increased livestock stocking rate (+106% of animal biomass per ha). The increase in livestock stocking is assumed to be only half of the potential increase identified in this study (+ 216%) since for at least 10 years the standing dead bushes are limiting the accessibility of the sites.
- Grass restoration success: Year 1: 41% perennials, 39% annuals, 20% bare area; from year 3: 75% perennials, 25% annuals (Van Eck & Van Lill 2008; Van Eck & Swanepol 2008)

- SOC inputs considered from litter fall, grass turnover, slow decomposition of dead wood, and manure from increased livestock stocking

The table below summarizes the GHG balance over 20 years for the different sources and sinks as well as the total GHG balance. All values in this and the subsequent scenario results are shown in tCO_2e per ha over 20 years.

Table 9: GHG Balance Scenario 0 – Bush chemically controlled with subsequent agricultural use (negative values indicate carbon sequestration)

	Removal of wood	**Growth woody plants**	**Growth grass bio-mass**	**Average soil emissions**	**Arboricide**	**Livestock emissions**	**Total GHG balance**
Emissions over 20 years (tCO_2e/ha)	23.90	-10.51	-10.27	-2.00	0.12	**5.01**	**6.24**
	GHG balance per ton wood utilized						**0.23 tCO2e /ton wood controlled**

In this scenario, the removal of bush biomass and loss of carbon respectively does not take place instantly but rather over time as the standing dead wood is slowly decomposing. Significant carbon sequestration from grass biomass occurs as well as some restoration of soil organic carbon (both indicted by the negative values in the table).

GHG scenario 1: Rangeland restoration & bushblok, bush-to-feed or pellet[7] production

This scenario has been set up to represent a savanna restoration without the use of aerial application of chemicals, however, with the precision application of arboricide. Some bush biomass is harvested and removed and used for bush bushblok, bush-to-feed or pellet production. Significant shares of harvested bush biomass is not removed from the site, however, used as additional organic inputs to soil. The following assumptions can be summarized:

- 78% of total average bush biomass harvested; removed biomass for processing is 12.4 t wood/ha.
- Medium-scale mechanized harvesting with excavator and medium-scale chipping

[7] The wood can be also used for producing bushbloks. Since there is not much data, the same emission factor for producing pellets is assumed as for bushbloks

- Aftercare through application of arboricide, 1.2 kg active ingredient/ha (+ 200 ml per ha in second year) based on Van Eck and Swanepol (2008)
- Transport: Tractor with double trailer, 50 km
- Increased livestock stocking rate post harvesting (+213% from 22 to 66 animal biomass per ha)
- Wood utilization: bushblok, bush-to-feed, or pellets
- Restoration success assumed is 100% with the return and growth of grasses (75% perennial, 25% annual grasses) (Van Eck & Van Lill 2008; Van Eck & Swanepol 2008)
- Organic inputs to the soil: Decomposition from harvested small wood (placed in trashlines along the contour), leaf carbon, root carbon; litter fall from remaining and re-growing trees; manure input from increased stocking of livestock, turnover input from returning grass biomass.

Table 10: GHG Results Scenario 1 - Rangeland restoration (negative values indicate carbon sequestration)

	Removal of wood	**Growth woody plants**	**Growth grass**	**Harvesting & Chipping**	**Average soil emissions**	**Arboricide**	**Transport**	**Livestock**	**Pellet production**	**Total GHG balance**
Emissions over 20 years (tCO_2e/ha)	22.69	-22.40	-10.27	0.22	-9.86	0.03	0.35	10.55	1.59	**-7.10 tCO_2e/ ha**
	GHG balance per ton wood utilized									**-0.54 tCO_2e /ton wood**

There is a strong desire of farmers to counteract bush encroachment in an economically viable way and be able to increase livestock stocking rates. This scenario with bushblok, bush-to-feed or wood pellets as the final product is believed to be a plausible restoration scenario for farmers. In the past, many farmers have tried restoring the former rangelands and have failed, due to the complex ecology of savannas. Therefore, care has to be taken to adopt correct rangeland management, including aftercare measures, and leaving large trees on site to suppress bush seedlings.

Harvesting 78% of total bush biomass is a strong thinning scenario. It resembles the removal of 60% of the maximum allowed ETTE/ha in Otjozondjupa. This thinning scenario is assumed to open up enough area for grasses to re-establish on the site and the organic inputs from various sources including trashlines of some of the harvested bush biomass will slowly increase site fertility over time. Significant carbon sequestration occurs over 20 years as a result of growth of woody plants, mainly desired larger trees as well as some bush re-growth, establishment of perennial and annual grass and as a result of soil carbon sequestration. This sequestration is higher than the emission caused, in particular from an increase of the livestock density. Even if goats are used instead of arboricide for a more biological aftercare, the total GHG balance would be negative (meaning sequestration). Therefore this scenario represents a real mitigation scenario with an impact of -7.1 tCO_2e per ha over 20 years (-0.25 tCO_2e per ha if goats are used for aftercare) or -0.54 tCO_2e for each ton of bush biomass harvested in the beginning.

GHG scenario 2: Bush farming & bushblok production

In contrast to the previous two scenarios, this scenario represents bush farming where sustainable production and use of bush biomass over time remains the prime objective. We use the following assumptions:

- 78% of total average bush biomass harvested in year 1 which resembles 15.3 t wood/ha
- Second harvesting cycle occurs in year 13
- Medium-scale mechanized harvesting with excavator and medium-scale chipping
- No aftercare, thus no restoration success and no additional livestock
- Transport: Tractor with double trailer, 50km
- Wood utilization: bushblok, bush-to-feed or pellet production

Table 11: Results Scenario 2 – Bush farming (negative values indicate carbon sequestration)

	Removal of wood[8]	Regrowth	Harvesting & Chipping	Average soil emissions	Transport	Pellet production	Total GHG balance
Emissions over 20 years (tCO_2e/ha)	52.71	-52.71	0.51	3.25	0.8	3.7	**8.26 tCO_2e/ ha**
GHG balance per ton wood utilized							**0.16 tCO_2e /ton wood**

Compared to the rangeland restoration, this scenario analyses a different strategic option for farmers with shifting their focus to bush biomass farming compared to the restoration of rangelands to continue livestock production. CO_2 levels as predicted for future climate will further give

[8] Two harvesting cycles over 20 years

an advantage to C3 plants like encroacher bushes. Thus, it has to be considered that farming for bush biomass as a “biomass-energy farmer” can become a viable option on farmland.

However, focusing on bush farming actually increases the problem posed by climate change as bush encroachment has also negative impacts on groundwater recharge and therefore this option should only be considered in combination with other, more restoration focused scenarios. The modelling shows (Table 11) that regrowth of bush biomass compensates for the removal of wood in terms of CO_2 emission losses. Harvesting, chipping, and transport remain low contributors to the overall GHG balance although all activities are conducted twice within 20 years.

In this scenario, soil organic carbon is released assuming no successful restoration of rangelands with the return of and subsequent carbon inputs from perennial grasses. Overall, the GHG balance per ton utilized biomass is also very close to neutral with 0.16 tCO_2e per ton of wood utilized.

GHG Scenario 3: Medium-scale charcoal production

Scenario 3 represents a likely business-as-usual scenario in Namibia. The charcoal industry is already well established and the sector is growing according to the “Growth Strategy for the Namibian Wood Charcoal Industry and Associated Value Chain (2016)”. The possibility exists to export charcoal on a larger scale in the future, and advanced kiln technologies might replace the traditional steel drum kilns currently used.

This scenario is split into two parts. First all sources and sinks are considered which are independent from the charcoaling process itself. Second, different kiln technologies are assessed to also understand the impact of these technologies on the overall GHG balance. In this scenario, we use the following bush management assumptions:

- 63% of total biomass harvested which is 13.07 t wood/ha
- All wood biomass is used for charcoal production
- Motor-manual harvest
- Aftercare through application of arboricide, 1.2 kg active ingredient/ha based on van Eck and Swanepol (2008)
- Restoration success, leading to increased livestock stocking rate post harvesting (+213% from 22 to 66 animal biomass per ha) as well as to the return of grasses similar to the chemical control scenario. However, less organic inputs to the soil are considered since more biomass is harvested and actually removed from the sites.
- Transport: Tractor transport, 50 km

Table 12: Results (1) of charcoal value chain without final charcoaling process (negative values indicate carbon sequestration)

	Removal of wood	Regrowth	Harvest	Arboricide application	Average soil emissions	Additional livestock	Sub-Total
Emissions over 20 years (tCO_2e/ha)	22.52	-22.52	0.52	0.028	-7.68	4.63	**-2.5 tCO_2e/ ha**

Charcoal production can utilize a manual harvesting process, where larger diameter bush is harvested manually or a harvesting process with larger wood chipping operations. In this scenario, it is assumed that all removed biomass can be used for charcoal making. The harvesting scenario is assumed under motor-manual harvesting, to provide a stronger force to encounter bush encroachment. In this scenario we assume charcoal producers to harvest less than 10 times the ETTE of the annual rainfall (Smit et al., 2015), corresponding to 63% effectively harvested biomass.

We conclude that this scenario only removes 63% of total bush biomass since only large diameter bushes (max. 18 cm) are used for charcoal making. It is assumed that perennial and annual grasses re-establish at the site leading also to soil carbon sequestration. The sequestered carbon more than compensates for the emissions produced by increased livestock stocking rate (see Table 12). Arboricide is applied after harvest to inhibit regrowth. Nevertheless, within 20 years regrowth compensates for the emissions caused by removal of biomass. Therefore, this scenario has to be taken with care. More harvesting cycles are probably necessary to ensure restoration success, which would result in higher emissions form the removal of wood. This first part of the charcoal value chain also represents a mitigation scenario leading to potential benefits of -2.5 tCO_2e/ ha over 20 years.

The common charcoal kiln technologies used are drum and mobile retort kilns (Figure 9) as well as stationary retort kilns (Figure 10). In comparison to kiln technologies used all over Africa, the Namibia traditional drum kiln and retort kiln are much more climate-friendly (Temmermann 2016). New developments introduce mobile and stationary retort kilns, which are more efficient in producing charcoal and emit less CO_2e per ton charcoal produced. Industrial retort kilns are the most climate-friendly option (Temmermann 2016). The emissions caused by transport to deliver the wood to stationary kilns are more than compensated by the emissions reductions.

Figure 9 Namibian traditional drum (left) and retort kiln (right) (Temmermann 2016)

Figure 10 Stationary retort kiln (Temmermann 2016)

Table 13 shows the final carbon balance including the charcoaling process by comparing the different kiln technologies. Transport emissions were relatively marginal with 0.34 tCO_2e/ha and only applicable for stationary kiln technologies.

Table 13: Results (2) of Scenario 3 with different kiln technologies (adapted from Temmermann 2016)

Kiln technology	Emissions in tCO_2e/ha	Total emissions of scenario 3 after 20 years (tCO_2e/ha) (from Table 11) (GHG balance per ton wood utilized; tCO_2e /ton wood) [GHG balance per usable charcoal produced; tCO_2e /ton charcoal][9]
Namibian traditional drum kiln	16.86	**14.36 tCO_2e/ ha (0.64 tCO_2e /ton wood) [2.83 tCO_2e /ton charcoal]**
Namibian retort kiln (mobile)	16.37	**13.87 tCO_2e/ ha (0.62 tCO_2e /ton wood) [1.87 tCO_2e /ton charcoal]**
Retort Kiln (Stationary, small Scale, incl. Transport)	10.14	**7.98 tCO_2e/ ha (0.35 tCO_2e /ton wood) [1.06 tCO_2e /ton charcoal]**
Industrial Retort Kiln (incl. Transport)	8.48	**6.32 tCO_2e/ ha (0.28 tCO_2e /ton wood) [0.85 tCO_2e /ton charcoal]**

In terms of GHG, it is advisable to shift from the use of mobile steel drum kilns to stationary industrial retort kilns as this would cut CO_2 emissions from charcoal production by half. Nevertheless, in this cradle-to-gate analysis, the production of charcoal is a source of emissions. When comparing the GHG impact per ton of utilized wood, the results range from 0.64 tCO_2e for Namibian traditional drum kilns to as low as 0.35 - 0.28 tCO_2e per ton of wood for a modern, stationary retort kiln.

With regards to the emission intensity of charcoal produced with these different kiln technologies, the traditional kiln used in Namibia results in 2.83 tCO_2e /ton charcoal over the 20-year period while retort kilns reduce the emission intensity in the range of 1.87 to 0.85 tCO_2e /ton charcoal. For this scenario, emissions from burning charcoal are not included because these are post-gate emissions and thus beyond the scope of this study.

[9] The following efficiency rates wood utilized / charcoal produced were used based on Demos Dracoulides (2018): Namibian traditional drum kiln 23%; retort kilns combined 33%

GHG Scenario 4: Use of fire wood

Scenario 4 shows the GHG balance when encroacher bush is harvested for fire wood use. Bush biomass, especially on community lands can be subject to such smallholder based utilization. An easy-to-apply rule of 50% with regards to removal is applied for smallholders on the limits of harvesting.

Furthermore, since firewood is most often harvested by hand, a stronger thinning scenario does not seem practical. This in turn means that there will not be any arboricide applied because smallholders are most likely to use bush biomass as a cheap resource and wouldn't want to invest resources into aftercare measures. We assume there is no final restoration success and therefore, also no additional livestock will be on the site.

This scenario is based on the following assumptions:

- 50% of total bush biomass is harvested per hectare, which resembles 9.31 t wood/ha and could also represent a typical scenario in communal areas where firewood is harvested over time in small quantities.
- Second harvesting cycle in year 7
- Manual harvest with saws and axes
- No aftercare
- No additional livestock
- No motorized transport

Table 14 shows the results of the analysis. Regrowth easily compensates for the emissions caused by the removal of wood. Since there is no restoration success, soil causes GHG emissions.

Table 14: Results Scenario 4 - Use of fire wood (negative values indicate carbon sequestration)

	Removal of wood	Regrowth	Average soil emissions	Total GHG balance
Emissions over 20 years (tCO_2e/ha)	32.1	-32.1	1.56	**1.56 tCO_2e/ ha**
	GHG balance per ton wood utilized →			**0.05 tCO_2e /ton wood**

Since fuelwood burning is not a clean reaction there are further post-gate emissions of Non-CO_2 GHGs such as CH_4 and N_2O. These powerful GHGs would contribute 3.54 tCO_2e/ha over 20 years in the utilization phase of the firewood. However, these emissions are beyond the scope of the study.

Scenario 4 represents a near neutral GHG balance calculation over 20 years. Firewood might be one of the biggest uses for bush biomass. However, firewood harvesting does not seem as a strategic control measure against large-scale bush encroachment because firewood collection is already a prevalent practice in Namibia.

GHG Scenario 5: Large-scale bush harvesting for electricity generation

One of the promising bush projects in Namibia is the utilization of bush biomass as substitution for imported electricity from the Southern African Power Pool, which is dominated by coal-fired plants. This would reduce energy dependencies on other countries and enable Namibia to invest into renewable energies as part of their climate action agenda. The common scenario is the establishment of several 20 MW power plants in Namibia.

