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CARBON FLOW ANALYSIS IN THE SOUTH AFRICAN FOREST AND THE FORESTRY SECTOR

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19 December 2014

DECLARATION

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ABSTRACT

Material flow analysis is a systematic assessment of the flows and stocks of materials in a well-defined system. It is based on the law of the conservation of mass and this characteristic makes the material flow analysis method attractive as a decision-support tool in resource management as it delivers complete and consistent information about all flows and stocks of materials in the system.

This study is one of five studies on carbon flow analysis in the forest, paper and pulp industry and the results obtained will be compiled with results from the other studies and integrated into static and dynamic models for a complete analysis of the entire forest product sector value chain. The ultimate objectives of all five studies are:

- To understand how carbon fluxes both in and out of the forest affects the total forest carbon stock
- Estimate the total quantity of wood to be harvested in order to make the forest region carbon positive or neutral
- Determine the most beneficial use of wood in terms of paper making, furniture making or wood pulping.

This study is limited to the carbon fluxes in and out of the South African plantation forests, and estimates the threshold harvest which will make the forest carbon neutral.

The commercial forests in South Africa have a total area of 1.27 million ha, with 83 % under private sector ownership and 17 % under public ownership. The predominant species grown in the plantations are *Pinus patula* (Pine), *Eucalyptus grandis* and *Acacia mearnsii* commonly known as black wattle. The wood harvested is grouped into two categories: softwood and hardwood. Softwood is wood produced by coniferous trees for example *Pinus patula*, and hardwood is wood produced by broad leafed trees such as *Eucalyptus* and *Acacia*.

The overall aim of this study was to analyse carbon stocks and flows in the South African plantation forests by applying the Material Flow Analysis Tool. The scope of this study is limited to the carbon flows through the commercial forest plantations, as such, timber import flows, and flows from indigenous forests and woodland forests are not considered. In the model, the input flow corresponds to tree growth (carbon sequestered in the forest) whereas the output flow is the removal of carbon from harvesting wood and also from carbon released to the atmosphere via damage such as fires or insect infestation.

It was hypothesised that the total plantation forest carbon stock decreases annually as a result of forest management activities and continuous usage of forest products. The total area under commercial forests was divided into 12 forest regions consistent with the report on commercial timber resources and primary roundwood processing in South Africa (2011). It was shown the entire region is, as a whole carbon positive. Six out of the twelve forest regions were carbon positive with respect to forest management activities in the year 2011. In these regions, more trees were being grown than were being harvested, hence the forest stock gradually increased. Also it was found that these regions are not sensitive to changes in input nor output flows.

The hypothesis was proven for the other six forest regions namely Mpumalanga Central Districts, Mpumalanga South, KwaZulu-Natal Maputaland, KwaZulu-Natal Midlands, KwaZulu-Natal South and the Eastern Cape forest regions. In these regions, fewer trees were being grown and there was less carbon input into the forest than was being removed from harvesting or damages. It was found that these regions with the exception of the Eastern Cape forest region, are extremely sensitive to carbon flow changes with the carbon stock change being positive or negative with slight changes in the input or output flows. It was suggested that more trees be grown, trees with greater mean annual increments or hybrid trees be planted in these regions. Further, the quantity of wood harvested should be substantially reduced or else the forest carbon stock will be depleted year after year.

The total tree growth in the forests in 2011 was 5.328 million ton carbon (dry mass) and this offset the total carbon emission from all industries and processes in South Africa by 6.1 %. It was concluded that, when the forest absorptions together with the pulp and paper making process emissions are combined, the net result was carbon dioxide absorption and a tax offset mechanism could be implemented to recognise the sequestration effects of private company owned plantations in South Africa.

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LIST OF ABBREVIATIONS

CO_2e	Carbon dioxide emitted
DAFF	Department of Agriculture, Forestry and Fisheries
DOM	Dead Organic Matter
DWAF	Department of Water Affairs and Forestry
EIA	Environmental Impact Assessment
FAO	Food and Agricultural Organisation of the United Nations
FSA	Forestry South Africa
HWP	Harvested Wood Product
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Analysis
MAI	Mean Annual Increment
MFA	Material Flow Analysis
NTFP	Non-Timber Forest Product
PAMSA	Paper Manufacturers' Association of South Africa
SA	South Africa
SOC	Soil Organic Carbon
Ton C d.m	Ton carbon dry mass

NOMENCLATURES

A	Area of land (ha)
$BCEF_R$	Biomass conversion and expansion factor
ΔC	Annual carbon stock change in a pool (ton C y^{-1})
ΔC_F	Carbon stock change in the forest
ΔC_B	Carbon change in forest biomass
ΔC_{DOM}	Carbon change in dead organic matter
ΔC_{SO}	Carbon change in forest soils
ΔC_{HWP}	Carbon change in harvested wood products
ΔC_G	Annual gain of carbon (ton C y^{-1})
ΔC_L	Annual loss of carbon (ton C y^{-1})
C_{t1}	carbon stock in the pool at time t_1 (ton C y^{-1})
C_{t2}	carbon stock in the pool at time t_2 (ton C y^{-1})
ΔC_{BG}	Annual increase in carbon stock due to biomass growth (ton C y^{-1})
ΔC_{BL}	Annual decrease in carbon stock due to biomass growth (ton C y^{-1})
CF	carbon fraction of dry matter (ton C per ton d.m)
D	Basic wood density (ton d.m. m^{-3})
EF	Emission factor for climate type c (ton ha^{-1} y^{-1})
G_{Total}	Mean annual biomass growth (ton C y^{-1})
G_w	average annual above-ground biomass growth for a specific wood type (ton d. m. ha^{-1} y^{-1})
H	Annual roundwood removals (m^3 y^{-1})
i	Ecological zone
j	Climate domain
$L_{Harvest}$	Annual carbon loss from harvesting (ton C y^{-1})
$L_{fuel\ wood}$	Annual carbon loss due to fuel wood removal (ton C y^{-1})
R	Ratio of below-ground biomass (dry mass) to above-ground biomass (dry mass) for a specific wood type

GLOSSARY

Above-ground biomass	All biomass of living vegetation above the soil including stems, stumps, branches, bark, seeds, and foliage
Bark	Covering of branches, stems and roots
Basic wood density	Ratio between oven dry mass and fresh stem-wood volume without bark
Below-ground biomass	All biomass of live roots. Fine roots of less than 2 mm are excluded as they cannot be distinguished from soil organic matter or litter
Biomass conversion and expansion factor	A multiplication factor that coverts merchantable volume of growing stock to above-ground biomass
Carbon content	Absolute amount of carbon in a pool or parts of it
Carbon fraction	Tonnes of carbon per tonne of biomass dry matter
Carbon stock	The quantity of carbon
Dead wood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground or in the soil
Disturbance	An environmental fluctuation or destructive event such as fires, pollution, insect infestation, etc. that affects forest health and vitality
Dry matter	Biomass that has been dried to an oven-dry state
Forest	Land spanning more than 0.5 hectare with trees higher than 5 meters and a canopy cover of more than 10 percent
Tree growth	Increase in volume of a tree stand over a given period of time (in $m^3 ha^{-1} y^{-1}$)
Gross primary production	carbon dioxide uptake via photosynthesis
Hardwood	Wood produced by broad leafed trees (no relation to hardness of the wood). Hardwood trees grow faster than softwood trees but have shorter fibres compared to softwood.
Litter	Includes all non-living biomass with a size greater than the limit for soil organic matter (2 mm) and less than the minimum diameter chosen for dead wood (e.g. 100 mm), lying dead, in various states of decomposition above or within the soil

Material	A material is a chemical element or its compound. Material fluxes are measured in mass per time.
Material Flow Analysis	It is a method to describe, investigate and evaluate the metabolism of anthropogenic and geogenic systems.
Net primary production	Total production of biomass and dead organic matter in a year
Pulpwood	The raw material for newsprint and Kraft paper production
Soil organic carbon	Live and dead fine roots and dead organic matter within the soil, that are less than the minimum diameter limit (2 mm) for roots
Softwood	Wood produced by Coniferous trees. Generally grown in cold climates. Softwood trees grow slower than hardwood trees but have longer fibres compared to hardwood trees.
System	A group of elements, interactions between these elements and the boundaries between these and other elements
Wood	Hard part of the stem of a plant lying between the pith and the bark
Yield	Volume produced by a tree stand at the end of a certain period (in m^3 ha^{-1})

1. AN INTRODUCTION TO THE STUDY

This chapter introduces the research topic, outlines the main aims and objectives of the study, hypothesis and research questions and gives a structure in which the dissertation will be presented.

1.1 Problem statement

Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials in a well-defined system. The MFA tool is based on the law of conservation of mass and this characteristic makes MFA attractive as a decision-support tool in resource management. This study seeks to assess the carbon stock in South African plantation forests by analysing the carbon fluxes in and out of the forests. A number of tools could be used to assess the forest carbon stock such as Material Flow Analysis (MFA) and Life Cycle Assessments (LCA). The Material Flow Analysis model was developed and used in this study as it delivers complete and consistent information about all flows and stocks of carbon in the system.

The Material Flow Analysis tool is based on the law of conservation of mass which states that total inputs must equal total outputs plus net accumulation, and it is used to determine the flow of materials, (e.g. carbon, water, energy and nutrients etc.) in a well-defined system. The system under consideration is the commercial forest in South Africa and the flows are limited to the flows of carbon within, into and out of the forest. Other flows such as water, energy, nutrients and minerals are not considered and fall beyond the scope of the study.

This study is one of five studies on carbon flow analysis in the forest, paper and pulp industry and the results obtained will be compiled with results from the other studies and integrated into static and dynamic models for a complete analysis of the entire forest product sector value chain. Organisations such as the Paper Manufacturers' Association of South Africa (PAMSA) and Forestry South Africa (FSA) could use this completed model to understand how carbon fluxes both in and out of the forest affects the total forest carbon stock; estimate the total quantity of wood to be harvested in order to make the forest region carbon positive or neutral; and determine the most beneficial use of wood. This will assist enormously in decision making on issues regarding forest resource management. This study is limited to the carbon fluxes in and out of the South African plantation forests, and estimates the threshold harvest which will make the forest carbon neutral.

1.2 Background

The forest, paper and pulp industry in South Africa utilizes wood as raw materials, grown mostly in commercial forest plantations. The commercial plantations form a total area of 1.27 million ha and this is only 1.1 % of the total land area of South Africa (122.3 million ha). The plantations are owned by both the public and private sectors and are found mostly in three provinces i.e. Mpumalanga, KwaZulu-Natal and the Eastern Cape. These plantations supply wood to the saw mills (for furniture, board manufacturing and construction), pulp and paper mills (for pulp and paper manufacture), mining timber mills, and pole and charcoal plants. Some of the wood is used as fuel wood and burned for heating purposes and electricity generation. Some of the logs are exported overseas while some are used in production and trade in the country. Eventually all the wood products are consumed and sent to landfills or are incinerated.

1.3 The aims and objectives of the study

The overall aim of this study is to analyse carbon stocks and flows in the South African forest and forestry sector using the Material Flow Analysis Tool.

The specific objectives therefore are:

a) To collect and delineate the time series data on carbon stocks and flows within South African plantation forests
b) To reduce the complexity of the forestry system by incorporating the data into a Material Flow Analysis using mass balance principles
c) To present the results about the flows and stocks in an understandable and transparent way
d) To evaluate the importance and relevance of the flows and stocks with respect to their use and
e) To assess the sensitivity of the model to errors and changes

1.4 Hypothesis

It is hypothesised that the total plantation forest carbon stock decreases annually as a result of forest management activities and continuous usage of forest products.

1.5 Research questions

This study will help answer specific questions on the forest and forestry sector. The research questions are therefore:

- How does the flow of carbon into and out of the forest affect the forest carbon stock?
- What is the effect of discrete events such as fires or insect infestation on the forest stock?

1.6 Research approach

The commercial forest plantations in South Africa is divided into twelve forestry zones consistent with the report on commercial timber resources and primary roundwood processing in South Africa (DAFF, 2011). These zones are based on climatic, provincial and economic considerations and are shown in Table 3.1. A mass (carbon) balance on each of the forest regions will be performed and all the results will be combined for a Material Flow Analysis for the entire forestry sector in South Africa.

1.7 Outline of the dissertation

Chapter One introduces the study and outlines the main aims and objectives of the study. This chapter also gives the hypothesis and research questions which will be analysed and concludes with an outline in which the dissertation will be presented.

Chapter Two provides a literature review on Material Flow Analysis and compares it with the Life Cycle Assessment tool. Further, this chapter reviews the forest and forest product sector in South Africa and the methods to estimate changes in forest carbon stock. Further, this chapter provides other studies on Material Flow Analysis of the forest industry and

Material flow analysis using other materials (plastic waste management), and some results from these studies.

Chapter Three outlines the methodology of the Material Flow Analysis model, and the method used to carry out the mass balancing in the study.

Chapter Four presents the results obtained from the mass balancing in each of the forest regions in a clear, understandable and transparent way (i.e. figures and tables).

Chapter Five presents a discussion and interpretation of the results obtained

Chapter Six presents the various conclusions drawn from the study and also gives recommendations

Chapter Seven provides a list of references used in this study and an appendix with the raw data used in the calculation and a sample calculation for the Limpopo forest region

This chapter introduced the research topic, outlined the main aims and objectives of this study and provided a hypothesis and some research questions. The following chapter presents a literature review on material flow analysis, its applications to the forest product sector in South Africa and shows methods for calculating forest carbon stocks and flows.

2. LITERATURE REVIEW

This chapter reviews the Material Flow Analysis tool and compares it with the Life Cycle Assessment tool. It also shows a review on the forest and forest product sector in South Africa and the method to estimate forest carbon stock.

2.1 The sustainability of the forest and forestry sector

Climate change caused by greenhouse gases in the atmosphere is of rising concern globally. Forests are important in the carbon cycle as they sequester carbon dioxide from the atmosphere through the process of photosynthesis. Over time, forests grow and accumulate carbon in living vegetation as biomass, in dead organic matter and in the soil. This ability to remove carbon dioxide from the atmosphere and store the carbon in biomass provides climate mitigation benefits (Trømborg et al., 2011). In total, the world's forests are carbon sinks with a positive net accumulation of carbon with almost one-third of the global green house gas (GHG) emissions ending up in terrestrial systems (Nabuurs et al., 2007).

The forest industry, however, is often perceived in a completely different light due to ill-conceived perceptions created by the public and local media. For example, trees capture carbon as they grow and forests store carbon. When forests are cleared or degraded, their stored carbon is released into the atmosphere as carbon dioxide (CO_2), moreover, clearing forests also destroys globally important carbon sinks that are currently sequestering CO_2 from the atmosphere and are critical to future climate stabilization (Stephens et al., 2007). Therefore one can conclude that trees and forests should be treated as carbon sinks and left alone (Bower et al., 2011). This reflects an incomplete understanding of the role of forests in carbon mitigation. There is therefore a need to understand and assess the forest carbon stock as forests have multiple roles to play in carbon mitigation.

According to Bower et al. (2011), a policy of active and responsible forest management is more effective in capturing and storing atmospheric carbon than a policy of hands-off management that precludes periodic harvests and use of wood products. Analysing carbon flows in the forest is therefore a first step in coming up with an effective policy on active and responsible forest management. This will involve questions such as: is it environmentally beneficial to cut down trees in sustainably managed or unmanaged forest? What is the carbon stock in the forest, and how does the stock change annually? These questions could be answered if the forest carbon stock could be well assessed.

Various tools are available to understand and estimate forest carbon stock, tools such as Material Flow Analysis (MFA) and Life Cycle Assessments (LCA). The Material Flow Analysis Tool delivers complete and consistent information about all flows and stocks of materials in a system and will be developed further in this study. Sections 2.2 and 2.3 discuss the MFA and LCA tools respectively and a comparison between them is made in section 2.4.

2.2 Material Flow Analysis

Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials in a well-defined system (Brunner and Rechberger, 2004). It examines the sources, pathways, intermediate and final sinks of a material in a system. It is based on the law of the conservation of mass which states that total inputs must equal total outputs plus net accumulation of materials in a given the system. This characteristic makes the MFA method attractive as a decision-support tool in resource management (Fisher-Kowalski, 1998) as it delivers complete and consistent information about all flows and stocks of materials in the system. The flows of waste and environmental loadings become available through the balancing of inputs and outputs, and their sources can then be identified. Minor changes that could lead to long term damages also become evident from the analysis.

Material flow analysis involves terminology such as the process, stocks, flows and the system under investigation. The process is defined as the transport, transformation, or storage of materials and are linked by flows or fluxes, whereas stocks are defined as material reservoirs (mass) within the system with units of kilograms or tonnes (Brunner and Rechberger, 2004). Stocks can stay constant, or they can increase in size (accumulation of materials) or decrease in size (depletion of materials). The seclection of substances depends on the purpose of the Material Flow Analysis and also on the kind of system on which the Material flow Analysis is based.

The system is defined by its boundaries in space and time and it is one of the most critical and demanding steps of the MFA as one is trying to represent reality in a simplified manner (Hendriks et al., 2000). The spatial boundary is usually determined by the scope of the project and often coincides with the politically defined region (geographical area) while the boundary in time is usually a period of one year. In general the system should be chosen to be as small and consistent as possible while still being broad enough to include all necessary processes and material flows (Brunner and Rechberger, 2004).