This final pre-defined scenario is based on the following assumptions:

- 90% of total bush biomass harvested, which resembles harvesting 17.07 t wood/ha
- Large commercial scale mechanized harvesting and chipping (400 m³/day)
- Aftercare through application of arboricide, 1.2 kg active ingredient/ha based on van Eck and Swanepol (2008)
- Restoration success, leading to increased livestock stocking rate post harvesting (+213% from 22 to 66 kg animal biomass per ha) as well as to the return of grasses similar to the chemical control scenario. However, less organic inputs to the soil are considered since more biomass is harvested and actually removed from the sites.
- Transport distance (by truck): 100 km
- Loss of biomass until power generation in to chipping, transport, and handling: 10%
- Energy density in woodchips: 3500 kWh/t
- Efficiency rate of power plant: 22%
- Substitution effect as compared to electricity from the Namibian power mix of 2010 (WSP 2012)

Feasibility studies have shown a general excess of biomass and modelled two scenarios with different grades of mechanization (Cirrus Capital 2018). The harvesting rates by SAIEA (2015) propose to harvest all biomass until the ETTE of 2x annual rainfall below rates of 450 mm and 3x above 450 mm. In combination with the given stratification by our study, this results in average harvesting rate of 90%. This is by far the heaviest thinning scenario and has been used for this exemplary scenario as a showcase for rangeland restoration in combination with electricity production and heavy machinery. The 20 MW biomass power plant would require 106,500 t dry biomass per year (Cirrus Capital 2018). According to the biomass densities in this study, an area of 6,932 ha would need to be harvested every year. For the entire 20-year period this would amount to 138,645 ha of bush encroached land. We assume that this area of bush encroached land imposes an average transport distance of 100 km.

Since these power plants have not been built yet, it remains a hypothetical scenario. Furthermore, the required large-scale bush thinning scenario has not been in practice yet (de Wet 2015).

Table 15 Results Scenario 5: – Large-scale bush harvest for electricity production (negative values indicate carbon sequestration)

	Removal of wood	Regrowth with aftercare	Arboricide application	Average soil emissions	Livestock	Harvesting & Chipping	Transport	Substitution of fossil fuels	Total GHG balance
Emissions over 20 years (tCO_2e/ha)	29.43	-10.56	0.03	-6.56	4.63	0.3	0.9	-5.6	**12.57 tCO_2e / ha**
	GHG balance per ton wood utilized								**0.74 tCO_2e /ton wood**

The depicted substitution effect refers to the Namibian power mix in 2010. The strong substitution effect could even be further enhanced if Namibia expands its biomass power production and exports electricity to the Southern African Power Pool (SAPP). According to numbers of the UNFCCC (2018) substituting energy of the SAPP would result in a substitution effect of ca -12 tCO_2e/ha as compared to the above -5.6 tCO_2e. Sequestration occurs as a result of woody biomass growth of trees and through soil carbon sequestration. The overall GHG balance shows emissions of 12.57 tCO_2e per ha over 20 years or 0.74 tCO_2e per ton of bush biomass utilized.

The next chapter takes a closer look at the general ecosystem impacts of large-scale bush control in view of climate change before the presented ha-based bush control scenarios are up-scaled to a national level to compare current bush control activities with potential future scenarios.

4.4 Impacts of large-scale bush thinning and climate change on ecosystem services

Large-scale bush thinning imposes significant changes on ecosystem processes. However, the larger the impacts on the environment, the higher the uncertainties regarding the thinning operations and related value chains, especially taking into account the effects of climate change. The evaluations presented are the result of an extensive literature review and expert consultations, but cannot claim to understand these impacts to a full extent. They rather point out tendencies.

Table 16 summarizes the results from the literature review and expert consultations. This section first describes the current state of ecosystem services and the expected climate change effects in a baseline of bush encroachment in Namibia including the impacts on soil fertility. Next, the effects of large-scale bush control based on two exemplary scenarios rangeland restoration and bush farming are presented.

Bush encroachment baseline in view of climate change

One of the most important factors considering bush control is the effect on soil organic carbon, which is closely linked to soil fertility, due to the ability of SOC and SOM (soil organic matter) to bind water and nutrients. Increased bush biomass, as currently experienced in the bush encroachment creates sufficient organic inputs, but alters soil microbial communities and therefore reduces decomposition ratios, thus SOC and ultimately soil fertility in bush encroached areas (Buyer et al., 2016).

There are two main factors, expected to arise under climate change: an increased atmospheric CO_2 level and a large decrease in precipitation. The current average annual rainfall in Otjozondjupa is 417mm, according to the project stratification. Climate change projections expect a change of rainfall patterns towards more erratic rainfalls and changes in the precipitation rates of + 30 to -200mm (Kigotho, 2005).

Given the existing aridity of Namibia, a cut in half of precipitation would pose high risks for the ecosystems. Considering that certain tree species can retrieve water at higher soil pressures (at less plant available water) than grasses (Smit & Rethmann, 2000) and higher CO_2 concentrations, which benefit C3 plants more than C4 (thus trees over grasses), a further decrease in SOC and thus soil fertility can be expected under a climate change scenario with bush encroachment (Wolfe and Erickson, 1993).

In fact, C3 plants will increase their growth efficiency by about 20-35% under elevated CO_2 concentrations, while C4 plants will only by 10% (Wolfe and Erickson, 1993), which benefits the growth of bush over grass, most likely irrespective of the management scenario.

Table 16: Impacts of bush control and climate change on ecosystem services

Ecosystem service	Bush encroach-ment (Baseline)	Bush control (Rangeland)	Bush control (Bush farming)
Soil			
SOC	↘	↗	↘
Fertility	↘	↗	↘
Physical properties	→	→	↘
Nutrients	↗	↘	↗
Microbial life	→	↗	→
Decomposition	↓	↑	↓
Erosion	↗	↘	→
Water			
Interception	↑	↓	↑
Groundwater	↓	↑	↓
Surface water	↗	→	↗
Soil moisture/ Plant available water	↓	↑	↓
Woody (C3) – Water use efficiency	↓	↗	→
Grass (C4) – Water use efficiency	↓	↑	↓
Biomass			
Tree/ Shrub	↑	↓	→
Grass	↓	↑	↗
Growth			
Tree/ Shrub	↑	↗	↑
Grass	↓	↑	↗
Biodiversity			
Plants	↓	↑	↓
Mammals	↘	↗	↘
Birds	↘	↗	↘
Invertebrates	↓	↑	↓
Grazing			
Palatable grass	↓	↑	↘
Livestock/ LSU	↓	↑	↘

Legend

Impact of climate change on ecosystem service		Impact of management on ecosystem service	
	Strong increase	↑	Strong increase
	Medium increase	↗	Medium increase
	No change or high uncertainties	→	No change or high uncertainties
	Medium decrease	↘	Medium decrease
	Strong decrease	↓	Strong decrease

Source: UNIQUE

Due to the expected reduced rainfall and strong bush growth, SOC and thus fertility are expected to decrease under climate change conditions. Microbial life in encroached sites compared to savannas/rangelands, as was mentioned before is reduced, but the process will not deteriorate further (Buyer et al., 2016). Plant available nutrients however increase with bush encroachment, due to the nitrogen fixing abilities of most bush species and the deeper roots reaching out to nutrients not reachable for grass (Smit, 2004). Under climate change with elevated CO_2 concentrations an increased bush growth will lead to further fixation of nitrogen. The last soil factor to be considered is soil erosion. Under bush encroachment increased soil erosion can be observed, due to bare areas between bushes, which are prone to wind erosion (Manjoro et al., 2012).

Water is an essential ecosystem service, which gains special attention in the arid conditions of Namibia. Rainfall occurs commonly as erratic, mosaic-distributed patterns and is important for plant growth and groundwater recharge. Bush encroachment impacts all water related ecosystem services due to interception. Interception is the direct evaporation from the leaf surface. Bush has larger leaf surface areas compared to grass and thus interception gains importance, when bush growth dominates. Studies have shown, that bush densities of 9,000 trees per ha can intercept a 60 mm rain event without enabling water to percolate into the soil (Bockmühl, 2006). In comparison to this, in open savannas approximately one third of the percolated water will replenish groundwater resources (Groengroeft et al., 2018). Thus, interception is increasing under bush encroachment and climate change and changing rainfall patterns with high interception rates will reduce groundwater recharge as well as overall soil moisture.

Interesting is the water use efficiency (WUE) of plants: High encroachment, with a high interception leads to less available plant water and thus to a decrease in water use efficiency for both C3 and C4 plants. However, the elevated CO_2 concentrations under climate change enables plants to reduce the duration of stomata opening which reduces stomata water loss (evaporation). This reduces the overall need of water for plants and contributes to the growth efficiency increase of grass and even more of bush species (Cernusak et al., 2013).

Biodiversity is negatively affected by bush encroachment as a result of the reduced original habitat, compared to open savanna conditions. Especially the botanical biodiversity is negatively affected by bush encroachment (de Klerk, 2004). However, the effects of climate change on biodiversity are too uncertain to allow for better projections. The strong effects of reduced rainfall and the possibility of a severe ecosystem change might lead to further decreases in biodiversity.

Many studies show the direct link between bush encroachment and livestock grazing. Bush encroachment reduces the amount of palatable grass, which leads to reduced livestock grazing (Kotzé, 2015; SAIEA, 2016). Climate change, especially the stronger growth of bush and less available rain will decrease the potential livestock stocking rates.

Impact of bush control on soil fertility

Bush control can have various impacts on soil fertility. The main factor is not whether the area is managed, but rather how the area is managed. Two exemplary bush control options were assessed: Rangeland restoration and bush farming (biomass utilization; NNF, 2016). In the worst case the management of bush control fails resulting into desertification with lower bush biomass, without grass establishment and bare areas (Ward, 2005).

Soil fertility is influenced by available water and nutrients as well as degradable biomass. The main indicator is soil organic matter (SOM) and in a broader sense soil organic carbon (SOC), which origins from decomposed organic matter. The absence of such organic inputs results in lower amounts of SOM und thus also lower soil fertility.

Rangeland restoration – Soil fertility

The organic inputs can be either decomposing roots, leaves or wood. After a harvesting operation, initially more biomass is left on the site as a result of the harvesting. This can be leaves, stumps and especially fine roots from dead stumps (after arboricide application). Therefore, organic inputs increase and therefore also SOC should increase. However, initially microbial communities of the encroached sites might dominate the decomposition. As SOC is connected to fertility (Gauquelin et al., 1998), a fully successful rangeland restoration will reach SOC equilibrium and pre-encroached fertility similar to a reference savanna ecosystem.

In general, SOC requires a long times to change. A study by Potter et al. (1999) claims that it might take up to centuries for degraded prairielands in the US to restore. A study by Nijbroek et al. (2015) found higher SOC concentrations in areas transformed to grassland after encroachment, compared to encroached areas with a time duration of 16 years.

Harvesting intensity and aftercare are crucial management tools, as they determine restoration success or failure, due to the amount of bare areas or the successful re-introduction of a grass layer. If the management not implemented in a sustainable manner the entire area may degrade further, with lower biomass growth (wood) and no establishment of perennial and palatable grasses (Zimmermann et al., 2017). Large bare areas are prone to wind erosion and nutrient leaching. Grasses will establish as patches and grow by time together to a continuous vegetation cover (Ward, 2005).

A study from Spain found a SOC decrease of 31% after 9 years since harvesting occurred (Martinez-Mena et al., 2002). Furthermore, an estimated 0.02 Mt C/ha/year got lost due to erosion and higher soil temperatures (Martinez-Mena et al., 2002). Lower SOC also decreases the water holding capacity of the soil (Olness and Archer, 2005). Studies also suggest difficulties by replenishing the nutrients taken from the site by harvest activities (Zimmermann et al., 2017). Therefore, the implementation of successful rangeland restoration is important for the desired ecosystem benefits.

Given the uncertain influence of climate change on soil fertility makes it difficult to estimate the final concluding impacts on soil fertility. The following graph presents the soil modelling results conducted in this study. It shows the annual SOC changes under different bush biomass removal rates (see Table 5) and under different post harvesting management activities.

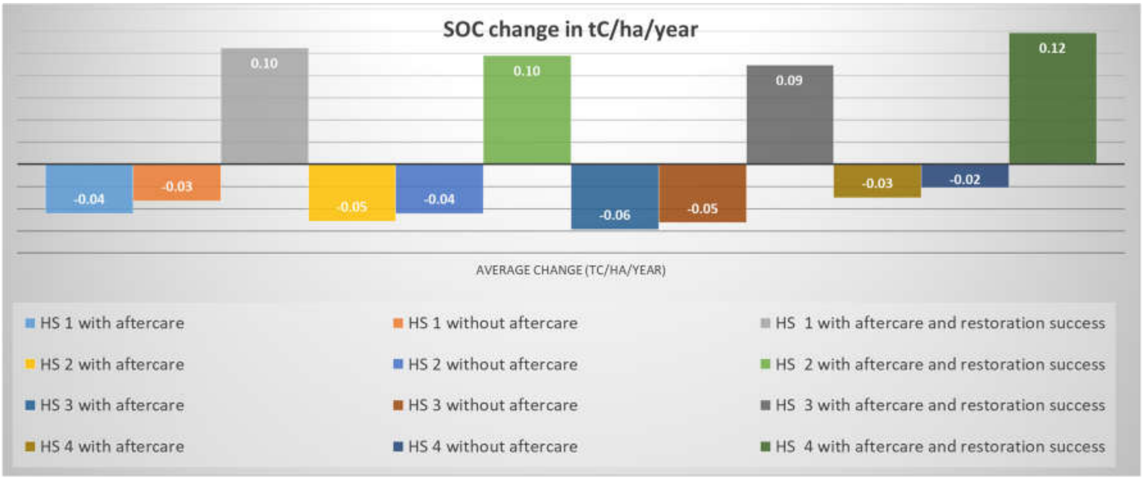

Figure 11: SOC changes for the different harvesting removal scenarios under different assumptions of post-harvesting management

Source: UNIQUE

It basically confirms that only under the assumption of aftercare and savanna restoration success SOC is increasing (sequestration), and the highest SOC increase is under a moderate harvesting of 50% bush biomass leading to 0.12 tC/ ha/ year or 0.44 tCO_2e/ ha/ year respectively.

Bush farming – Soil fertility

Bush farming focuses on the regrowth of bush biomass. This will have major impacts on SOC maintenance and management. The area under bush farming will be managed homogeneously, if restoration and thus livestock farming is not anymore the major management goal. This contrasts the patchy mosaic landscapes in an ideal savanna ecosystem (Ward, 2005). It is also likely that arboricides will not be applied, in order to facilitate the regrowth from stumps. As a result, less roots will decompose, compared to the restoration scenario, leading to a maintenance of SOC values, rather than an increase. Bush encroachment leads to increased SOC contents on drier sites, while wetter sites lose SOC and thus soil fertility (Jackson et al., 2002).

Also other studies found more carbon below woody plants than below grasses (Gill & Burke, 1999, Hibbard et al., 2001). However, the soil type has a huge impact on the carbon sequestration potential of savannas (Hudak et al., 2003). Worldwide bush encroachment increased SOC in semi-arid regions with sandy soils, but decreased SOC on silty or clay soils. In the project region approximately 47% are sandy soils (Arenosols). SOC seems to generally correlate with precipitation, temperature and bulk density, while it is negatively correlated with nitrogen availability (Li et al., 2016). This contradicts the findings by Nijbroek (2016), who found higher SOC contents in grasslands than in encroached areas, which might be due to the large variety of soils. The findings by Nijbroek (2016) are based on direct samples in the project region, as well as measured on a time horizon, which should show differences in the SOC development (16 years). The variety of factors that influence the SOC content (grazing management, age of trees) make it difficult to generalize facts. However, we believe that bush farming will not leave trees to grow to their full size and thus the high SOC contents as observed in other studies cannot be reached.

In conclusion, we expect only a smaller temporal decrease of SOC that also recovers faster, compared to the rangeland restoration scenario (Figure 12b). Due to the re-growth from stumps, grasses will only establish temporarily. Following Nijbroek (2016), SOC contents will not increase as much as in the rangeland scenario. We expect the bulk density to increase and face more compaction on the long-run, due to use of machinery for harvesting.

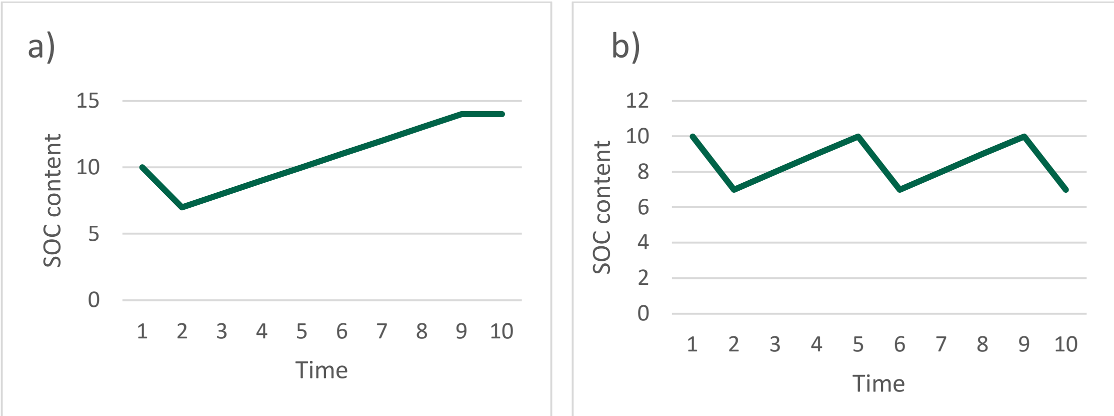

Figure 12: Theoretical SOC content development after disturbance in rangeland restoration (a) and bush farming (b).

Source: UNIQUE

Both scales, time and SOC content show relative differences, not absolute values (years or percent). SOC under bush farming increases fast, due to no application of arboricides to facilitate bush growth, while the rangeland restoration scenario will ultimately reach higher SOC concentrations, but a functioning grass cover needs some time to evolve and to produce organic soil inputs.

Rangeland restoration – ecosystem impacts

While soil fertility and SOC content increase in the rangeland restoration scenario, the nutrient availability will decrease, considering plant available nitrogen. Most bush species fix atmospheric nitrogen and contribute to a nutrient enhancement of the site (Smit, 2004). Microbial life and decomposition are likely to increase with the restoration of rangelands/savannas (Buyer et al, 2016). The impact of climate change is too uncertain, given the effects of rainfall and bush growth efficiency increase, as mentioned before. However, most ecosystem services will likely have a higher/positive level than under bush encroachment or bush farming scenarios.

Depending on the harvest intensity more or less biomass will be extracted from the site resulting in lower bush densities. This will decrease by default the amount of interception, depending on the leftover leaf biomass. Under climate change an increased growth of bush biomass might increase interception again. Closely linked with interception is groundwater levels and recharge (Stafford et al., 2017). If bush biomass is reduced, also interception gets reduced and thus more water can percolate and contribute to groundwater recharge. Precipitation is expected to decrease so strongly, that even under rangeland restoration conditions groundwater might not necessarily benefit, but will not suffer as much as under bush farming or even encroachment.

Surface water likely maintains its rates, while less rainfall might also decrease this ecosystem service (de Klerk, 2004). Due to lower rates of interception, also soil moisture and plant available water will increase under the rangeland restoration scenario. The water use efficiency development stays the same for bush and grass under climate change conditions, as this process is largely independent of the management. In the rangeland restoration scenario sufficient water can also contribute to an increase of WUE while under encroachment water gets scarce and thus will increase competition and therefore might decrease also the WUE.

The impacts of rangeland restoration on biodiversity are clearly positive. The effect of climate change remains uncertain, as was mentioned in the encroachment scenario. Grazing is an important part of savanna rangelands. These ecosystems are adapted to intense, but temporal grazing/browsing, caused by mega-herbivores (Ward, 2005). The savanna mega-herbivores were well adapted to the ecosystem, by browsing on grass competing vegetation, such as bush (Oliveras, 2016), and grazing with a high intensity for a very short time (Kotze, 2015).

Restoring rangelands depends on the successful establishment of grassy vegetation. These grass species however need browsing for establishment. Restoration without grazing may therefore lead to a weak grass establishment or the establishment of annual grass species, instead of perennial species (Ward, 2005). Improving grassland management with high intensity grazing also can boost SOC increase by 0.47 t C/ha/year (Conant et al., 2017).

Restoring rangelands is challenging, but there is no doubt about a positive and increasing effect on palatable grass establishment and livestock carrying capacities. In fact, most authors expect at least a doubling of the carrying capacity with rangeland restoration (Directorate of Veterinary Services, 2015; In Stafford et al., 2017).

Bush farming – ecosystem impacts

As illustrated in

Table 16, most impacts of bush farming on ecosystem services are approximately the same as mentioned in the bush encroachment. This is due to the nature of this scenario, as bush farming manages bush encroachment more intensively, but maintains the overall impacts as bush encroachment, because it does not control bush, but utilizes it permanently. Bush farming means to harvest bush for the purpose of biomass utilization. The bush is harvested in short rotations and the regrowth is not hampered by the application of arboricides.
Regarding climate change, the effects in the bush farming scenario lies between the bush encroachment and the rangeland restoration scenarios, as the continuous harvesting interrupts the normal growth of bush and enables temporarily the introduction of grasses with all mentioned effects in the chapters above.

Therefore, it can be concluded that the bush farming scenario will only allow temporary livestock grazing, due to the potential fast regrowth of bush. The case of establishing grass under such a scenario is still tied to a lot of uncertainty. However, the establishment of grass in this scenario is not the main objective. Finally, it can be concluded that rangeland restoration, although uncertainties persist lead to a more resilient ecosystem, increased biodiversity and increases in groundwater, as well as soil fertility.

4.5 National GHG baseline and future bush utilization scenarios

In this chapter, we used the ha-based GHG scenario results to assess the GHG emission and removals on a national level both under current (baseline) conditions of bush control as well as for selected future utilization scenarios. The results are always shown in a 20 years' timeframe, implying that bush control activities are implemented annually on specified areas. For the baseline, bush control implementation areas, the figures presented in chapter 4.1 are used. Studies (SAIEA, 2018) claim that between 30 and 45 million ha of former savannas are currently encroached by bush. A total area of 45 Mio ha of encroached bush systems in Namibia is assumed.

In addition to the GHG balances of the bush utilization scenarios, carbon sequestration as a result of new annual encroachment is also considered. Honsbein (2016) estimates a bush encroachment rate of 3.18% without harvesting intervention resulting in the prediction that all livestock production areas of 51.5 Mio ha would be covered by bush in approximately 2035. In this study, we used this general assumption to assess the annual bush encroachment rate until 2035, i.e. 0.43 Mio ha. For this encroachment rate we further derived a conservative carbon sequestration rate of -0.61 tCO_2e/ ha/ year which reflects 50% of the average bush growth rate of all ha-based scenarios in this study. This conservative rate is assumed to also represent all bush systems including bush encroachment with low biomass species.

Since no additional growth of already encroached bush areas is assumed, this results in a conservative assumption[10] to reflect the carbon sink capacity of the bush biomass in Namibia.

The baseline scenario shown in Table 17 assumes an annual implementation of bush control on 198,510 ha (GIZ 2014).

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[10] Even if this rate of new encroachment might be smaller, this value can be also considered as equivalent area increase to reflect the potential growth of already existing bush systems.

Table 17: Baseline scenario – bush control activities and GHG emissions over 20 years default period

Bush control activity	Area implemented per year (ha)	Average emission factor applied (tCO_2e/ha/year)	Total Annual Emissions (Mio tCO_2e/ year)	Total Emissions/ removals after 20 years (Mio tCO_2e)
Bush chemically controlled (no wood recovery)	68,000	0.3	0.42	8.49
Aftercare (does not contribute to utilization)	7,500	-0.4	-0.05	-1.07
Bush used for biomass processing: charcoal w. trad. kiln	121,810	0.7	1.75	34.98
Bush used for biomass processing: wood chips	1,200	0.4	0.01	0.20
3% bush growth and encroachment	433,333	-0.6	-4.2	-84.81
Total GHG balance			-2.11	-42.20

Figure 13 gives an overview of the results after 20 years.

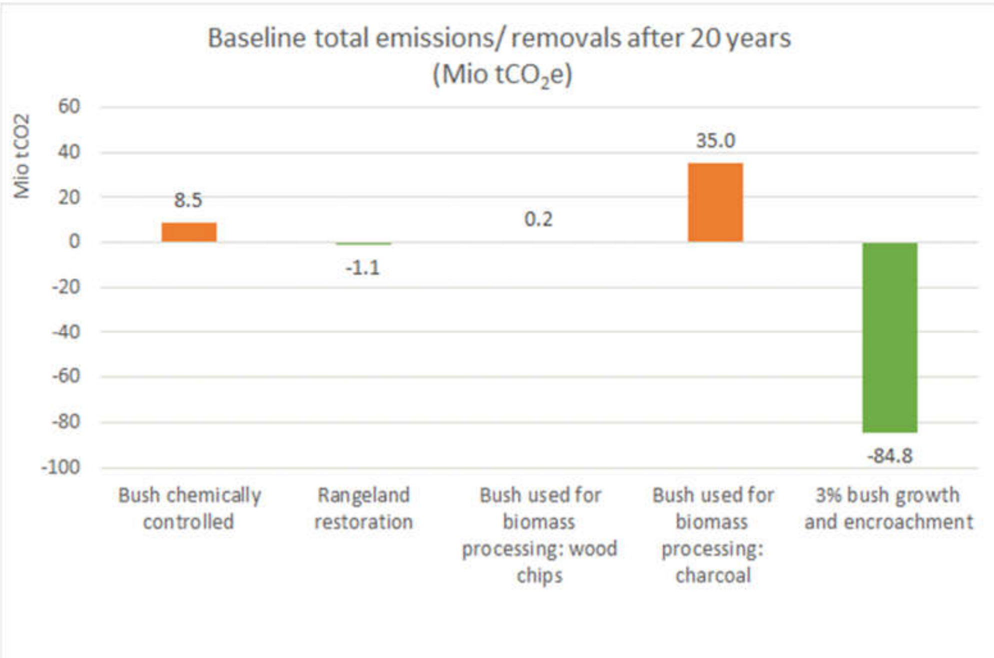


Figure 13: Overview total emissions and removals of baseline bush control activities compared to carbon sink of bush growth and encroachment over 20 years; values are given in Mio tCO_2e, negative values indicate carbon removals.

The chemically controlled bush represents a significant source of emissions in a 20-year baseline scenario, with total emissions of 8.5 Mio tCO_2e, or annually 0.42 Mio tCO_2e. High significance can be seen for the charcoal production using traditional kiln technology with a total of 35 Mio tCO_2e after 20 years and 1.75 Mio tCO_2e per year. Both of these activities provide an opportunity for emission reduction if the aerial chemical control is replaced by aftercare measures (including the precision use of arboricides to tree stumps) leading to a rangeland restoration. Nevertheless, the baseline is still showing a net sink given the huge growth and encroachment sink, i.e. - 42.2 Mio tCO_2e of net removals after 20 years or -2.1 Mio tCO_2e on an annual basis.

These results reflect emissions and removals over 20 years for each of the activities including regrowth potential of the bush and/or grass after utilization, soil organic carbon losses or gains etc. In comparison to this, it is also interesting to assess the GHG footprint of the bush utilization along the value chain without the effects over time. For this, the latest NIR 3 report provides a good summary of wood removals in a given year for the different bush control activities. By applying the accounting tool developed for this study, the emissions due to removal of biomass, the emissions during biomass utilization processes and the total footprint of each utilization activity were calculated (Table 18).

Table 18: 5 years averages of wood removals 2010 – 2014 based on Table 6.17 of the NIR 3; all values in t biomass (wood)

	Charcoal production	**Fuelwood**	**Poles removal**	**Bushblok**	**Industrial consumption**
5-year average annual removal biomass (t wood)	529,857	222,269[11]	141,248[12]	8,000	28,000
Emissions due to removal of biomass (tCO_2e)	913,120	383,044	243,417	13,787	48,253
Emissions of utilization (tCO_2e)	694,232	5,134,419	-[13]	1,127	-16168[14]
Total footprint of utilization activity (tCO_2e)	1,607,351	5,517,462	243,417	14,913	32,085
Total	**7,415,229 Mio tCO_2e or 7.41 Gg CO_2e**				

In total, the average annual emissions of all the different baseline activities amount to 7.4 Mio t CO_2e. When comparing this to the total AFOLU emissions of the NIR 3, it is lower than the 5-year

[11] Fuelwood exported and fuelwood collected is combined
[12] Based on the NIR 3, 70% of the total average removal of poles is from the open wood land category, i.e. bush systems
[13] No emissions for processing are assumed due to lack of information
[14] This scenario assumes energy substitution effect

average for the total sector being 11.4 Mio tCO_2e. This is realistic since the AFOLU sector in the NIR 3 also includes emission from forestry and livestock.

Future Scenario I

As mentioned above, there exists a significant mitigation potential in the baseline scenario if the chemical bush control is replaced by rangeland restoration approach. By maintaining the overall areas under bush control, however, now implementing rangeland restoration on 68,000 ha annually results in an overall mitigation potential of 9.7 Mio t CO_2 over 20 years, or 0.5 Mio tCO_2e annually. An increase in soil organic carbon as a result of successful rangeland restoration with more than 13.4 Mio tCO_2e being sequestered over 20 years has significant positive impacts with regards to climate change adaptation as the soils will be more resilient and productive. In addition, the establishment of a 20 MW power plant is also considered under this scenario which requires annually 6,932 ha for biomass supply.