When the system boundary in time is chosen, criteria such as goals and objectives, data availability, appropriate balancing period and residence time of materials within the stocks have to be taken into account. Information about relevant material flows is taken from literature or other sources such as company and national reports and materials less than 1 % of the total system throughput are often neglected (Brunner and Rechberger, 2004). It is often important to check weather these small neglected flows are relevant in view of the objectives of the investigation. Indicator materials such as carbon, energy and water usage are typically selected. The flows/fluxes of the materials entering the process are *inputs* while those exiting are *outputs*. For steady state conditions where total inputs equal total outputs, the mean residence time of materials in the stock can be calculated by dividing the material mass in the stocks by the material flow in or out of the stock in the system.

2.2.1 Material Flow Analysis method

Material flow analysis begins with the problem definition, determination of the system boundaries and the selection of the relevant substances to be investigated. Next, mass flows of the substances are calculated and the uncertainties are considered. This is depicted in Figure 2.1. The results are presented in an appropriate way to visualize conclusions and to facilitate implementation of goal-oriented decisions (Brunner and Rechberger, 2004).

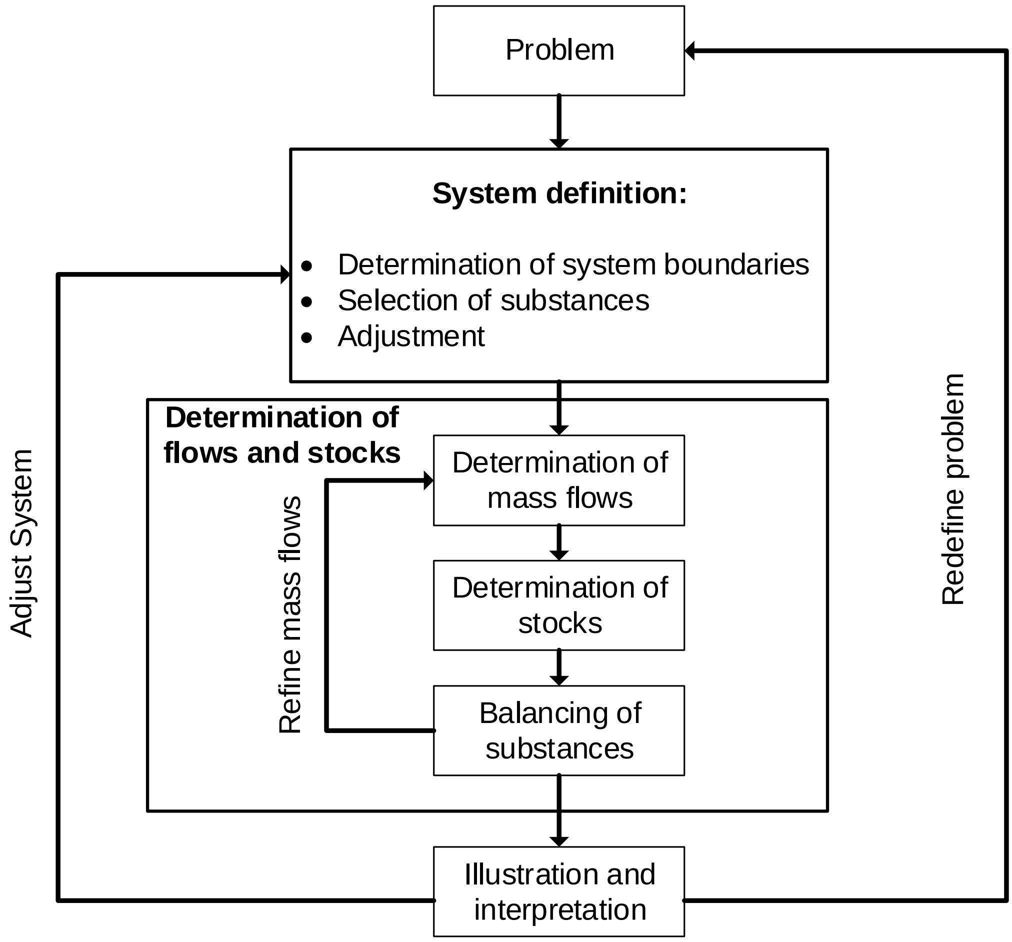

Figure 2.1: MFA procedures and steps (after Brunner and Rechberger, 2004)

2.2.2 Objectives of Material Flow Analysis

Material flow analysis is a suitable tool to analyse the flows and stocks of any material-based system as it gives an insight into the behaviour of the system. According to Brunner and Rechberger (2004), the objectives of MFA are to:

i. Delineate a system of material flows and stocks by well-defined, uniform terms
ii. Reduce the complexity of the system as far as possible while still guaranteeing a basis for sound decision making
iii. Assess the relevant flows and stocks in quantitative terms, thereby applying the balance principles and revealing sensitivities and uncertainties
iv. Present results about flows and stocks of a system in a reproducible, understandable, and transparent way
v. Use the results as a basis for managing resources, the environment, and wastes, in particular for:

a. Early recognition of potentially harmful or beneficial accumulations and depletions of stocks, as well as for timely prediction of future environmental loadings
b. The setting of priorities regarding measures for environmental protection resource conservation, and waste management
c. The design of goods, processes, and systems that promote environmental protection, resource conservation, and waste management.

2.2.3 Applications of Material Flow Analysis

Material Flow Analysis can contribute to the design of better products that are more easily recycled or treated once they become obsolete and the tool can enable quick and flexible reactions to new policy demands through the data structure (Hinterberger et al., 2003). The MFA tool can be applied in diverse areas such as environmental-engineering and management, industrial ecology, resource management, and waste management. It is a basis for life-cycle assessments, Eco balancing, environmental impact statements, and waste-management concepts. This section outlines some of the applications of material flow analysis.

2.2.3.1 Environmental-engineering and management

Environmental engineering is the study of the fate, transport, and effects of substances in the natural and engineered environments and the design and realization of options for treatment and prevention of pollution (Valsaraj, 2000). Environmental engineering require a thorough understanding of the flows and stocks of materials within and between the environment and the anthroposphere. Material flow analysis can therefore be used in a number of environmental engineering applications including remediation of hazardous-waste sites, design of air-pollutions strategies, and sewage and soil management applications. The tool alone will not suffice to assess or support engineering or management measures, nevertheless it is an indispensable first step and should be followed by an evaluation or design step.

2.2.3.2 Industrial ecology

Industrial ecology strives to develop methods to restructure the economy into a sustainable system and to optimise the total materials cycles from virgin materials to finished materials, components, products, waste products and finally to disposal (Jelinski et al., 1992). Material flow analysis is applied in several design principles in industrial ecology such as:

i. Controlling pathways for materials use and industrial processes
ii. Creating loop-closing industrial practices
iii. Dematerializing industrial output

iv. Systematizing patterns of energy use
v. Balancing industrial input and output to natural ecosystem capacity.

2.2.3.3 Resource and waste management

Resource management comprises the analysis, planning and allocation, exploitation, and upgrading of resources (Brunner and Rechberger, 2004). Material flow analysis is applied in resource management for analysis and planning. This is due to the fact that material flow analysis is the basis for modelling resource consumption as well as changes in stocks, implying it is important in forecasting the scarcity of resources.

In waste management, it is a valuable tool in that it can cost effectively determine the elemental composition of waste which is crucial if the goal is to assign a waste stream to the best-suited recycling or treatment technology.

2.2.4 Shortcomings of Material Flow Analysis

Material flow analysisis not used as a standard analytical tool in everyday decisions on materials management as it is yet to achieve a major breakthrough on the level of production, manufacturing, trade and commerce. This is because the accounting of substances is a new, laborious, and costly task, hence most institutions do not see an economic advantage in applying MFA (Brunner and Rechberger, 2004).

Further, aggregated MFA indicators can, to a large extent, be dominated by only one material category which may obscure detailed information on development of other materials leading to misinterpretation of results (Hinterberger et al., 2003).

Weight-based MFA indicators do not tell anything about actual environmental impacts which is a crucial factor in the evaluation of economic development from the perspective of environmental sustainability (Matthews et al., 2000).

Lastly the results are usually presented without uncertainty intervals, and this may give an incorrect impression of accuracy (Danius, 2002).

2.3 Life Cycle Assessments

Material flow analysis is complementary to Life Cycle Assessment (LCA) and some overlaps exist between the different methods as they both share a system and use the mass balance principle. The LCA tool assesses the environmental aspects and potential impacts associated with a product or process by compiling an inventory of energy and material inputs and environmental releases (Curran, 2006). LCA also evaluates the potential environmental impacts associated with inputs and releases and interprets the results to help make informed decisions.

LCA is a “cradle-to-grave” tool for assessing industrial systems. “Cradle-to-grave” means raw materials are gathered from the earth, resource extraction phase ('cradle'), to create the product and ends at the point when all materials are returned to the earth, the disposal phase ('grave'). There are also other variants to LCA such as “cradle-to-gate” and “gate-to-gate.” The “cradle-to-gate” is the assessment of a partial product life cycle from resource extraction to the factory gate before it goes to the consumer while “gate-to-gate” is a partial LCA looking at only one value-added process in the entire production chain (Jiménez-González et al., 2000).