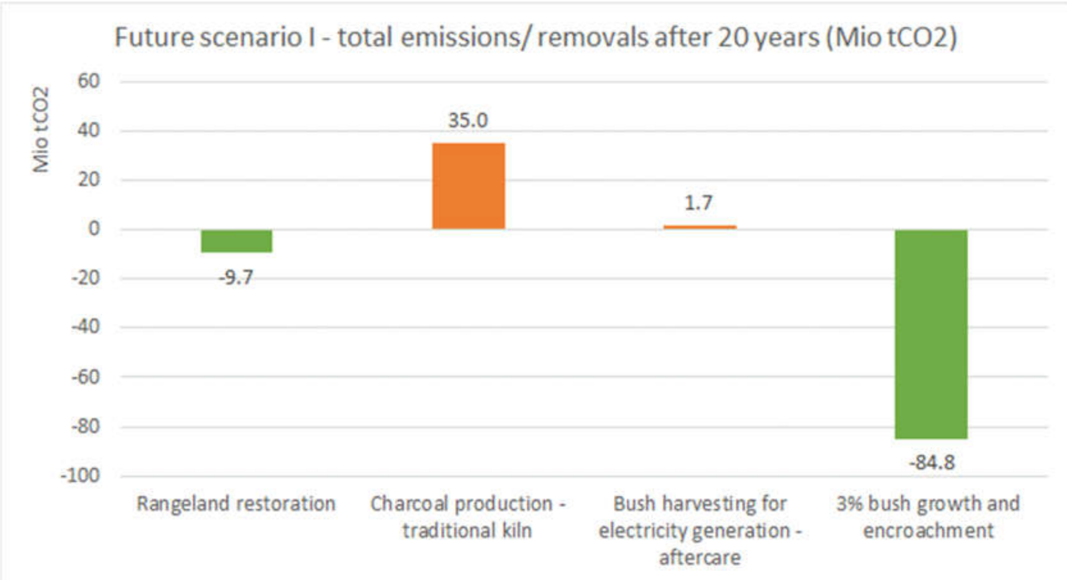


Figure 14: Overview total emissions and removals of baseline bush control activities where chemical control is replaced by rangeland restoration.

Future Scenario II

Based on literature and interviews during field consultation with national experts of the different bush control activities, a future national bush control and utilization scenario is presented here for an up-scaled large-scale bush control expecting an increase in charcoal production to 320,000 ha per annum. It is furthermore assumed that 270,000 ha of bush are utilized with the traditional kiln technology while another 50,000 ha is implemented with an advanced stationary retort kiln technology. 130,000 ha annually are successfully restored towards a more savanna ecosystem by consequently applying precision arboricide application as aftercare (1.2 kg active ingredient per ha). Restoration success is assumed with the return of perennial grasses which also contributes significantly to the increase of soil fertility and soil organic carbon sequestration. The biomass is used for different uses, such as bushbloks, bush-to-feed applications and, if realistic, pellet production.

Furthermore, Stafford et al. (2016) mentions NamPower to increase their electricity capacities by 170 MW fueled by biomass, although prefeasibility studies by NamPower itself only calculated the impact and biomass requirements for one 20MW biomass power plant (Cirrus Capital, 2018). In order to show options for future developments the requirements and impacts of 170MW extra biomass power are modelled here, using the assumption to use 58,924 ha annually. Table 19 summarizes this future scenario and Figure 15 provides the total overview of the GHG balance of each of the activities. Similar to the baseline, GHG emissions and removals are compared against the carbon sink potential of bush growth and encroachment using the same 3 % increase assumption.

Table 19: Up-scaled future bush control and utilization scenario over the 20 years default period; negative values indicate carbon removals or emission reduction as a result of substituting electricity generation

Bush control activity	Area implemented per year (ha)	Average emission factor applied (tCO_2e/ha/year)	Total Annual Emissions (Mio tCO_2e/year)	Total Emissions / removals after 20 years (Mio tCO_2e)
Rangeland restoration	130,000	-0.4	-0.92	-18.47
Charcoal - traditional kiln	270,000	0.7	3.88	77.55
Charcoal - retort kiln	50,000	0.3	0.32	6.32
Bush farming for electricity generation - no aftercare	58,924	0.6	0.74	14.81
3% bush growth and encroachment	433,333	-0.6	-4.2	-84.81
Total balance			-0.23	-4.6

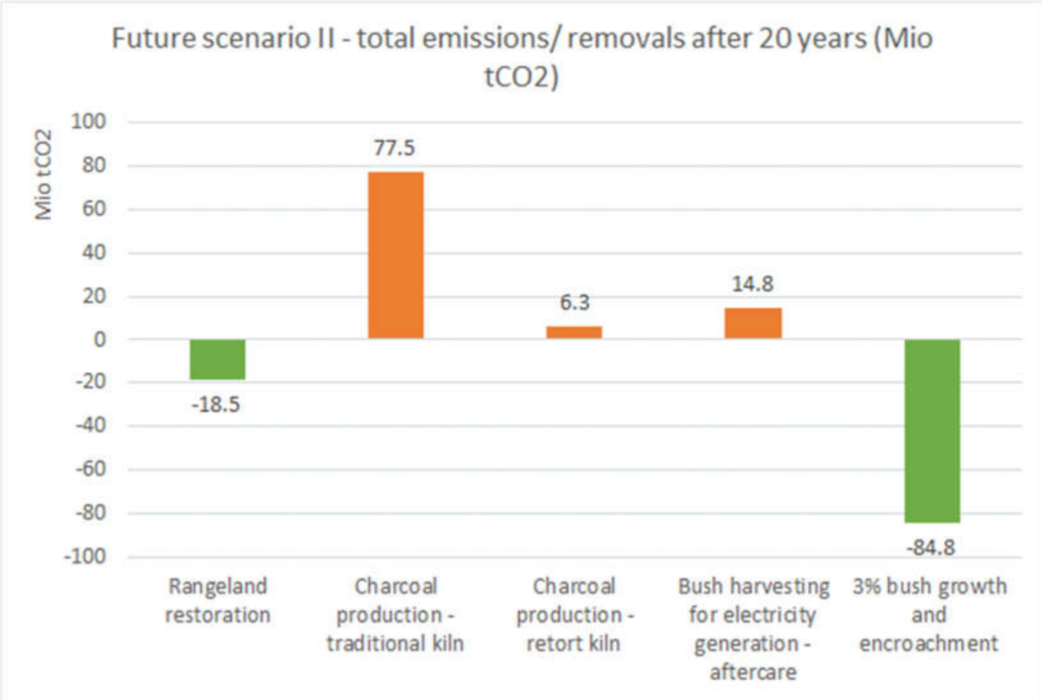


Figure 15: Overview total emissions and removals of future bush control activities compared to carbon sink of bush growth and encroachment over 20 years.

In total, all utilizations and harvest options in the future scenario would require the biomass of around 508,924 ha per year. The largest emission source would still be the traditional charcoal sector with 77.5 Mio tCO_2e over 20 years. Compared to this, advanced kiln methodologies would emit 6.3 Mio tCO_2e over the same period. Annual emission for the charcoal sector would amount to 3.9 Mio tCO_2e and 0.3 Mio tCO_2e respectively.

Electricity generation would result in 14.8 Mio tCO_2e of emissions over 20 years or 0.7 Mio tCO_2e annually with a substitution effect of -6.6 Mio tCO_2e or -0.3 Mio tCO_2e annually. Factoring in the 3% bush growth and encroachment, the net GHG result of this future scenario would almost result in a carbon neutral situation with a sink of annually 0.2 Mio tCO_2e. Since most of the 45 Mio. ha of bush systems still would remain without control and utilization, the carbon sink is potentially much higher.

5 CONCLUSIONS

This section summarizes the findings of the study, draws conclusions and provides recommendations. It is important to highlight again that this study is meant as a technical guidance document which used the logic of pre-defined bush control scenarios all the way from pre-defined harvesting rates, potential harvesting options and bush biomass utilization pathways. The selection of these pre-defined bush control and biomass utilization scenarios was based on national stakeholder consultations as well as extensive literature review. However, these scenarios should not be viewed as a policy recommendation with regards to future bush control action planning in Namibia.

The GHG balances first presented as ha-based models and then up-scaled to a national level only show the technical GHG balances and potential mitigation options. In order to derive policy recommendations for future bush control activities in Namibia the study results should be further assessed in the frame of an economic assessment. Furthermore and in view of the high vulnerability of Namibia against future climate change, it is highly recommended to also conduct a similar study for climate change adaptation benefits and trade-offs using the scenarios of this study as a starting point.

When directly comparing the pre-defined ha-based bush control scenarios (Table 20) over a default period of 20 years, it can be concluded that the highest emissions are caused in charcoal production when using a traditional Namibian steel drum kiln. If charcoal is produced in industrial retort kilns, emissions drop to levels below the ones of bush farming. Despite the substitution effect of electricity generation from bush biomass, this scenario also result in some GHG emissions over 20 years.

The rangeland restoration scenario represents the only real mitigation activity and with the various benefits associated to rangeland restoration, this activity might offer a climate-friendly way to restore former savanna rangeland. The study shows that sequestration of SOC more than compensates for the emissions from increased livestock densities over the modelling period - provided that restoration is successful and perennial grasses reestablish on formerly bush encroached land. This offers further possibilities to ameliorate economics in Namibia by benefitting the livestock sector in a climate-friendly way.

The current activity of chemical bush control also to some extent results in restoration effects, however, on a smaller scale compared to the defined restoration scenario. There exists a significant mitigation potential if the chemical bush control is replaced by rangeland restoration as defined in this study. This could be even developed under a carbon crediting scheme which allows to incentivize land users the shift towards rangeland restoration.

Use of bush biomass for firewood resembles a low emission land management scenario. However, it does not seem to provide a significant change in the landscape because firewood has been collected in the past and still bush encroachment is continuing.

Table 20 Summary of ha-based bush control scenarios

	GHG scenario 0: Bush chemically controlled (no wood recovery)	GHG scenario 1: Rangeland restoration & bushblok, bush-to-feed or pellet production	GHG scenario 2: Bush farming & bushblok production	GHG Scenario 3: Medium-scale charcoal production (traditional kiln / improved retort kiln)	Scenario 4: Use of firewood	GHG Scenario 5: Large-scale bush harvesting for electricity generation
Total Emissions over 20 years (tCO_2e/ha)	6.24	-7.10	8.26	14.36 / 6.32	1.56	12.57

The GHG balances in this study end at the factory gate. Some scenarios may benefit from substitution effects beyond the factory gate. Especially wood pellets and charcoal can produce substitution effects globally if these replace fossil fuels. However, one has to also see if or where these substitution effects will be accounted for. If Namibia exports wood pellets, the substitution effect will not be accounted for in Namibia's carbon balance according to IPCC 2006 logic on national GHG inventories. Also, the export of charcoal for household use in other countries will not produce a substitution effect within Namibia, if at all. Therefore, these products are rather a liability for Namibia in its carbon balance.

Of course, harvesting regimes and utilization scenarios can be arranged differently than from how it is presented in these pre-defined scenarios. For example, rangeland restoration could be combined with electricity production. The large-scale harvesting operations necessary for sufficient biomass supply pose a strong option to counteract bush encroachment. Transport might pose an economic barrier to such a strategy. However, in terms of GHG it is a very feasible option because transport emissions are marginal. In certain cases, transport emissions are a good climatic "investment". For example, transport emissions for wood being delivered to stationary kilns are more than compensated by the lower emission balance of stationary kilns as compared to mobile ones.

After successful piloting of a biomass power plant, the concept could be up-scaled and transport costs could be subsidized to catalyze carbon-neutral or even carbon-saving rangeland restoration. Surplus electricity from bush biomass could be exported to the SAPP and generate even higher climate benefits for Southern Africa, moving away from carbon-intensive fossil fuel electricity.

Suitable ha-based scenarios were then used to assess the GHG balance on a national level first for a baseline with current bush control activities on a total annual implementation area of 198,510 ha. This highest emissions in the baseline over the same 20-year period is caused by the charcoal sector, however, the total 35 Mio tCO_2e are more than compensated by the sequestration of bush biomass of newly encroached areas as well as growth of existing bush systems (-85 Mio tCO_2e). This is realistic as the bush control activities causing emissions would occur on approx. 4 Mio ha over 20 years, which is still only 9% of the total actual encroached area of 45 Mio ha in Namibia.

In a first future bush control scenario with more or less the same baseline implementation areas, a mitigation potential is shown by shifting from chemical control to a more ecological restoration approach. A second future bush control scenario increases the total annual implementation area to 538,924 ha which includes an increase of annual restoration (130,000 ha), charcoal production both with traditional and improved retort kiln technology (350,000 ha), as well as the electricity generation of 170 MW from bush biomass (58,924 ha). This bush control would amount to 10.8 Mio ha over 20 years representing 23% of the total bush encroached area. This scenario still results in a net sink of almost -5 Mio tCO_2e as a result of additional encroachment and bush growth.

In the following, this study presents some key recommendations drawn from the GHG assessment as well as from the consultations, discussion, meeting and workshops conducted in Namibia in the frame of this study.

Develop National Bush Management and Information System

This study compiled a bush accounting database based on spatial explicit information as well as national, regional and global default values in order to systematically account for carbon stocks in bush systems to assess GHG emissions along different bush management value chains. In line with the IPCC Good practice Guidance, this accounting database follows a Tier 2/3 approach. At the same time, a high resolution GIS study is conducted in Namibia leading to a Bush Information System in the near future.

Given the importance of the bush encroachment in Namibia and the need for a national paradigm shift in the bush management sector, the accounting logic of this study should be combined with the bush information system study to develop a National Bush Management and Information System. This system should allow to combine spatial information on bush encroachment on a national level with activity data on bush control activities and emission factors along their different value chains. It could be designed as a dynamic system to monitor bush control activities (for instance through the development of user-friendly applications on smartphones) as well as to provide recommendations and information back to the bush sector stakeholders on aspects such as spatially explicit optimal harvesting rates, management guidance, regulations, etc.

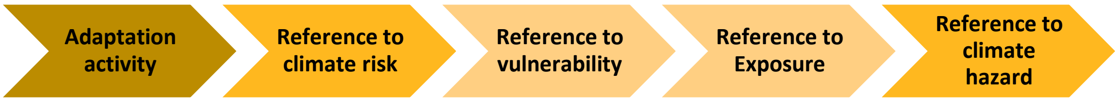
The monitoring data can then be used to measure bush control activities and assess their impacts on different jurisdictional levels. This can be combined and lined also to the assessment of other ecosystem services including climate change adaptation, water or biodiversity. Through this system, the sector also becomes ‘ready’ to integrate the accounting in the wider national GHG inventory (as well as other national reporting requirements) and the future enhanced transparency framework under the UNFCCC.

Conduct climate change adaptation study for the bush sector

Assessing mitigation impacts of different bush control activities can only be done in view of the high climate change vulnerability of Namibia and the strong need to adapt to its adverse effects, in particular in the bush sector which is economically linked to many other sectors such as livestock, agriculture and tourism. Therefore a larger climate change adaptation study is recommended to assess impacts in line with the Climate Risk and Vulnerability Assessment Framework of the IPCC (AR5). Following this framework for assessing climate risks and vulnerability, the following factors and analytical steps should be considered to evaluate the adaptation impact of bush control activities: (1) apparent climate signals (2) climate hazard and direct (physical) impacts, (3) exposure and (4) vulnerability. These factors should be defined and assessed as a linear climate impact chain with a clearly defined climate risk as the outcome for which specific bush control activities can be assessed in terms of their impact by again developing a specific adaptation impact chain.

1. A simplified **linear climate impact chain** in line with IPCC

2. An **impact chain** separately for each identified/ proposed bush control adaptation activity



Such a study is relevant also for tapping into climate finance such as the GCF with regards to a bush sector transformation since the adaptation and mitigation reliance of bush control activities most likely result in a cross-cutting approach.

Recommendations related to the study results

- The mitigation potential by shifting from chemical bush control to a more intensive rangeland restoration should be further assessed also in terms of developing a carbon crediting scheme also under the voluntary carbon market. The VCS (Verra) Standard allows to also account for removals and emission reductions in agricultural landscapes (since bush systems in Namibia are not defined as forests) considering a range of sources and sinks including the accounting for soil organic carbon.
- In general, all bush control scenarios which actively increase soil fertility through soil carbon sequestration should be promoted on a national level. This could be combined with a wider restoration approach including wetland restoration to establish more diverse conditions in favor of grasses.
- Bush-to-feed systems should be assessed more in terms of potential emission reductions of the livestock sector.

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ANNEX 1 BUSH MANAGEMENT SCENARIOS – ANNUAL RESULTS OVER 20 YEARS

Scenario 0 Bush chemically controlled (no wood recovery) - with increased livestock

negative number means carbon sequestration or emission reduction

		Emissions in (tCO2e/ha)												
Year	Area (ha)	Biomass removal	Remaining Bush Biomass	Regrowth Grass Biomass		Harvesting /Chipping	Average soil	Arboricide	Transport	Livestock	Pellet production	Substitution fossil fuels	Total Annual Emissions (tCO2e/ha)	Cumulative emissions (tCO2e/ha)
1	1	1.2	-0.53	-0.5			-0.10	0.12					0.17	0.17
2	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	0.49
3	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	0.81
4	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	1.13
5	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	1.45
6	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	1.77
7	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	2.09
8	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	2.41
9	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	2.73
10	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	3.05
11	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	3.37
12	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	3.69
13	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	4.00
14	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	4.32
15	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	4.64
16	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	4.96
17	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	5.28
18	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	5.60
19	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	5.92
20	1	1.2	-0.53	-0.5			-0.10			0.26			0.32	6.24
Total emissions 20 years		23.90	-10.51	-10.27		0	-2.00	0.12	0	5.01	0	0	**6.24**	
												Emission factor (tCO2e/year)	0.312	

Scenario 1 Rangeland restoration with arboricide application

negative number means carbon sequestration or emission reduction

		Emissions in (tCO2e/ha)											
Year	Area (ha)	Biomass removal	Regrowth Biomass	Regrowth Grass Biomass	Harvesting/Chipping	Average soil	Arboricide	Transport	Livestock	Pellet production	Substitution fossil fuels	Total Annual Emissions (tCO2e/ha)	Cumulative emissions (tCO2e/ha)
1	1	22.7	-1.12	-0.51	0.22	-0.49	0.03	0.35	0.53	1.59		23.27	23.27
2	1		-1.12	-0.51		-0.49	0.00		0.53			-1.59	21.68
3	1		-1.12	-0.51		-0.49			0.53			-1.60	20.08
4	1		-1.12	-0.51		-0.49			0.53			-1.60	18.48
5	1		-1.12	-0.51		-0.49			0.53			-1.60	16.88
6	1		-1.12	-0.51		-0.49			0.53			-1.60	15.28
7	1		-1.12	-0.51		-0.49			0.53			-1.60	13.68
8	1		-1.12	-0.51		-0.49			0.53			-1.60	12.08
9	1		-1.12	-0.51		-0.49			0.53			-1.60	10.48
10	1		-1.12	-0.51		-0.49			0.53			-1.60	8.89
11	1		-1.12	-0.51		-0.49			0.53			-1.60	7.29
12	1		-1.12	-0.51		-0.49			0.53			-1.60	5.69
13	1		-1.12	-0.51		-0.49			0.53			-1.60	4.09
14	1		-1.12	-0.51		-0.49			0.53			-1.60	2.49
15	1		-1.12	-0.51		-0.49			0.53			-1.60	0.89
16	1		-1.12	-0.51		-0.49			0.53			-1.60	-0.71
17	1		-1.12	-0.51		-0.49			0.53			-1.60	-2.31
18	1		-1.12	-0.51		-0.49			0.53			-1.60	-3.90
19	1		-1.12	-0.51		-0.49			0.53			-1.60	-5.50
20	1		-1.12	-0.51		-0.49			0.53			-1.60	-7.10
Total emissions 20 years		22.69	-22.40	-10.27	0.22	-9.86	0.03	0.35	10.55	1.59	0	**-7.10**	
											Emission factor (tCO2e/year)	-0.355	

Scenario 1 Rangeland restoration with goats as aftercare

negative number means carbon sequestration or emission reduction

Year	Area (ha)	Emissions in (tCO2e/ha) Biomass removal	Regrowth Biomass	Regrowth Grass Biomass	Harvesting/Chipping	Average soil	Goats for aftercare	Transport	Livestock	Pellet production	Substitution fossil fuels	Total Annual Emissions (tCO2e/ha)	Cumulative emissions (tCO2e/ha)
1	1	22.7	-1.12	-0.51	0.22	-0.49	3.44	0.35	0.53	1.59		26.69	26.69
2	1		-1.12	-0.51		-0.49	3.44		0.53			1.85	28.53
3	1		-1.12	-0.51		-0.49			0.53			-1.60	26.94
4	1		-1.12	-0.51		-0.49			0.53			-1.60	25.34
5	1		-1.12	-0.51		-0.49			0.53			-1.60	23.74
6	1		-1.12	-0.51		-0.49			0.53			-1.60	22.14
7	1		-1.12	-0.51		-0.49			0.53			-1.60	20.54
8	1		-1.12	-0.51		-0.49			0.53			-1.60	18.94
9	1		-1.12	-0.51		-0.49			0.53			-1.60	17.34
10	1		-1.12	-0.51		-0.49			0.53			-1.60	15.74
11	1		-1.12	-0.51		-0.49			0.53			-1.60	14.14
12	1		-1.12	-0.51		-0.49			0.53			-1.60	12.55
13	1		-1.12	-0.51		-0.49			0.53			-1.60	10.95
14	1		-1.12	-0.51		-0.49			0.53			-1.60	9.35
15	1		-1.12	-0.51		-0.49			0.53			-1.60	7.75
16	1		-1.12	-0.51		-0.49			0.53			-1.60	6.15
17	1		-1.12	-0.51		-0.49			0.53			-1.60	4.55
18	1		-1.12	-0.51		-0.49			0.53			-1.60	2.95
19	1		-1.12	-0.51		-0.49			0.53			-1.60	1.35
20	1		-1.12	-0.51		-0.49			0.53			-1.60	-0.25
Total emissions 20 years		22.69	-22.40	-10.27	0.22	-9.86	6.89	0.35	10.55	1.59	0	**-0.25**	
											Emission factor (tCO2e/year)	-0.012	

Scenario 2 Bush farming & bushblok production

negative number means carbon sequestration or emission reduction

Year	Area (ha)	Emissions in (tCO2e/ha) Biomass removal	Regrowth Biomass	Harvesting /Chipping	Average soil	Arboricide	Transport	Livestock	Pellet production	Substitution fossil fuels	Total Annual Emissions (tCO2e/ha)	Cumulative emissions (tCO2e/ha)
1	1	26.35	-2.64	0.255	0.16		0.4		1.85		26.38	26.38
2	1		-2.64		0.16						-2.47	23.91
3	1		-2.64		0.16						-2.47	21.44
4	1		-2.64		0.16						-2.47	18.97
5	1		-2.64		0.16						-2.47	16.49
6	1		-2.64		0.16						-2.47	14.02
7	1		-2.64		0.16						-2.47	11.55
8	1		-2.64		0.16						-2.47	9.08
9	1		-2.64		0.16						-2.47	6.60
10	1		-2.64		0.16						-2.47	4.13
11	1		-2.64		0.16						-2.47	1.66
12	1		-2.64		0.16						-2.47	-0.82
13	1	26.35	-2.64	0.255	0.16		0.4		1.85		26.38	25.57
14	1		-2.64		0.16						-2.47	23.10
15	1		-2.64		0.16						-2.47	20.62
16	1		-2.64		0.16						-2.47	18.15
17	1		-2.64		0.16						-2.47	15.68
18	1		-2.64		0.16						-2.47	13.21
19	1		-2.64		0.16						-2.47	10.73
20	1		-2.64		0.16						-2.47	8.26
Total emissions 20 years		52.71	-52.71	0.51	3.25	0	0.8	0	3.7	0	**8.26**	
										Emission factor (tCO2e/year)	0.413	

Scenario 3 Medium-scale charcoal production (Traditional kiln)

negative number means carbon sequestration or emission reduction

Year	Area (ha)	Emissions in (tCO2e/ha) Biomass removal	Regrowth Biomass	Harvesting /Chipping	Average soil	Arboricide	Transport	Livestock	Charcoal production with Traditional Namibian drum kiln	Substitution fossil fuels	Total Annual Emissions (tCO2e/ha)	Cumulative emissions (tCO2e/ha)
1	1	22.52	-1.13	0.52	-0.38	0.028	0	0.23	16.86		38.65	38.65
2	1		-1.13		-0.38			0.23			-1.28	37.37
3	1		-1.13		-0.38			0.23			-1.28	36.09
4	1		-1.13		-0.38			0.23			-1.28	34.81
5	1		-1.13		-0.38			0.23			-1.28	33.54
6	1		-1.13		-0.38			0.23			-1.28	32.26
7	1		-1.13		-0.38			0.23			-1.28	30.98
8	1		-1.13		-0.38			0.23			-1.28	29.70
9	1		-1.13		-0.38			0.23			-1.28	28.42
10	1		-1.13		-0.38			0.23			-1.28	27.14
11	1		-1.13		-0.38			0.23			-1.28	25.87
12	1		-1.13		-0.38			0.23			-1.28	24.59
13	1		-1.13		-0.38			0.23			-1.28	23.31
14	1		-1.13		-0.38			0.23			-1.28	22.03
15	1		-1.13		-0.38			0.23			-1.28	20.75
16	1		-1.13		-0.38			0.23			-1.28	19.47
17	1		-1.13		-0.38			0.23			-1.28	18.20
18	1		-1.13		-0.38			0.23			-1.28	16.92
19	1		-1.13		-0.38			0.23			-1.28	15.64
20	1		-1.13		-0.38			0.23			-1.28	14.36
Total emissions 20 years		22.52	-22.52	0.52	-7.68	0.028	0	4.6324	16.86	0	**14.36**	
										Emission factor (tCO2e/year)	0.718	

Scenario 3 Medium-scale charcoal production (stationary industrial kiln)

negative number means carbon sequestration or emission reduction

		Emissions in (tCO2e/ha)										
Year	Area (ha)	Biomass removal	Regrowth Biomass	Harvesting/Chipping	Average soil	Arboricide	Transport	Livestock	Charcoal production with Traditional Namibian drum kiln	Substitution fossil fuels	Total Annual Emissions (tCO2e/ha)	Cumulative emissions (tCO2e/ha)
1	1	22.52	-1.13	0.52	-0.38	0.028	0.34	0.23	8.48		30.61	30.61
2	1		-1.13		-0.38			0.23			-1.28	29.33
3	1		-1.13		-0.38			0.23			-1.28	28.05
4	1		-1.13		-0.38			0.23			-1.28	26.77
5	1		-1.13		-0.38			0.23			-1.28	25.50
6	1		-1.13		-0.38			0.23			-1.28	24.22
7	1		-1.13		-0.38			0.23			-1.28	22.94
8	1		-1.13		-0.38			0.23			-1.28	21.66
9	1		-1.13		-0.38			0.23			-1.28	20.38
10	1		-1.13		-0.38			0.23			-1.28	19.10
11	1		-1.13		-0.38			0.23			-1.28	17.83
12	1		-1.13		-0.38			0.23			-1.28	16.55
13	1		-1.13		-0.38			0.23			-1.28	15.27
14	1		-1.13		-0.38			0.23			-1.28	13.99
15	1		-1.13		-0.38			0.23			-1.28	12.71
16	1		-1.13		-0.38			0.23			-1.28	11.43
17	1		-1.13		-0.38			0.23			-1.28	10.16
18	1		-1.13		-0.38			0.23			-1.28	8.88
19	1		-1.13		-0.38			0.23			-1.28	7.60
20	1		-1.13		-0.38			0.23			-1.28	6.32
Total emissions 20 years		22.52	-22.52	0.52	-7.68	0.028	0.34	4.6324	8.48	0	**6.32**	
										Emission factor (tCO2e/year)	0.316	

Scenario 4 Use of firewood

negative number means carbon sequestration or emission reduction

		Emissions in (tCO2e/ha)										
Year	Area (ha)	Biomass removal	Regrowth Biomass	Harvesting /Chipping	Average soil	Arboricide	Transport	Livestock	Pellet production	Substitution fossil fuels	Total Annual Emissions (tCO2e/ha)	Cumulative emissions (tCO2e/ha)
1	1	16.05	-1.61		0.08						14.52	14.52
2	1		-1.61		0.08						-1.53	13.00
3	1		-1.61		0.08						-1.53	11.47
4	1		-1.61		0.08						-1.53	9.94
5	1		-1.61		0.08						-1.53	8.42
6	1		-1.61		0.08						-1.53	6.89
7	1	16.05	-1.61		0.08						14.52	21.41
8	1		-1.61		0.08						-1.53	19.89
9	1		-1.61		0.08						-1.53	18.36
10	1		-1.61		0.08						-1.53	16.83
11	1		-1.61		0.08						-1.53	15.30
12	1		-1.61		0.08						-1.53	13.78
13	1		-1.61		0.08						-1.53	12.25
14	1		-1.61		0.08						-1.53	10.72
15	1		-1.61		0.08						-1.53	9.20
16	1		-1.61		0.08						-1.53	7.67
17	1		-1.61		0.08						-1.53	6.14
18	1		-1.61		0.08						-1.53	4.62
19	1		-1.61		0.08						-1.53	3.09
20	1		-1.61		0.08						-1.53	1.56
Total emissions 20 years		32.10	-32.10	0	1.56	0	0	0	0	0	**1.56**	
										Emission factor (tCO2e/year)	0.0781	

Scenario 5 Large-scale bush harvesting for electricity generation

negative number means carbon sequestration or emission reduction

Year	Area (ha)	Biomass removal	Regrowth Biomass	Harvesting /Chipping	Average soil	Arboricide	Transport	Livestock	Pellet production	Substitution fossil fuels	Total Annual Emissions (tCO2e/ha)	Cumulative emissions (tCO2e/ha)
		Emissions in (tCO2e/ha)										
1	1	29.43	-0.53	0.3	-0.33	0.03	0.90	0.23		-5.6	24.44	24.44
2	1		-0.53		-0.33			0.23			-0.62	23.81
3	1		-0.53		-0.33			0.23			-0.62	23.19
4	1		-0.53		-0.33			0.23			-0.62	22.56
5	1		-0.53		-0.33			0.23			-0.62	21.94
6	1		-0.53		-0.33			0.23			-0.62	21.31
7	1		-0.53		-0.33			0.23			-0.62	20.69
8	1		-0.53		-0.33			0.23			-0.62	20.06
9	1		-0.53		-0.33			0.23			-0.62	19.44
10	1		-0.53		-0.33			0.23			-0.62	18.81
11	1		-0.53		-0.33			0.23			-0.62	18.19
12	1		-0.53		-0.33			0.23			-0.62	17.57
13	1		-0.53		-0.33			0.23			-0.62	16.94
14	1		-0.53		-0.33			0.23			-0.62	16.32
15	1		-0.53		-0.33			0.23			-0.62	15.69
16	1		-0.53		-0.33			0.23			-0.62	15.07
17	1		-0.53		-0.33			0.23			-0.62	14.44
18	1		-0.53		-0.33			0.23			-0.62	13.82
19	1		-0.53		-0.33			0.23			-0.62	13.19
20	1		-0.53		-0.33			0.23			-0.62	12.57
Total emissions 20 years		29.43	-10.56	0.3	-6.56	0.03	0.9	4.63	0	-5.6	**12.57**	
									Substitution factor (tCO2e/year)	-0.28		
										Emission factor (tCO2e/year)	0.628	

ANNEX 2 ADDITIONAL INFORMATION ROTHC SOIL CARBON MODEL

Original model: RothC (version 26.3)

RothC models the turnover of soil organic matter. It can predict the change in soil organic carbon stock in the topsoil (30 cm) of non-waterlogged soils based on weather data, soil characteristics, and carbon inputs from organic matter. The model can also run in inverse mode and predict the necessary monthly carbon inputs from organic matter based on known SOC stocks, soil properties and climate data.