The LCA method assesses the environmental aspects and potential impacts associated with a product by (John, 2007):

- Compiling an inventory of relevant inputs and outputs of a system,
- Evaluating the potential impacts associated with those inputs and outputs,
- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

2.3.1 The Life Cycle Assessment Method

The model comprises of four phases, namely, the goal and scope definition, inventory analysis, impact assessment and interpretation (ISO-14040, 2006). The relationship between the phases is illustrated in Figure 2.2.

According to Curran (2006), the goals and definition describes the product, establishes the context in which the assessment is to be made and identifies the boundaries and environmental effects to be reviewed. The inventory analysis identifies and quantifies energy, water and material usage and environmental releases. The impact assessment assesses the potential human and ecological effects of energy, water, and material usage and the environmental releases. And finally the interpretation evaluates the results of the inventory analysis and impact assessment to select the preferred product with a clear understanding of the uncertainty and the assumptions used to generate the results.

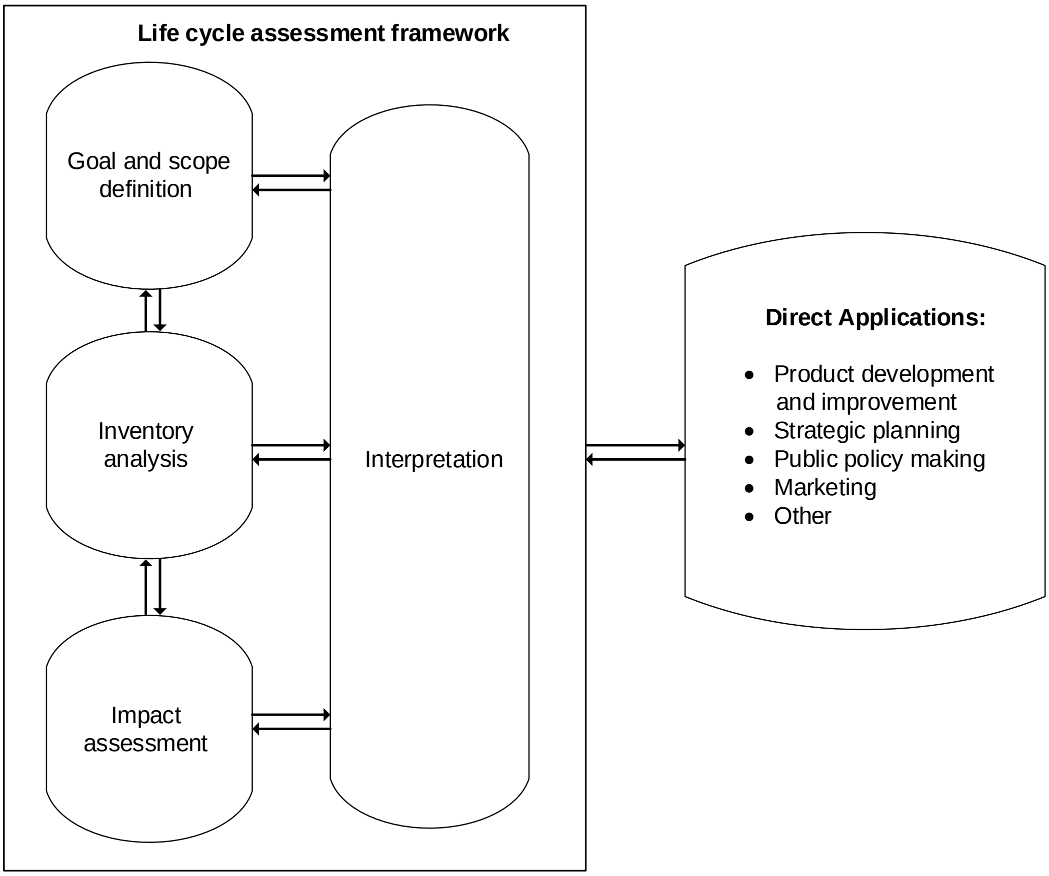

Figure 2.2: Phases of an LCA (ISO-14040, 2006).

2.3.2 Benefits of Life Cycle Assessments

There are many benefits of performing an LCA study on products but only a few are mentioned in this report.

- LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product and process selection
- A Life Cycle Assessment could be used to help decision-makers select the product or process that results in the least impact to the environment (Curran, 2006)
- The transfer of environmental impacts from one media to another is easily identified with the data collected from an LCA study
- An LCA study can help to quantify environmental releases to air, water, and land in relation to each life cycle stage and/or major contributing process
- Finally, analysts can use LCA to compare the health and ecological impacts between two or more rival products/processes or identify the impacts of a specific product or process.

2.3.3 Shortcomings of Life Cycle Assessments

Conducting an LCA study on a product or process is very resource and time intensive depending on how thorough the user wishes to conduct the study. Also the LCA data are not easily available hence the gathering of data is very problematic and time consuming. Finally LCA does not determine which product or process is the most cost effective, hence the information should be used with a more comprehensive decision process tool which assesses cost and performance.

2.4 Comparison between Material Flow Analysis and Life Cycle Assessments

Both tools comprise of a system with system boundaries and materials flow in and out of the system. A basic mass balance on the system is performed to have a sense on the flows. Both tools require the collection of large amounts of data which is usually laborious and time consuming.

MFA is less complex compared to LCA and it comprises just a simple mass balance around the system based on the law of conservation of mass. LCA on the other hand takes into account the major activities in the course of the product's life-span, from its manufacture, use and maintenance, to its final disposal.

LCA is structured around a functional unit which is a measure of the function of the studied system and it provides a reference to which the inputs and outputs can be related (John, 2007). MFA, on the other hand, is based on indicator materials such as carbon, energy or water usage.

Finally, LCA addresses the environmental aspects and impacts of a product system while weight-based MFA indicators do not tell anything about actual environmental impacts.

2.5 Forest and forest resources in South Africa

Forests are essential to the protection and conservation of the soil, and play a vital part in water cycling. South Africa is lightly forested with forests scattered eastwards from the Cape Peninsula through the Outeniqua mountains of the Southern Cape, through the midlands of the Eastern Cape, and into KwaZulu-Natal (FAO, 2012). Northwards, the forests are found along the Drakensberg mountains of KwaZulu-Natal and the incline of Mpumalanga and Limpopo Provinces.

2.5.1 Forest and plantations

In terms of the National Forests Act (1998), forests include all natural forests, plantations and woodlands as well as the forest products produced from it (DWAF, 2005b). According to the Department of Agriculture, Forestry and Fisheries (DAFF), natural forests and woodland forest provide little wood suitable as raw material for the forest industry hence the wood demand in South Africa is met predominantly from commercial forest plantations. The total land area in South Africa is 122.3 million ha and only 1.1 % of this area is covered by commercial plantations. The plantations are owned by both the public and private sector with 83 % of the plantation area under private sector ownership and the other 17 % under public ownership (FSA, 2011). Individuals and partnerships (family trusts), own only 12.8 % of the plantation area of which with areas of less than 500 ha.

These plantations supply raw materials (wood) to the sawmills, pulp and paper mills, mining timber mills, pole plants and charcoal plants which then process the raw materials (DAFF, 2013). Figure 2.3 shows the locations of major commercial plantations in South Africa. More detail of this information is shown in Table 2.1.

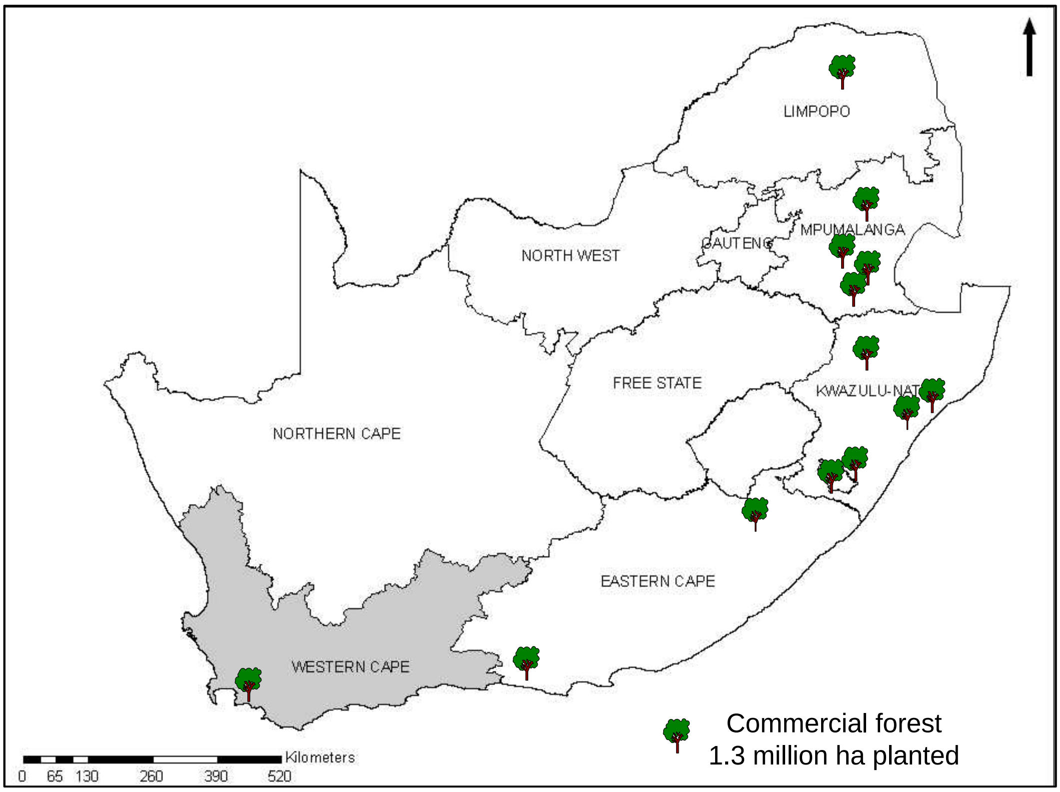

Figure 2.3: Locations of commercial plantations in South Africa (Kerr, 2013, StatsSA, 2013).

Table 2.1: The 2011 reported plantation area by province (DAFF, 2011)

Province	Afforested Area [ha]	Afforested Area [%]
Limpopo Province	48 280	3.8
Mpumalanga	518 700	40.7
North West Province	304	0.0
KwaZulu-Natal	503 200	39.5
Eastern Cape	141 400	11.1
Western Cape	61 450	4.8
	1 273 000	100

2.5.2 Wood species and types

The predominant genera grown in the plantations are *Pinus* (Pine), *Eucalyptus* and *Acacia*. Wood is a key raw material to which value is added in many industries for construction of houses and buildings, furniture, pulp and paper manufacture etc. The wood harvested for pulp and paper is generally grouped into two categories: softwood and hardwood.

Softwood is wood produced by coniferous trees and have a rotational age typically from eighteen to thirty years. They are mainly grown for sawn timber and pulpwood markets (Budhram and Kerr, 2005). In South Africa the softwoods species are dominant in the Northern and Southern regions of the country with the most extensively planted species being the *Pinus patula*. This species comprises 51.3 % of the total softwood forestry area and occurs mainly in Mpumalanga, KwaZulu-Natal and the Eastern Cape provinces (FSA, 2011). Other softwood species grown are *Pinus elliottii*, comprising 27.4 % of the softwood plantation area and is found in all regions except the Western Cape, and *Pinus radiata* which is mainly confined to the Cape regions (DAFF, 2011).

Hardwood is wood produced by broad leafed trees. Examples are *Eucalyptus* and *Acacia* and are dominant in the middle regions i.e. KwaZulu-Natal and Mpumalanga South. The dominant hardwood species in South Africa is *Eucalyptus grandis*, and it accounts for 49.2 % of the total hardwood forestry area. Hardwoods are grown primarily for pulpwood and mining timber production on an eight to twelve year rotation which explains the relative young ages of Eucalyptus plantations.

2.5.3 Primary management purpose of plantations

Plantations are generally grown for a specific purpose for example; sawlog production, pulpwood or mining timber production and this dictates the appropriate silvicultural practice. Table 2.2 shows the intended purpose for which softwood and hardwood plantations are grown. Of all the plantations, 56 % are managed for pulpwood, 36 % for sawlog, 4 % for mining timber and 4 % for other purposes. Softwood plantations are managed mainly for sawlog production (68 %) while hardwood plantations are managed mainly for pulpwood production (83 %).

Table 2.2: Purpose of plantations in South Africa (DAFF, 2011)

Product	Softwood [%]	Hardwood [%]
Sawlogs	68	3
Pulpwood	30	83
Mining Timber	-	9
Other	2	5
Total	100	100

2.5.4 Effect of the forest industry on the economy

The commercial forest industry is a major rural job and wealth creator for South Africa, which is estimated to economically support nearly 2 % of South Africa's population (DWAF, 2005b). The industry employs more than 135 000 people both in primary production and primary wood processing operations (FAO, 2012).

The forest industry has a very large rural foot print which helps eradicate poverty in the rural areas in South Africa. The industry offers opportunities for individuals or group enterprises in growing trees, contracting, wood processing, or harvesting and processing products of the forest. The great attraction is that it does not require high skill levels and people with limited education and few resources can find opportunity in the forest sector.

Further the industry provides a significant number of informal economic activities which estimated to between 3 and 4 billion rand in household income annually from non-timber forest products and fuelwood, and these activities support a large proportion of the rural population (DWAF, 2005a).

The forestry and forest product sector contributes about 1.2 % to gross domestic product (GDP) (Dyer and Wingfield, 2005). Regionally this is distributed in the respective provinces as 4.5 % in KwaZulu-Natal, 4.7 % in Mpumalanga, 0.9 % in the Eastern Cape and about 0.5 % in Limpopo (Anon, 2013a).

Forestry also provides 4 % of South Africa's total annual exports which contributes R6 billion per annum to the foreign exchange earnings and contributes 10 % of manufacturing employment (DWAF Annual Timber Statistics, 2003).

2.5.5 Impacts of the industry on society and the environment

Millions of South Africans live in or close to the nation's forests and woodlands, and obtain part of their livelihoods from non-wood forest products such as medicinal plants, ornaments, fodder, wild fruits, nuts, vegetables and bush meat (FAO, 2012).

Forestry also brings other benefits to people's lives for example the commercial forest industry invests R80 million p.a. on schools, roads, health clinics, and many community-based initiatives (Anon, 2013a).

Forests are crucial to the protection and conservation of the soil, and in water cycling as they help modulate water flows and reduce sedimentation in streams and reservoirs. The relationship between forests and water is very important but this is outside the scope of this study.

Forestry may impact the environment in many ways; according to FAO (2014), forest activities may

- Eliminate or damage nesting sites including hollow trees and some animals may be killed outright or displaced, which could induce reproductive and other stress in existing animal populations in uncut forest.
- Logging may increase ground temperatures and lower atmospheric humidity locally which in turn may interfere with seedling growth and micro-organismis in the soil.
- Afforestation in semi-arid regions may deplete soil moisture, lower water tables and result in decreased groundwater recharge and baseflow and this negative effect may be in part offset by increased infiltration capacity of soils under forest.

2.5.6 The forest sector value chain in South Africa

The carbon cycle in the forest can be defined as the combined processes including photosynthesis, respiration and decomposition, where carbon moves between the atmosphere, soils, water, and living organisms (Anon, 2011). The cycle can be extended to include harvested wood, manufacturing, production, trade and consumption of timber and paper products as well as the use and disposal of the products.

The main source of fibre and timber for the forest sector value chain is from the roundwood produced from industrial plantations. The roundwood production and the primary processing activities using roundwood generate more than 90 % of the revenue in the value chain, but this represents only about 60 % of roundwood consumption in South Africa (DWAF, 2005b). Other volume consumption is from the use of roundwood for fuel, construction and other purposes in rural livelihoods. Figure 2.4 summarises the South African forest sector value chain, showing forest products and primary processing production activities. NTFP stands for Non-Timber Forest Product, and it is any biological resource harvested from forested lands by rural households for domestic consumption or small-scale trade, with no or limited capital investment (Shackleton, 2004).

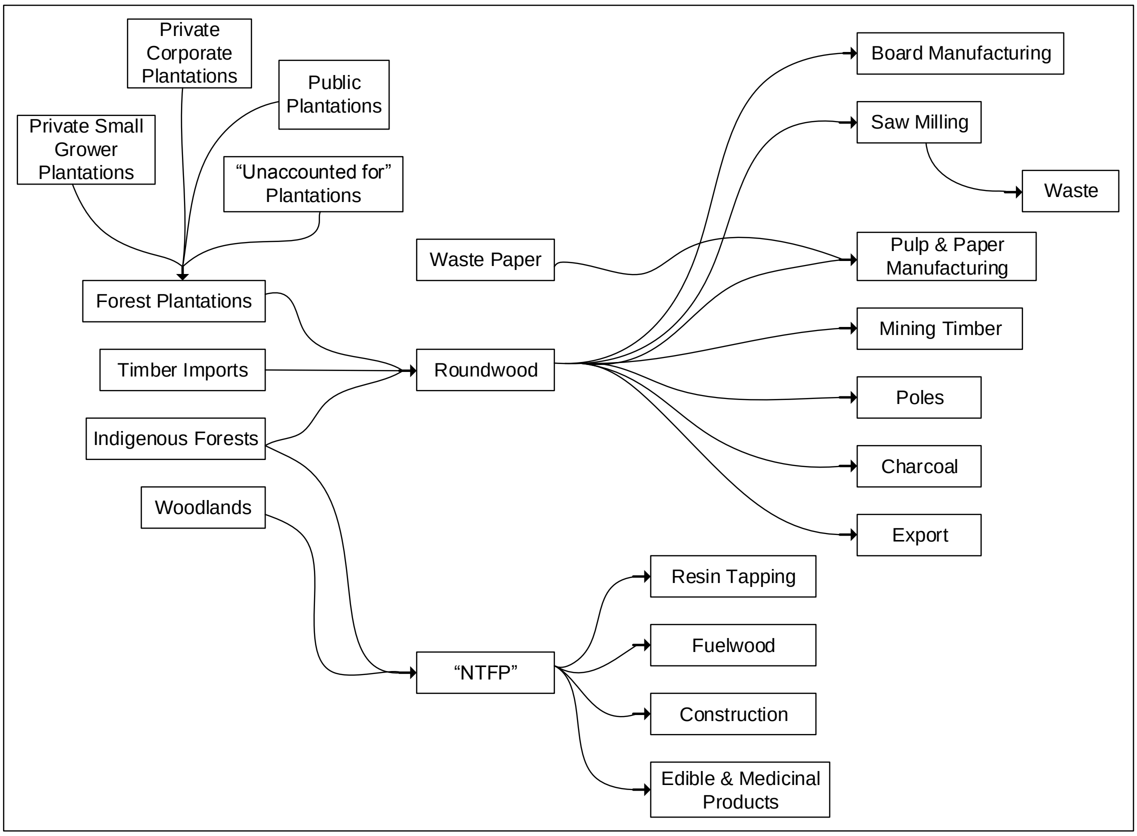

Figure 2.4: South African forest sector value chain (DWAF, 2005b).