Concretely, RothC calculates the change in SOC on the basis of monthly average rainfall (mm), monthly open pan evaporation (mm), average monthly mean air temperature (°C), clay fraction of the soil (%), depth of the soil layer (cm), monthly input of plant residues (tC ha^{-1}), monthly input from farmyard manure (tC ha^{-1}), the applicable DPM/RPM ratio as explained in the following, and specifications in which months of the year the soil is vegetated or bare.

RothC is split up into 5 carbon pools: Decomposable Plant Material (DPM), Resistant Plant Material (RPM), Microbial Biomass (BIO), Humified Organic Matter (HUM), and Inert Organic Matter (IOM). The BIO pool is also divided into two sub-pools: "BIO slow" (BIO-S) and "BIO fast" (BIO-F), which indicates the speed of decomposition. At the end of each month modeled the sum of the carbon content of each of the five carbon pools delivers the total change in SOC stock.

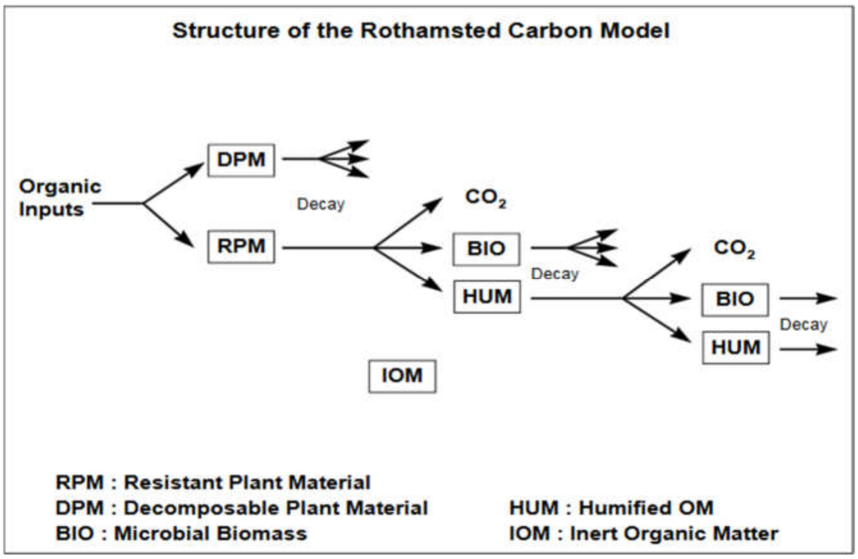

Figure 16: Cascade - Structure of RothC with 5 distinct carbon pools

Source: modified from Coleman & Jenkinson, 1996)

As shown in Figure 5 these five carbon pools build a cascade where organic inputs enter the system flowing into the first two pools DPM and RPM, and from there, continue their journey through the other carbon pools or decompose into CO_2. The only exception is the IOM pool.

The IOM pool is resistant to decomposition and thus can be seen as a constant in the model.

The size of the IOM pool can be calculated from radiocarbon measurements, if available. If no such radiocarbon measurements are available, one can also estimate the IOM with the help of the equation by Falloon et al (1998):

$$IOM = 0.049 \times Total\ Organic\ Carbon^{1.139} \quad (1)$$

Radiocarbon measurements were not available. Therefore, the IOM pool in this study was estimated using the equation by Falloon et al (1998) (Eq. 1).

The other four carbon pools DPM, RPM, BIO, and HUM are part of the cascade in RothC.

The organic matter entering the system is split into the first two pools DPM and RPM. This DPM-RPM-ratio is 0.67 for unimproved grassland and scrub including savanna (Coleman & Jenkinson, 1996) and is used for this study.

DPM and RPM both decay into CO_2, BIO, and HUM. The clay content in the soil determines the proportion of how much carbon leaves the soil as CO_2 and how much stays within the two carbon pools BIO and HUM.

This is expressed by the so-called "CO_2-to- (BIO+HUM)-ratio".

It is calculated as follows:-

$$\frac{CO2}{BIO + HUM} = 1.67 \quad (1.85 + 1.6^{-0.0786 \quad \%clay}) \quad (2)$$

The carbon that stays in BIO and HUM is split between the two carbon pools as 46% BIO and 54% HUM. The carbon in BIO and HUM then decays further back into the same pools producing more CO_2 according to the applicable decay function.

The logic of RothC is that microbial decomposition processes drive carbon loss in the soil (Skjemstad et al 2004). These microbial decomposition processes are affected by temperature and available soil water content in the model (Skjemstad et al 2004). To reflect these processes, RothC calculates the monthly remaining carbon (Y) in a particular active carbon pool with the following exponential function:

$$Y = Y_0 \left(1 \quad e^{-abckt}\right) \quad (3)$$

using the initial amount of carbon in that pool (Y_0), a rate modifying factor for temperature (a), a rate modifying factor for soil water content (b), a rate modifying factor for soil cover (c), a decomposition rate constant for that particular carbon pool (k), and the constant (t) of 1/12 to convert the yearly decomposition rate constant (k) into monthly time steps (Skjemstad et al 2004).

The calculation of the rate-modifying factor for temperature (a) is based on the average monthly air temperature (T) in °C.

It is calculated as follows:-

$$a = \frac{47.91}{1 + e^{(\frac{106.06}{T+18.27})}} \quad (4)$$

The soil cover factor (c) is used to account for the effects of plant cover on soil water balance. The soil can only be modeled as "covered" or "bare". A "partially covered" state does not exist in RothC. If the soil is vegetated with living plants, factor c equals 0.6 and thus slows down decomposition. If the soil is bare, then c = 1. The soil cover factor (c) used to be the "retainment factor" in earlier versions of RothC.

The decomposition rate constant (*k*) is assigned to the active carbon pools DPM, RPM, BIO, and HUM. These rate constants are as follows:-

- DPM : *k* = 10.0
- RPM : *k* = 0.3
- BIO : *k* = 0.66
- HUM : *k* = 0.02

These rates stem from the long-term field experiments in Rothamsted (Jenkinson et al 1987 as cited by Coleman & Jenkinson, 1996; Jenkinson et al 1992). They are usually not changed using the model (Coleman and Jenkinson 1996).

The soil water content (b) is resembled in the model by a soil moisture deficit (SMD). SMD depends on clay content, monthly average rainfall, and pan evaporation.

Soil moisture in RothC is reflected through the topsoil moisture deficit (TSMD). The rate-modifying factor for soil moisture is calculated in several steps.

First, the Maximum TSMD is calculated. The Maximum TSMD reflects the permanent wilting point of -15 bar (Farina et al 2013). RothC is originally calibrated to model the 0 - 23cm topsoil layer. To calculate topsoil layers of different depth one has to divide the Maximum TSMD by 23 and multiply the result with the desired thickness in cm.

$$Maximum\,TSMD = \quad (20.0 + 1.3(\%clay) \quad 0.01(\%clay)^2) \quad \frac{dept \ \ (cm)}{23} \quad (5)$$

The Maximum TSMD as calculated above is the Maximum TSMD under growing vegetation.

If the soil is bare in a certain month, dry topsoil shields liquid and vapor flow from the surface and thus reducing evaporation (Farina et al 2013). To account for this in the model, there is also a Bare Soil Moisture Deficit (BareSMD) which is calculated as:

$$BareSMD = \frac{Maximum\,TSMD}{1.8} \quad (6)$$

The equation translates into, if the soil is bare in one month it can only dry out to 55.6% of Maximum TSMD.

Second, the accumulated TSMD must be calculated. The logic is that a topsoil moisture deficit can only occur when in one month more water goes out through evapotranspiration than comes in through precipitation. The accumulated TSMD is calculated from the first month where evapotranspiration is higher than precipitation and accumulates over time if evapotranspiration stays greater than precipitation. The TSMD in a month can only go as low as the Maximum TSMD when the soil is vegetated and BareSMD when the soil is bare. In some cases, the soil goes bare in a particular month when accumulated TSMD is already lower than BareSMD. Then the soil does not dry out further and the accumulated TSMD cannot drop further. This soil water deficit is then compensated as soon as precipitation is higher than evapotranspiration again.

To calculate the accumulated TSMD the model needs inputs on average monthly rainfall (in mm) and evapotranspiration (in mm). The rate modifying factor *b* for each month is then calculated as:-

$$b = 1 \qquad (7)$$
$$if\ acc.TSMD < 0.444 \quad max.TSMD$$

Which means that there is no modification of decomposition if the soil stays sufficiently wet and the TSMD in a particular month doesn't fall below 44.4% of Maximum TSMD. If the soil dries out beyond that point in a particular month it is assumed that microbial decomposition processes start slowing down and *b* is calculated as:

$$b = 0.2 + 0.8 \quad \frac{max.TSMD \quad acc.TSMD}{max.TSMD \quad 0.444 \quad max.TSMD} \qquad (8)$$

The RothC model (26.3) is freely available as a DOS-based software directly from the Rothamsted research center[15]. It also exists as a Microsoft-Excel version as developed for the Australian Greenhouse Office[16]. The latter one is used for this study because it allows for the necessary modifications to develop RothC10_N.

Dryland modified model: RothC10_N

Farina et al (2013) developed a modified version of RothC called RothC10_N for more realistic SOC turnover modeling in dryland areas. In RothC10_N the soil is allowed to dry out further than in the original RothC version so that more rain is necessary to compensate the water loss. In RothC10_N bare soil can dry up to the permanent wilting point instead of only up to 55.6% of TSMD. This is justified by the fact, that in semi-arid Mediterranean areas, soils crack during the hot and dry summers (Corbeels et al 1998 as cited by Farina et al 2013). So there is no "protective" dry layer which shields liquid and vapor flow from the soil. Most of the water leaving bare soil passes through the walls of cracks and not through the dry surface (Ritchie & Adams, 1974 as cited by Farina et al 2013). Under these soil and climate conditions, when vegetated the soils can lose water beyond the permanent wilting point (De Vita et al 2007 as cited by Farina et al

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[15] URL: https://www.rothamsted.ac.uk/rothamsted-carbon-model-rothc [Jan 24, 2019]
[16] URL: wbcarbonfinance.org/docs/Roth-C-model.xlsm [Jan 24, 2019]

2013). Thus the maximum TSMD in RothC10_N corresponds to the point where only capillary water is retained at a water tension of -1000 bar. The maximum TSMD and BareSMD are calculated using the van Genuchten (1980) equations as provided in Annex 1. For these calculations silt content, bulk density, and organic carbon content are further necessary inputs to use the model.

Beyond the modifications of TSMD and BareSMD, Farina et al (2013) also modified the soil moisture modifying factor *b* for semiarid areas. In RothC10_N the minimum soil moisture modifying factor *b* is not 0.2 anymore but 0.1:

$$b = \mathbf{0.1} + 0.8 \quad \frac{max.TSMD \quad acc.TSMD}{max.TSMD \quad 0.444 \quad max.TSMD} \tag{9}$$

Pedotransfer functions

The pedotransfer functions by van Genuchten (1980) and adapted from Farina et al (2013) form the basis of calculating soil moisture deficit at certain water content levels.

$$\begin{aligned}\alpha = EXP(\quad & 14.96 + 0.03135 \quad Clay + 0.0351 \quad Silt + 0.646 \quad (OC \quad 1.72) + 15.29 \quad BD \\ & 0.192 \quad t \quad 4.671 \quad BD^2 \quad 0.000781 \quad Clay^2 \quad 0.00687 \quad (OC \quad 1.72)^2 \\ & + 0.0449 \quad (OC \quad 1.72)^{-1} + 0.0663 \quad LN(Silt) + 0.1482 \quad LN(OC \quad 1.72) \\ & 0.04546 \quad BD \quad SIlt \quad 0.4852 \quad BD \quad (OC \quad 1.72) + 0.00673 \quad Clay \quad t)\end{aligned}$$

$$\begin{aligned}\theta_S = (& 0.7919 + 0.001691 \quad Clay \quad 0.29619 \quad BD \quad 0.000001491 \quad Silt^2 + 0.0000821 \\ & (OC \quad 1.72)^2 + 0.02427 \quad Clay^{-1} + 0.01113 \quad Silt^{-1} + 0.01472 \\ & LN(Silt) \quad 0.0000733 \quad (OC \quad 1.72) \quad Clay \quad 0.000619 \quad BD \quad Clay \\ & 0.001183 \quad BD \quad (OC \quad 1.72) \quad 0.0001664 \quad Silt \quad t)\end{aligned}$$

$\theta_R = 0{,}01$ (*Volumetric water content referring to levels at the permanent wilting point. Adapted from Farina et al (2013)*)

$$\begin{aligned}n = EXP(\quad & 25.23 \quad 0.02195 \quad Clay + 0.0074 \quad Silt \quad 0.194 \quad (OC \quad 1.72) + 45.5 \quad BD \\ & 7.24 \quad BD^2 + 0.0003658 \quad Clay^2 + 0.002885 \quad (OC \quad 1.72)^2 \quad 12.81 \\ & BD^{-1} \quad 0.1524 \quad Silt^{-1} \quad 0.01958 \quad (OC \quad 1.72)^{-1} \quad 0.2876 \quad LN(Silt) \\ & 0.0709 \quad LN(OC \quad 1.72) \quad 44.6 \quad LN(BD) \quad 0.02264 \quad BD \quad Clay \\ & + 0.0896 \quad BD \quad (OC \quad 1.72) + 0.00718 \quad Clay \quad t) + 1\end{aligned}$$

$$m = 1 \quad \frac{1}{n}$$

$$WC = \theta_R + (\theta_S \quad \theta_R)/(1 + (\alpha \quad mbar)^n)^m$$

Where

Clay is the percentage clay (%)

Silt is the percentage silt (%)

OC is the percentage organic carbon (%)

BD is the bulk density (g/cm³)

t is a qualitative constant of 1, indicating that hydraulic properties are calculated for topsoil

WC is water content at a given matric potential (cm³/cm³)

mbar is matric potential (cm), which is 50 at field capacity (0,05bar), 1000 at 1 bar, 15000 at permanent wilting point (15 bar) and 1000000 at 1000bar, which reflects the point where only capillary water is retained.