The South African forest plantations include the private corporate plantations, public plantations and private small grower plantations. The private plantations are owned by individuals and partnerships, companies and close corporations and associations, educational or religious institutions. The public plantations, on the other hand, are owned by the South

African Forestry Company Limited (SAFCOL), government departments and local authorities.

Carbon flows in the forest comprise of all carbon removal from the atmosphere via the process of photosynthesis and carbon is released to back to the atmosphere via continuous processes such as respiration and decomposition and carbon emissions from discrete events like fires and storms. Harvesting of roundwood also removes carbon from the forest and this is used in the production of many products such as furniture, poles, pulp and paper, match-boxes etc. Some of these products, such as waste paper, are recycled but they eventually find their way to landfills or are degraded or incinerated and the carbon is returned to the atmosphere.

The pulp and paper industry is part of the forest sector value chain and is characterized by rapidly increasing economies of scale (DWAF, 2005b). The pulp and paper industry has to constantly increase its processing capacity for the industry to remain active which results in an increase demand for roundwood.

There are also additional carbon flows from imports and from indigenous forests to the forest sector. This report is limited to the flows in the commercial forest plantations, as such, timber import flows, and flows from indigenous forests and woodland forests are not considered. The scope of this study is shown in Figure 2.5.

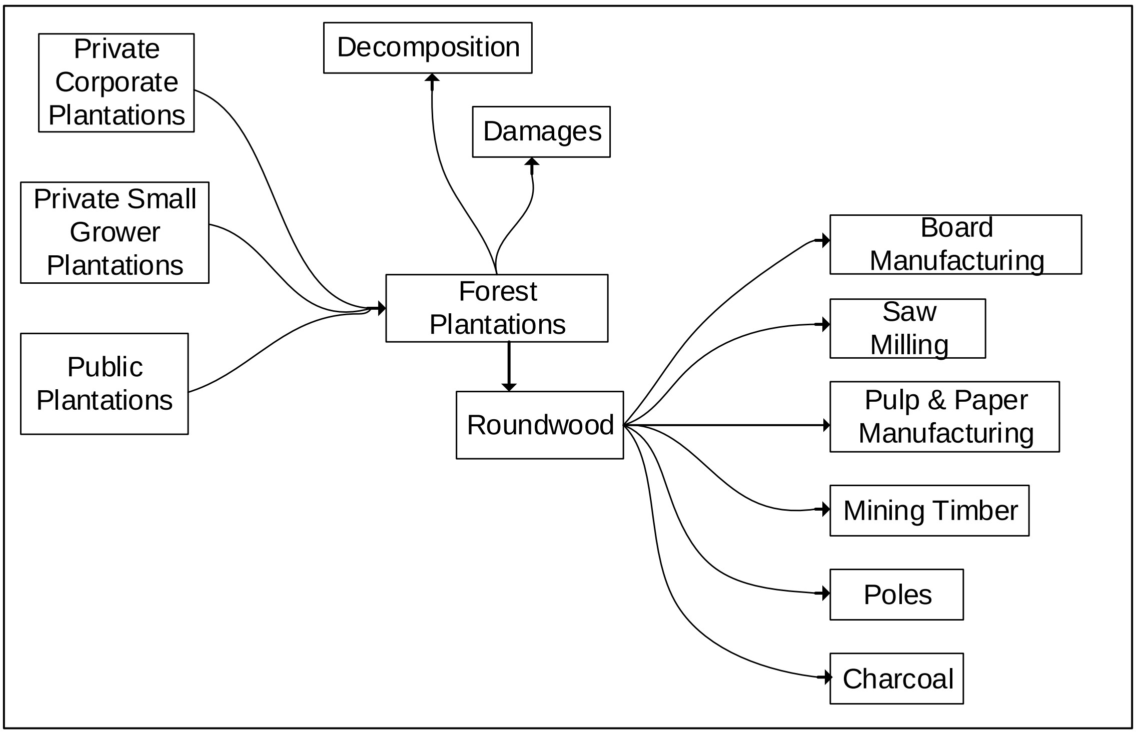

Figure 2.5: Scope of the study.

2.6 Forest carbon pools

Material inputs to forests consist of water, carbon dioxide from the air, nitrogen fixation also from the air, and minerals and nutrients from the top soil (Ayres and Ayres, 1998). Carbon makes up about half of the dry weight of wood and it is contained in the bark, roots, branches and leaves of trees and also in the forest soil and litter (Bower et al., 2011). The carbon stock in the forest may be based on three aggregate carbon pools, namely: biomass, dead organic matter and soil organic carbon.

2.6.1 Living biomass

Forest biomass includes both above-ground and below-ground biomass. Above-ground biomass is made of all biomass of living vegetation above the soil including stems, stumps, branches, bark, seeds, and foliage. The above-ground living biomass is the largest pool and the most directly impacted by forest management activities (Gibbs et al., 2007). The main channel for carbon dioxide removal from the atmosphere is forest biomass through the process of photosynthesis. Under normal growing conditions, photosynthesis leads to an increase in the amount of carbon stored in forests whereas metabolic changes such as respiration and decomposition and physical changes such as fires and insect infestations decrease the carbon in the forest (Anon, 2013b).

Carbon dioxide uptake via photosynthesis is referred to as gross primary production (GPP) and about half of the GPP is respired by plants, and returned to the atmosphere, with the remainder constituting net primary production (NPP) (Keith et al., 2006). Carbon accumulates quickly in the forest in the first few years because the growth rate in young forest is relatively high. As a forest matures, the growth rate slows down and the ability to sequester new carbon drops and eventually falls off quickly. Figure 2.6 shows the growth curve for *Pinus patula* . See Table A1 in **Appendix A** for growth curves for different species.

Below-ground biomass is made of all biomass of live roots. It is typically estimated to be 20 % of the above-ground forest carbon stocks (Houghton et al., 2001).

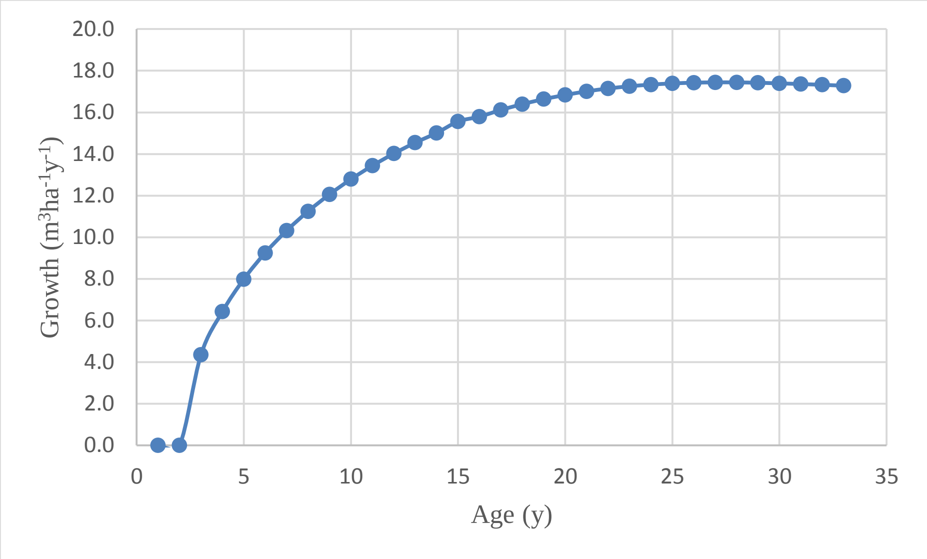

Figure 2.6: Growth curve for *Pinus patula* (Godsmark, 2013).