Water content (WC) was converted to soil moisture deficit (in mm) as it is the needed input for RothC calculations, using the following equation:

$$M_i = \left(WC_i \quad WC_{fc}\right) \quad 10 \quad dept \ \ (cm)$$

Where

M_i is the soil moisture deficit at M, M_b, or M_c

WC_{fc} is the water content at field capacity

WC_i is the water content at -1 bar, -15 bar, or -1000 bar

ANNEX 2 POLICY FRAMEWORK REVIEW

PART 1: NAMIBIA-RELATED

Namibia's policy framework for climate change mitigation and adaptation with relevance to bush control and biomass use includes international agreements & voluntary commitments, national legislation, national plans, policies, strategies, and more. Some of the framework items are entirely focused on Namibia's efforts to address climate change mitigation and adaptation, but others are focused on other sectors but include a section or statements that are relevant to bush encroachment and climate change. The following are those items that do not have climate change as their primary focus. Explanation is provided as to how they are relevant to climate change, bush control and biomass use.

United Nations Framework Convention on Climate Change

In 1994, Namibia became a party to the United Nations Framework Convention on Climate Change (UNFCCC). Namibia is required to submit a National Communication (NC) report to the UNFCCC every four years. The NC includes sections on the GHG inventory, mitigation, and vulnerability & adaptation. See Section 4.1 for a discussion of Namibia's Third National Communication (TNC) to the UNFCCC.

"The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change" (IPCC website). The Intergovernmental Panel on Climate Change (IPCC) is a body of the United Nations that is responsible for scientific reports on the status and understanding of climate change, including the development of a global carbon budget. The IPCC has established required procedures for performing GHG emissions and removals accounting. Using IPCC guidelines, Namibia's bush encroachment area has been determined to be a carbon sink that removes CO_2 from the atmosphere as a result of it continuing expansion. This project includes the development of a carbon accounting model that will allow Namibian climate change stakeholders to more accurately model emissions and removals associated with bush encroachment, bush harvesting, and biomass use.

A noteworthy, biomass-related development was announced in the IPCC's 8 October 2018 *Special Report: Global Warming of 1.5^{o}C*. Biochar is now considered a negative emission technology (NET). As such, the production and use of biochar as a soil amendment may now be incorporated and accounted for in a country's GHG inventory, and mitigation and adaptation strategies.

The Paris Agreement of 2015 is the follow-up agreement to the Kyoto Protocol. The Paris Agreement required each party country to prepare and submit an Intended Nationally Determined Contributions (INDC) report in 2015. An INDC report sets out, and provides supporting quantitative information for, a country's plans for climate change mitigation and adaptation. See Section 4.1 for a discussion of Namibia's INDC report.

The Constitution of the Republic of Namibia (1990)

The following is stated in Namibia's *Constitution* in Chapter 11 – Principles of State Policy, Article 95 - Promotion of the Welfare of the People Article Namibian:

> "The State shall actively promote and maintain the welfare of the people by adopting, *inter alia*, policies aimed at….maintenance of ecosystems, essential ecological processes and biological diversity of Namibia and utilization of living natural resources on a sustainable basis for the benefit of all Namibians…."

This article indicates that both bush control (i.e. maintenance of ecosystems, essential ecological processes and biological diversity) and biomass use (i.e. utilization of living natural resources on a sustainable basis) are important to the State's desire to promote and maintain the welfare of the Namibian people.

Vision 2030 (2004)

Chapter 5 of *Vision 2030* acknowledges bush encroachment as a serious form of land degradation that threatens Namibia's future agricultural output:

> "The environmental manifestations of land degradation in Namibia – soil erosion, bush encroachment and soil salination – are causes of economic loss and escalating poverty, through declining agricultural production and loss of food security."

Namibia's 5th National Development Plan (2017)

There are important statements made in *Namibia's 5th National Development Plan (NDP5)* that make clear bush control and biomass use are very important to Namibia's development.

In Chapter 1 – Namibia on the Move, Section 5 – Game Changers, Sub-section 5.1 – Increase investment in infrastructure development, Sub-sub-section 5.1.1 – Energy:

> "Promotion of Independent Power Producers (IPPs) and of renewable energy such as solar, wind and biomass resources will be accelerated."

In Chapter 2 – Economic Progression, Section 2.2 – Structural transformation through value added industrialization, Sub-section 2.2.3 Agricultural Sector and Food Security, one of four listed Strategies and Desired Outcomes for 2017 - 2022:

> *Strategy*: "Increase agricultural production for cereals, horticulture and livestock"
>
> *Desired Outcomes*: "5 536 ha of land for irrigation will be developed. 82 200 ha of land is bush thinned annually. Advance the use of Conservative Agriculture (CA) with at least 50% of farmers practicing CA. Expand green scheme, support small scale and subsistence farmers."

In Chapter 4 – Environmental Sustainability, 4.1 Conservation and Sustainable Use of Natural Resources, one of four listed Strategies and Desired Outcomes for 2017 – 2022:

> *Strategy*: "Strengthen sustainable Land Management"
>
> *Desired Outcomes*: "By achieving land degradation neutrality and optimum land productivity. The sustainable management of rangelands, restoration of bush-encroached land and the expansion of conservation agriculture will be the main priority programmes under this strategy."

Namibia's Forest Act 12 of 2001

The *Forest Act* sets out the government's responsibilities and rights with respect to forestry and defines different types of forests, none of which bush encroached rangeland appears t fall under.

The following statements in the *Act* do apply to encroacher bush:

i. "….no person shall on any land which is not part of a surveyed erven of a local authority area as defined in section 1 of the Local Authorities Act, 1992 (Act No. 23 of 1992) cut, destroy or remove…. any living tree, bush or shrub growing within 100 metres of a river, stream or watercourse."
ii. "A person who wishes to obtain a licence to cut and remove the vegetation referred to in subsection (1) shall, in the prescribed form and manner, apply for the licence to a licensing officer who has been designated or appointed for the area where the protected area is situated."
iii. "(1) Unless approval has been given by the Director, no person shall –
    (a) plant trees, other than fruit trees, on more than 15 hectares of land on any piece of land or several pieces of land situated in the same locality;
    (b) clear the vegetation on more than 15 hectares on any piece of land or several pieces of land situated in the same locality which has predominantly woody vegetation; or
    (c) cut or remove more than 500 cubic metres of forest produce from any piece of land in a period of one year.
   (2) The Director may require a person seeking authority required under subsection (1), to prepare an environmental impact assessment report and the report shall, in addition to the requirements imposed by any law for such reports, contain information and analysis which the Director requires."
iv. "Unless otherwise authorised by this Act, but subject to subsection (2), no person shall remove or destroy a dwelling place or structure of a honey producing organism which is situated on any land, remove wax or honey from any dwelling place or structure of a honey producing organism or remove or destroy honey producing organisms which are at any place in Namibia."

Namibia's Forest Policy

The *Forest Policy* sets out the aims, objectives and agenda underlying the management and development of Namibia's forests and woodlands.

The following are the aims of the *Forest Policy* which are all relevant to bush encroachment and control, particularly in recognizing that forests/woodlands offer multiple benefits and opportunities.

a) "Reconcile rural development with biodiversity conservation by empowering farmers and local communities to manage forest resources on a sustainable basis.
b) Increase the yield of benefits of the national woodlands through research and development, application of silvicultural practices, protection and promotion of requisite economic support projects.
c) Create favorable conditions to attract investment in small and medium industry based on wood and non-wood forest raw materials.

d) Implement innovative land-use strategies including multiple use conservation areas, protected areas, agro-forestry and a variety of other approaches designed to yield forestry global benefits."

Environmental Management Act (2007), List of Activities (2012) and Regulations (2012)

The *Environmental Management Act* was established to prevent and mitigate the negative effects of activities on the environment. The *Act* requires that there is sufficient time to review the potential impacts of a proposed activity before it is carried out, and that there is adequate opportunity for participation by interested and affected parties. The Act includes twelve principles of environmental management, including the following selected ones which have clear relevance to climate change adaptation and mitigation, and bush control and biomass use:

- "renewable resources must be used on a sustainable basis for the benefit of present and future generations;"
- "community involvement in natural resources management and the sharing of benefits arising from the use of the resources, must be promoted and facilitated;"
- "assessments must be undertaken for activities which may have significant effects on the environment or the use of natural resources;"
- "the option that provides the most benefit or causes the least damage to the environment as a whole, at a cost acceptable to society, in the long term as well as in the short term must be adopted to reduce generation of waste and polluting substances at source;"

The *List of Activities that May Not be Undertaken Without Environmental Clearance Certificate* identifies that types of activities that require an application to the Environmental Commissioner of the Ministry of Environment and Tourism for review and approval in the form of an Environmental Clearance Certificate. The following listed activities are clearly relevant to climate change adaptation & mitigation and bush control & biomass use:

- "The construction of facilities for – (a) the generation of electricity;"
- "The clearance of forest areas, deforestation, afforestation, timber harvesting or any other related activity that requires authorization in terms of the Forest Act;"
- "Any process or activity which requires a permit, license or other form of authorization, or the modification of or changes to existing facilities for any process or activity which requires an amendment of an existing permit, license or authorization or which requires a new permit, license or authorization in terms of a law governing the generation or release of emissions, pollution, effluent or waste."

The *Regulations* sets out the details of the process and reporting that are required for an application for Environmental Clearance.

Small-scale bush harvesting operations smaller than 15 ha do not require an Environmental Clearance Certificate, but do require a harvesting permit from the relevant District Forestry Office. With increasing harvesting area, different requirements are to be fulfilled by the applicant. This is nicely explained in the booklet, *Forestry and Environmental Authorizations Process for Bush Harvesting Projects 2017.* The figure below was taken from the booklet.

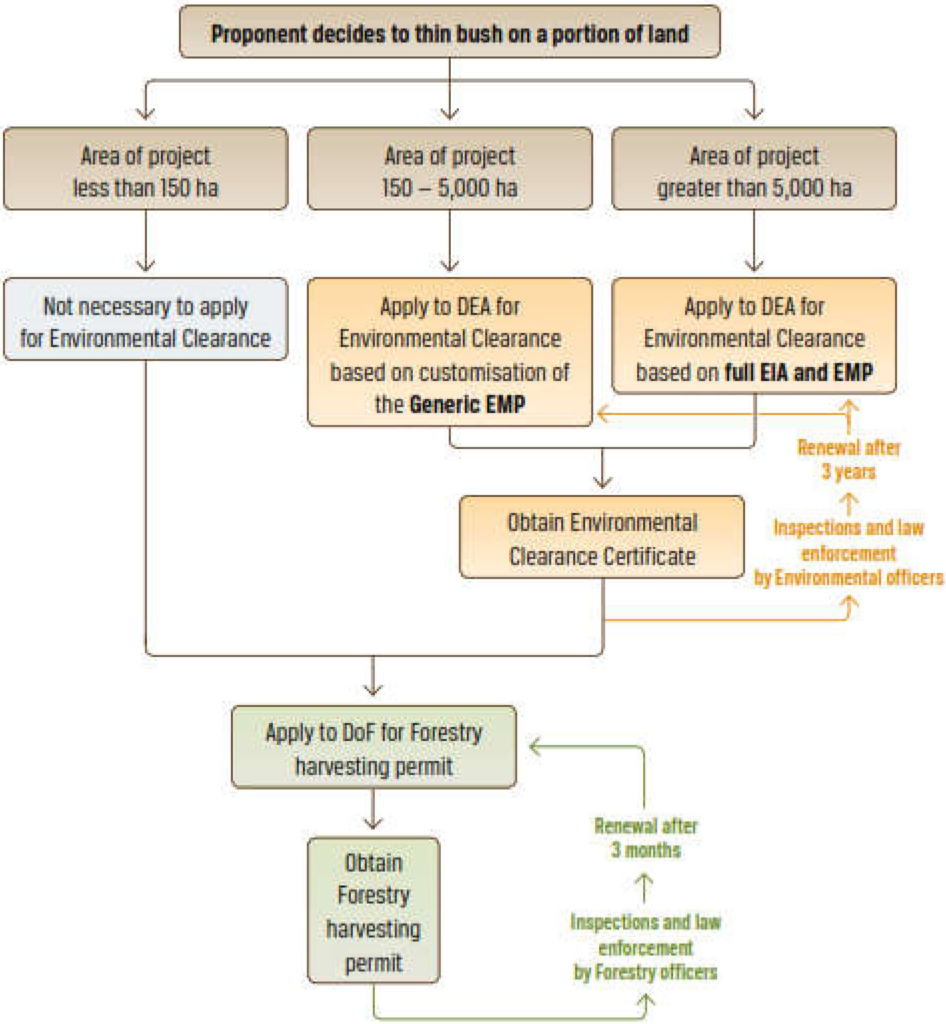

Figure 1 Different types of permits required depending on harvesting area

Source: Forestry and Environmental Authorizations Process for Bush Harvesting Projects 2017

The GIZ BCBU project funded a review of the conditions requiring an application for environmental clearance. The review resulted in several recommendations to amend the Environmental Management Act and associated regulations. The recommendations are included in the report, *Proposed Forestry Listed Activities Amendments to the Environmental Management Act and Associated Regulations*, prepared by Environmental Compliance Consultancy (2018).

Namibia Agricultural Policy (2015)

Only one statement was found in the *Agricultural Policy* that is clearly relevant to climate change adaptation & mitigation and bush control & biomass use. The following policy statement is given in Chapter 1 – Agricultural Production, Section 2 – Policy Statements, Sub-section 2.2 – Livestock Production, Policy number 2.2.5:

> "Develop and promote programmes aimed at improving the productivity of rangeland."

National Rangeland Management Policy & Strategy, Restoring Namibia's Rangelands (2012)

The topic of bush encroachment is discussed throughout the *National Rangeland Management Policy & Strategy* due to the problem being so widespread and devastating to livestock production in central and eastern Namibia. In Chapter 1 of the *Policy*, Section 1.4 - Major causes of poor rangeland conditions and productivity of the National Rangeland Management Policy, the following is stated regarding the causes of bush encroachment:

> "The causes of bush encroachment are wide, varied and intricate. A wide range of factors have been listed as contributory factors. These include the exclusion of occasional fires, replacement of most of the indigenous browsers and grazers by domestic livestock, restriction of movement of livestock through the construction of fences, and poor grazing management in general, leading to the loss of perennial grasses."