2.6.2 Dead organic matter

Dead organic matter (DOM) consist of both dead wood and litter. Dead wood includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil (Takahashi et al., 2010). Litter includes all non-living biomass with a size greater than the limit for soil organic matter (2 mm) and less than the minimum diameter chosen for dead wood (e.g. 100 mm), lying dead, in various states of decomposition above or within the soil. Some DOM decomposes quickly, returning carbon to the atmosphere, but a portion is retained for months to years to decades (Keith et al., 2006).

Most of the unharvested biomass is added to the deadwood and litter pool. The type of forest or plantation and the purpose behind the protection of a forest and the raising of a new forest affects the dynamics of dead organic matter. In fuelwood plantations for example, the woody part of the DOM is likely to be used as fuelwood, whereas in the case of avoided deforestation in the protection of a forest, the DOM accumulates on the forest floor. Further, land use change leads to the complete loss of dead organic matter as in the case of the change of a forest and/or plantation to cropland or grassland (Ravindranath and Madelene, 2007).

2.6.3 Soil organic carbon

Soil organic carbon (SOC) or soil organic matter is live and dead fine roots within the soil, that are less than the minimum diameter limit (2 mm) for roots. It is composed of organic substances in various stages of decomposition in the soil. It is very essential as it stores and supplies plant nutrients and aids in water filtration, soil stability and reduces soil erosion (Ruth, 2009). Some of the organic material consists of labile compounds that are easily decomposed by microbial organisms, returning carbon to the atmosphere whereas some is converted to organic-mineral complexes that are very slowly decomposed and thus retained in the soil for decades to centuries (Keith et al., 2006).

The quality of soil carbon stock depend on the interaction between climate, soils, tree species and management, and chemical composition of the litter as determined by the dominant tree species (Lal, 2005). The soil carbon stock can be significantly enhanced by adequate soil drainage, growing tree species with a high net primary production, applying nitrogen and micronutrients, e.g. Fe, as fertilizers, and conserving soil and water resources.

2.7 Intergovernmental Panel on Climate Change

Annex I Parties of the United Nations Framework Convention on Climate Change (UNFCCC) are required to submit information on their national inventory of carbon emissions and removal every year using the common reporting format provided by the UNFCCC office (Takahashi et al., 2010). The Intergovernmental Panel on Climate Change (IPCC) has prepared guidelines in order to assist in this process, guidelines such as the 2006 IPCC Guidelines for National Greenhouse Gas Inventories for Agriculture, Forestry and Other Land Use. Most countries can use these guidelines to calculate carbon dioxide emissions and removal in agriculture, forestry and other land-use sectors.

The Intergovernmental Panel on Climate Change (IPCC) is the leading scientific international body for the assessment of climate change. It was first established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). It is an intergovernmental body open to all member countries of the United Nations (UN) and WMO. Its mission is to provide comprehensive scientific assessments of current scientific, technical and socio-economic information about the risk of climate change caused by human activity, its potential environmental and socio-economic consequences, and possible options for mitigating the effects (Anon, 2006).

The main activity of the IPCC is publishing special reports on topics relevant to the implementation of the UNFCCC and by endorsing the IPCC reports, governments acknowledge the authority of their scientific content.

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, provides guidance for preparing annual greenhouse gas inventories in the Agriculture, Forestry and Other Land Use (AFOLU) Sector. The Guidelines are designed to assist in estimating and reporting national inventories of anthropogenic greenhouse gas emissions and removals (Keith et al., 2006).

Some of the 2006 IPCC guidelines include:

- Adoption of six land-use categories (i.e., Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land);
- Reporting on all emissions by sources and removals by sinks from managed lands, which are considered to be anthropogenic, while emissions and removals for unmanaged lands are not reported;
- Generic methods for accounting of biomass, dead organic matter and soil carbon stock changes in all land-use categories and generic methods for greenhouse gas emissions from biomass burning that can be applied in all land-use categories;
- Incorporating methods for non-CO_2 emissions from managed soils and biomass burning, and livestock population characterization and manure management systems from Agriculture;
- Adoption of three hierarchical tiers of methods that range from default emission factors and simple equations to the use of country-specific data and models to accommodate national circumstances;
- Description of alternative methods to estimate and report carbon stock changes associated with harvested wood products;
- Adherence to principles of mass balance in computing carbon stock changes.

2.7.1 Tier definitions for methods

There are three hierarchical tiers methods proposed in the 2006 IPCC guidelines (i.e. Tier 1, Tier 2 and Tier 3). In general, moving to higher tiers improves the accuracy of the inventory and reduces uncertainty, but the complexity and resources required for conducting inventories also increases for higher tiers (Keith et al., 2006). The method presented in this study focused on Tier 1 inventories but the default data presented for Tier 1 were partly or wholly replaced with national data as part of a Tier 2 estimation.

2.7.1.1 Tier 1

Tier 1 methods are the simplest to use and the IPCC guidelines provide equations and default parameter values (e.g., emission and stock change factors). Some country-specific activity data are needed but there are often globally available sources of activity data estimates for example deforestation rates, agricultural production statistics, global land cover maps, fertilizer use, livestock population data, etc.

2.7.1.2 Tier 2

Tier 2 can use the same methodological approach as Tier 1 but applies emission and stock change factors that are based on country- or region-specific data (Keith et al., 2006). For climatic regions, land-use systems and livestock categories, country-defined emission factors are more appropriate in that country. Tier 2 typically uses higher temporal and spatial resolution and more disaggregated activity data, and these correspond with country-defined coefficients for specific regions and specialized land-use or livestock categories.

2.7.1.3 Tier 3

Tier 3 uses higher order methods including models and inventory measurement systems made to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national level (Keith et al., 2006). These higher order methods provide estimates of greater certainty than Tier 1 or Tier 2. Some high order methods used include, comprehensive field sampling repeated at regular time intervals and geographic information-based systems (GIS-based systems) of age, class/production data, soils data, and land-use and management activity data. Statistically a piece of land where a land-use change occurs can usually be tracked over time.

2.8 Forest carbon stock changes or flows

One method of estimating the net carbon flux in forests is to begin with forest inventory data collected from statistically based surveys and then estimate carbon stock using relationships between inventory variables and carbon stocks augmented with models for pools that are not sampled (Woodbury et al., 2007). The method adopted in this study is based on the 2006 IPCC Guidelines for estimating greenhouse gas inventories for Tier 1 quality (simplest to use; globally available data).

An increase in total carbon stock in the forest is associated with a net removal of carbon dioxide from the atmosphere whereas a decrease in total carbon stock is associated with net emission of carbon dioxide. It is important to note that the net flux between forests and the atmosphere is not equivalent to the net change in forest carbon as timber harvests do not cause an immediate flux of carbon to the atmosphere. The carbon in the harvested timber is emitted over time as carbon dioxide and/or other gases like carbon monoxide or methane when the wood product combusts or decays. The wood product may be released many years later if they are disposed of in landfills.

Figure 2.7 shows the generalised carbon cycle within the forest with flows of carbon into and out of the system as well as between the pools. The cycle includes changes due to continuous processes like growth and decay and discrete events like fires and insect infestations (disturbances). The continuous processes affect the carbon stocks each year and in all areas but the discrete events cause carbon emissions in particular areas and in the year of the event.

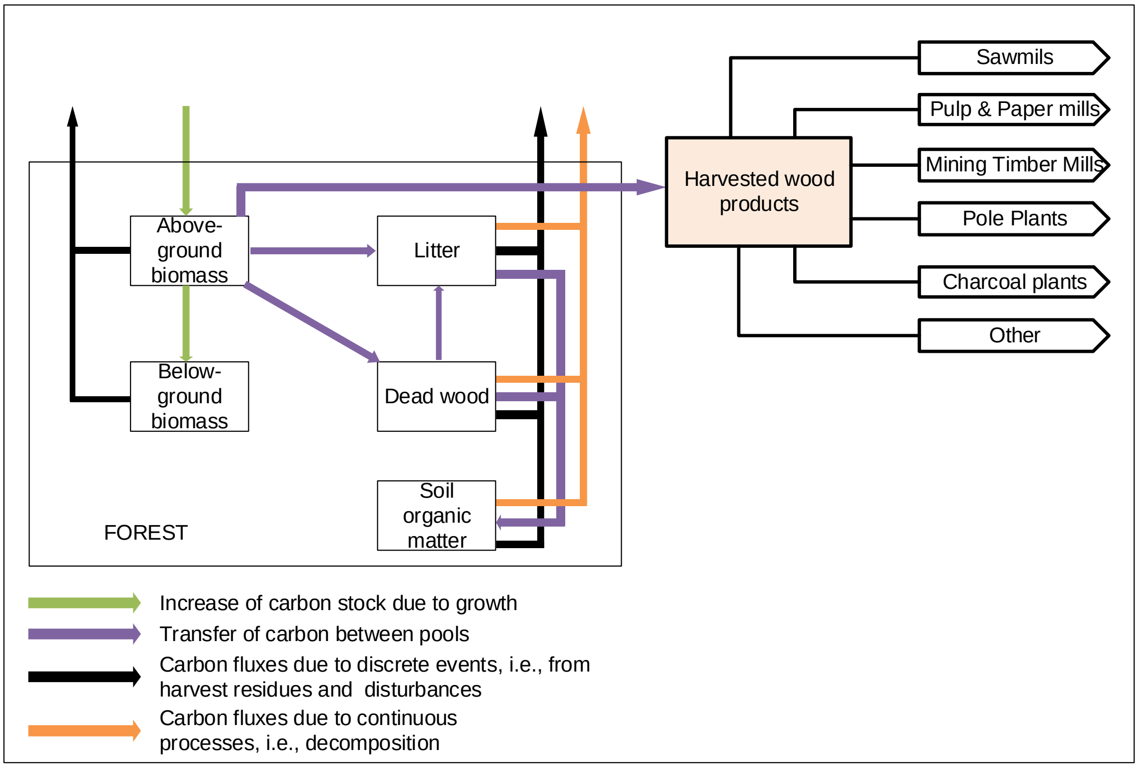

Figure 2.7: Generalised carbon cycle within the forest, showing the flows of carbon into and out of the system as well as between the pools (after Harald et al., 2006).