In Section 1.5 – Major effects of poor rangeland conditions and productivity, the following is stated regarding the effects of bush encroachment:

> "Bush encroachment causes a large amount of rainfall to be intercepted and transpired back into the atmosphere without producing fodder of economic value to livestock farmers. This causes less water available to grass plants that could produce fodder for grazing animals."

In Chapter 2 of the *Policy* – Analysis of the current policy framework, the following important statement is made regarding who will be most responsible for preventing bush encroachment and rectifying it where it has already occurred:

> "The role of the State is limited to regulatory functions and providing technical support that will enable farmers to improve their capacity to manage resources more effectively….This implies that that farmers will have to bear the responsibility of managing their rangelands. More specifically, they will be responsible for the prevention of bush encroachment and for its eradication where densities are too high."

In Chapter 2 of the *Strategy*, there are seven objectives listed. Objective number six is: The adverse effects of bush encroachment are reversed. Thirteen activities are then listed for achieving this objective, and responsible ministries are identified for each activity.

Chapter 5 of the *Strategy* discusses strategies to mitigate the effects of climate change. One of the nine strategies proposed is debushing. The following is stated:

> "Suffice it to say that selective clearing of land from invasive bush generally results in processes such as an increased grass cover, lower soil surface temperatures, better grass seedling germination rates, higher water infiltrations levels, better organic material content in soils and a host of other benefits to the rangeland environment. Sufficient evidence exists to show that debushing ultimately results in hugely increased productivity from rangelands, and can therefore be viewed as an essential strategy to mitigate the expected effects of climate change."

Third National Action Programme for Namibia to Implement the United Nations Convention to Combat Desertification: 2014 – 2024 (2014)

Although title only mentions desertification, the *Action Programme* also covers land degradation and drought. Bush encroachment is identified as one of five manifestations of land degradation in Namibia, along with overgrazed / overstocked land, deforested land, soil degradation and water degradation. The proposed actions to combat bush encroachment land degradation are relevant to Namibia's climate change adaptation and mitigation because of the impacts that such actions have on GHG emissions and removals, food security, water resources and more.

Namibia's Second National Biodiversity Strategy and Action Plan: 2013 – 2022 (2014)

The *Strategy and Action Plan* sets out a number of goals, targets, indicators and strategic initiatives. In Section 4.2.3, bush encroachment is mentioned as a problem resulting from unsustainable land management practices. The *Strategy and Action Plan* establishes a target to address unsustainable land management, and thus bush encroachment: Target 6 – By 2022, principles of sound rangeland and sustainable forest management, and good environmental practices in agriculture are applied on at least 50% of all relevant areas.

In Section 4.4.1, bush encroachment is again mentioned:

> "The most serious type of degradation requiring rehabilitation and restoration in Namibia is bush-encroached land. An estimated 26 million hectares of land is bush-encroached and the rehabilitation of this land has considerable economic, social and ecological potential."

The proposed strategies and actions to preserve and promote biodiversity by addressing the bush encroachment problem are relevant to Namibia's climate change adaptation and mitigation activities because restoring bush encroached land includes bush thinning and increased growth of perennial grasses, which impact GHG emissions and removals, food security, water resources and more.

National Renewable Energy Policy (2017)

Bush encroachment and biomass use feature importantly in the *Renewable Energy Policy*. In the Forward section, the following is stated:

> "Namibia is uniquely placed to transform the challenge of an invasive species (encroacher bush) into an opportunity for biomass-based energy, with large areas that have the potential to generate between 6-30 MWh/hectare from conversion of bush into bioenergy."

In the section, Goal and Targets of the National Renewable Energy Policy, under Goal VII – Pursue Climate-Resilient Energy Sector Development through Renewable Energy, the following is stated:

> "The Government of Namibia shall strengthen the country's climate resilience by diversifying the energy mix with more non-hydro renewable energy. Renewable power offers abundant fuel sources (be it solar, wind, or invader-bush based bioenergy), a negligible carbon-footprint, and is less prone to inter-annual or seasonal variability than hydropower."

A noteworthy point in the *Renewable Energy Policy* is the identification of the potential opportunity of using bush biomass to manufacture ligno-cellulosic ethanol, a liquid fuel that can replace a portion of the petrol that is used by road vehicles (and mitigate GHG emissions). The *Policy* states that the energy potential for ligno-cellulosic ethanol may be as much as 25 terawatts / ha in some areas of bush encroached land.

The *Renewable Energy Policy* also recommends that Namibia should develop a Bioenergy Policy to help navigate the establishment and management of a new renewable fuel industry.

Growth Strategy for the Namibian Wood Charcoal Industry and Associated Value Chain (2016)

The *Growth Strategy for the Namibian Wood Charcoal Industry and Associated Value Chain*, was produced by the Namibia's Ministry of Industrialisation, Trade and SME Development. According to the *Growth Strategy*, currently 35,000 to 50,000 ha of land are debushed annually for charcoal production, mainly on commercial livestock farms in central and northern Namibia. The *Growth Strategy* indicates that this number increased to as much as 400,000 ha if the charcoal production sector is adequately supported and expanded.

The *Growth Strategy's* first objective is to "Increase the industry's contribution to debushing by means of improved production planning and sustainable management of the natural resource base." The *Growth Strategy* aims to increase the bush harvesting area for charcoal production by 70% between 2014 and 2020. The production and use of bush-based charcoal briquettes is also supported by the *Growth Strategy*, which states that charcoal briquettes could help reduce the pressure put on Namibian forests from fuelwood collection. The reduced pressure on forests would result in greater GHG removals.

The FSC National Forest Stewardship Standard of Namibia (Draft V1.0)

The Forest Stewardship Council (FSC) is an international, non-profit organization that promotes sustainable forest management. The FSC promotes sustainable management through a comprehensive certification system for forest products. For example, some Namibian charcoal producers have pursued FSC certification of their charcoal. To achieve FSC certification, a charcoal producer must follow guidelines on how the encroacher bush should be thinned, on how labour should be supported, and more. Before certification can be achieved, an approved FSC auditor must inspect the charcoal producer's operations to ensure that the guidelines are being followed.

The FSC allows for individual countries to establish their own local FSC standard that is better tailored for local conditions than a generic, international standard. This has been underway in Namibia, and is nearly completed. A six-person Standard Development Group (SDG) was established in Namibia to investigate how local environmental, economic and social conditions should be incorporated into the Namibian FSC Standard. This involved a significant consultation with local experts / stakeholders in the Namibian forestry and biomass products sectors.

The *FSC Standard for Namibia* is relevant to climate change adaptation and mitigation in that it affects how bush thinning is performed, which affects the carbon balance of the affected rangeland/woodland, it's biodiversity and how much rain water is able to recharge aquifers.

PART 2: OTHER COUNTRIES

For comparison purposes, a survey was performed of the climate change policy frameworks of other countries to find and review policies that are relevant to bush control and biomass use. The survey was focused on the policies of African countries and countries that have had experience with bush encroachment.

Australia

The *2017 Review of Climate Change Policies* was produced by the Commonwealth of Australia and provides an overview and discussion of Australia's climate change policy framework. The *2017 Review* discusses how, in 2014, the Australian government established the *Emissions Reductions Fund* which it now considers as the centerpiece of its climate change policy and one of the world's largest carbon offset markets. With respect to climate change mitigation and adaptation relevant to bush control and biomass use, the *2017 Review* describes how the Fund has provided millions of Australian dollars' worth of support to savanna fire management initiatives. The Fund supports early dry season fire management so that larger, high intensity fires are avoided later in the season. The *2017 Review* states that the fire management initiatives mitigate GHG emissions, preserve biodiversity, and contribute to agricultural productivity and food security.

Australia's renewable energy policy is called the Renewable Energy Target (RET). The RET scheme aims to ensure that 20% of Australia's electricity generation capacity is based on renewable energy sources by the year 2020. The RET is an important part of Australia's GHG mitigation strategy. The report, *Overview of Bioenergy in Australia* (2010) was produced by the Commonwealth of Australia and provides an overview of Australia's bioenergy sector. There are a number of biomass-based power stations in Australia that contribute to Australia's 20% renewable target for electricity generation. The power stations combust biomass in the form of wood & wood waste and agricultural waste.

In the policy-related report, *Australian Agriculture: Reducing Emissions and Adapting to a Changing Climate, Key findings of the Climate Change Research Program* (2013), states that biochar could play an important role in improving moist or irrigated agricultural soils (buy not dryland soils) by both providing long-term carbon storage and reducing nitrous oxide emissions. Biochar could thus be employed as both an effective soil amendment and new opportunity for GHG mitigation.

South Africa

South Africa has a well-developed climate change policy framework. With respect to biomass use, South Africa's *Third Annual National Communication to the UNFCCC* (TNC), identifies biomass energy and biochar as two options for GHG mitigation to be further developed. Restoration of thickets, woodlands and forests are also listed areas to be further developed to increase carbon sequestration.

In the Forward to South Africa's *White Paper on Renewable Energy* (2003), attention is given to the health hazards of using firewood on a daily basis, as is done in so many South African households. The *White Paper* calls for the problem to be addressed by the use of cleaner technologies. The White Paper also considers biomass for heat and electricity generation and states that the biggest opportunities are where both the heat and electricity can be used, such as for certain large industries.

It should be noted that although there are academic research papers that discuss the problem of bush encroachment occurring in South Africa, including one that indicates 10-20 million ha of land of impacted (Ward, 2005), discussions of bush encroachment were not identified in the government policy documents reviewed.

Zimbabwe

Zimbabwe's National Climate Change Response Strategy (2018) identifies the use of biomass for household cooking and heating as one of the country's most serious sources of air pollution. Fuelwood accounts for 60% of the country's energy supply. Fuelwood is high not only in rural areas but also in urban areas due to widespread interruptions of electricity supply. In addition to GHG emissions, the combustion of biomass for cooking and heating releases dangerous short-lived climate pollutants, such as black carbon. The *Response Strategy* calls for the promotion and use of cleaner cooking technologies.

Bush encroachment is mentioned in the *Response Strategy* as problem occurring in Zimbabwe's rangelands as a result of overgrazing and soil erosion. Veldt fires are another problem that greatly impact Zimbabwe's rangelands. The *Response Strategy* call for strategies to reduce the over-exploitation (like overgrazing) of natural resource and to reduce veldt fires.

Botswana

Botswana does not yet have a climate change policy and strategy, but it is in the process of developing them. The UNDP estimates that 46% of households in Botswana rely on fuelwood for their daily cooking.

Botswana's *10th National Development Plan (NDP10)* proposes increased use of solar and biofuel renewable technologies to improve its energy security.

Vision 2036 indicates that Botswana will develop new generation capacity to become less dependent on electricity imports. However, *Vision 2036* states that the development of new generation will be coal-based, using Botswana's large coal resources.

Botswana has a *Biomass Energy Strategy* (2009). That *Strategy* states that approximately 53% of rural households and 13% of urban households rely on wood for daily cooking at the time of the writing of the *Strategy*. Bush encroachment is not mentioned much in the *Strategy* but there is a list of estimated land areas with different cover types. One of the cover types listed is "mixed savanna including bush encroachment", which has an estimated area of 3,714,100 ha. Later in the *Strategy*, there is a discussion of biomass technology options. With respect to woody biomass, the following are considered: fuel-efficient biomass stoves for household use, and gasification of encroacher bush for electricity generation. Biomass combustion for electricity generation is considered for municipal waste but for some reason not for woody biomass from bush encroachment. The strategy performs cost-benefit analyses of the different options and concludes that fuel-efficient biomass stoves offer the best cost-benefit ratio. Gasification of encroacher bush is indicated to be less attractive. The following statement is made regarding biomass technologies:

> "Gasification and charcoal production that can be produced from invasive species will reduce carbon sink and contribute to GHGs. While improving the grazing areas and freeing arable land for the farmers, the tree cutting may disturb the biodiversity, unless the source of woody biomass is sustainable."

In the end, the *Strategy* recommends that two biomass technologies are supported for further development: fuel-efficient biomass stoves for household and institutional use, and charcoal production from encroacher bush.

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ANNEX 3 STAKEHOLDERS CONSULTED DURING THE FIELD MISSION IN NOVEMBER 2018

Table 21: Local Expert consultation

National Experts	Topics Covered
Colin Lindique, N-BiG	Wide-ranging discussion of various topics such as harvesting technologies, identification of local experts and key stakeholders, basic bush encroachment information, and more
GIZ BCBU staff members	Identification of local experts and key stakeholders, and more
Jasper Saint-Paul, GIZ BCBU charcoal expert	Namibian charcoal sector and charcoal technologies
John Pallet & Peter Tarr, SAIEA	Available GIS information, views on causes of bush encroachment and different harvesting technologies, aftercare, and more
Dr. Dave Joubert, consultant	Available information/research and local experts regarding bush density, soil carbon, bush characteristics, sustainable harvest guidelines, and more
Grant Moller and Gordon Gadney, NamPower	Available information on NamPower's planned biomass power station and studies on large-scale bush harvesting.
Dr. Dagmar Honsbein, iDEAL-x Integrated Scientific Services	Views on sustainable harvest guidelines, available information regarding large-scale harvesting and different biomass energy technologies
Colin Nott, consultant	Views and available information regarding rangeland management, bush encroachment and aftercare
Dr. Angombe, UNAM	Available information on relationship between soil carbon and bush encroachment
Matti Nghikembua, Cheetah Conservation Fund	Sustainable bush harvesting, harvesting technologies, bush bloks, charcoal, charcoal retorts, and availability of information on the relationship of grass biomass vs density of encroacher bush
David van Breda, Biomass Producers Namibia	Details of large-scale bush harvesting and technologies
Dr. Ibo Zimmerman, NUST	Views and available information regarding the causes of bush encroachment; sustainable harvesting, aftercare and rangeland restoration; composting and biochar; and more
Amon Andreas, MET	Views and available information regarding bush encroachment density mapping, aftercare and climate change
Jerome Boys, MAWF	Details about his PhD research on bush regrowth after harvesting, aftercare, available information, and more
Anton Dresselhaus, Ankawini	Details about all aspects of making and using bush biomass-based animal fodder
Dr. Cornelis van der Waal, consultant	Details and available information about the relationship between grass biomass, soil carbon and bush encroachment
Michael Dege, Namibia Charcoal Association	Provided information on emissions testing of Namibian charcoal kilns and retorts
Dr. Axel Rothauge, AgriConsult Namibia	Views and available information on harvesting technologies, sustainable harvesting, fence poles, and grass biomass.

UNIQUE forestry and land use GmbH
Schnewlinstraße 10
79098 Freiburg

Tel.: +49 (0) 761 - 20 85 34 - 0
unique@unique-landuse.de
www.unique-landuse.de