According to Harald et al. (2006), the overall carbon stock change within the forest is estimated by adding up changes in all pools as shown in equation 2.1.

$$\Delta C_F = \Delta C_B + \Delta C_{DOM} + \Delta C_{SO} \qquad (2.1)$$

Where:

ΔC_F = carbon stock change in the forest

ΔC_B = carbon change in forest biomass

ΔC_{DOM} = carbon change in dead organic matter

ΔC_{SO} = carbon change in forest soils

There are two fundamentally different and equally valid approaches to estimate carbon stock changes in the pools, namely; the process-based approach and the stock-based approach (Harald et al., 2006).

2.8.1 The process-based approach for estimating carbon stock change

The process-based approach estimates the net balance of additions to and removals from a carbon stock. It makes use of the *Gain-Loss Method* to estimate annual changes in carbon stocks in any pool. The *Gain-Loss Method* includes all processes that bring about changes in a pool and is analogous to the law of conservation of mass which states that total inputs must equal total outputs plus net accumulation. The carbon gain refers to increase in biomass (carbon growth) and transfer of carbon into a pool (total inputs). Carbon loss refers to transfer of carbon out of a pool, or emissions due decay, harvest, burning etc. (total outputs). The annual carbon stock change in any pool is estimated using the process-based approach as shown in equation 2.2.

$$\Delta C = \Delta C_G - \Delta C_L \tag{2.2}$$

Where:

ΔC = annual carbon stock in a pool

ΔC_G = annual gain of carbon in a pool

ΔC_L = annual loss of carbon in a pool

2.8.2 The stock-based approach for estimating carbon stock change

The stock-based approach estimates the difference in carbon stocks at two points in time. It makes use of *Stock-Difference Method* whereby the carbon stocks in any pool are measured at two points in time and net annual carbon flux is estimated by subtracting one stock estimate from the other and dividing by the number of years between stock estimates (Harald et al., 2006). This is shown in equation 2.3.

$$\Delta C = \frac{C_{t_2} - C_{t_1}}{t_2 - t_1} \tag{2.3}$$

Where:

ΔC = annual carbon stock in a pool (ton C y^{-1})

C_{t_1} = carbon stock in a pool at time t_1 (ton C)

C_{t_2} = carbon stock in a pool at time t_2 (ton C)

2.9 Estimating carbon stock changes in forest pools

The overall estimate of carbon stock change in the forest is obtained by adding up the stock changes in the different pools. This section presents methods for estimating carbon gains, losses and net changes in the different pools.

2.9.1 Biomass estimates

The biomass pool is an important pool because of the substantial carbon flows as a result of forest management and harvest, natural disturbances, natural mortality and forest regrowth (Harald et al., 2006). The *Gain-Loss Method* is used where gains include biomass growth in the above and below components and the losses are from harvest, fuelwood gathering and losses form disturbances. It requires the biomass carbon loss to be subtracted from the biomass carbon gain as shown in equation 2.4.

$$\Delta C_B = \Delta C_{BG} - \Delta C_{BL} \qquad (2.4)$$

Where:

ΔC_B = carbon change in forest biomass (ton C/y)

ΔC_{BG} = annual increase in carbon stock due to biomass growth (ton C/y)

ΔC_{BL} = annual decrease in carbon stock due to biomass loss (ton C/y)

2.9.1.1 Increase in biomass (ΔC_{BG})

The annual increase in biomass (**ΔC_{BG}**) is estimated using the mean annual biomass growth or mean annual increment (MAI) and area for each climatic zone, ecological zone and vegetation type as shown in equation 2.5.

$$\Delta C_{BG} = \sum_{i,j}\left(A_{i,j} \times G_{Total\ i,j} \times CF_{i,j}\right) \qquad (2.5)$$

Where:

A = area of land (ha)

G_{Total} = mean annual biomass growth (ton C d. m. ha^{-1} y^{-1})

i = ecological zone ($i = 1\ to\ n$)

j = climate domain ($j = 1\ to\ m$)

CF = carbon fraction of dry matter (ton C/ ton d.m)

The mean annual biomass growth (**G_{TOTAL}**) is the biomass growth for all above-ground biomass (**G_W**) and it is expanded to include below-ground biomass growth using the ratio (R) of below-ground biomass to above-ground biomass (equation 2.6).

$$G_{Total} = \sum\{G_W \times (1 + R)\} \qquad (2.6)$$

Where:

G_w = average annual above-ground biomass growth (ton C d. m. ha^{-1} y^{-1})

R = ratio of below-ground biomass (dry mass) to above-ground biomass (dry mass)

The average biomass approach provides rough approximations that can be immediately used to estimate the country's carbon stocks (Tier 1). For higher tiers (Tier 2 and 3) ground-based measurements of tree diameters and height can be combined with predictive relationships to estimate forest carbon stocks (Gibbs et al., 2007).

2.9.1.2 Losses in biomass (ΔC_{BL})

The annual decrease in carbon stocks due to biomass loss (**ΔC_{BL}**) is the sum of losses from wood removal (harvest), fuel wood removal, and losses from disturbances such as fires or storms (Harald et al., 2006).

$$\Delta C_{BL} = L_{wood\ removal} + L_{fuel\ wood} + L_{disturbances} \qquad (2.7)$$

Where:

$L_{wood\ removal}$ = loss due to wood removals (ton C y^{-1})

$L_{wood\ removal}$ = loss due to fuel wood removal (ton C y^{-1})

$L_{disturbances}$ = loss due to disturbances (ton C y^{-1})

The losses from wood removal (harvesting) is estimated using biomass conversion and expansion factors shown in equation 2.8.

$$L_{wood\ removal} = \{H \times BCEF_R \times (1 + R) \times CF\} \qquad (2.8)$$

Where:

H = annual roundwood removals (m^3 y^{-1})

$BCEF_R$ = biomass conversion and expansion factor for wood removals (ton m^{-3})

R = ratio of below-ground biomass to above-ground biomass

CF = Carbon fraction of dry matter (ton C/ ton d.m)

Biomass expansion factors (BEF) expands merchantable volume to total above-ground biomass volume to account for non-merchantable components of the tree, stand and forest. But the merchantable volume must first be converted to dry-weight by multiplying with the basic wood density. Biomass conversion and expansion factors (BCEF) combine both conversion and expansion and transform in one single multiplication growing stock or wood removals directly into above-ground biomass or biomass removals.

The losses due to disturbances are generally estimated using equation 2.9

$$L_{disturb} = [A_{disturb} \times B_W \times (1 + R) \times CF \times fd] \qquad (2.9)$$

Where:

$A_{disturb}$ = area affected by disturbances (ha y^{-1})

B_W = average above-ground biomass in land affected by disturbance (ton C ha^{-1})

R = ratio of below-ground biomass to above-ground biomass

CF = carbon fraction of dry matter (ton C/ ton d.m)

fd = fraction of biomass lost in disturbance

The fraction of biomass lost in disturbance (fd) defines the proportion of biomass that is lost from the biomass pool: a stand-replacing disturbance will kill all (fd = 1) biomass while an insect disturbance may only remove a portion (e.g. fd = 0.3) of the average biomass C density (Harald et al., 2006). It is assumed that all losses due to disturbances are emitted in the year of the disturbance.

2.9.2 Stock-Difference Method for biomass estimates

The *Stock-Difference Method* could also be used for biomass estimates, but it requires biomass carbon stock inventories for a given land area, at two points in time. The annual biomass change is the difference between the biomass stock at time t_2 and time t_1, divided by the number of years between the inventories as shown in equation 2.10. This method is applicable in any country that has national inventory systems for forests, where the stocks of different biomass pools are measured at periodic intervals (Harald et al., 2006).

$$\Delta C_B = \frac{C_{t_2} - C_{t_1}}{t_2 - t_1} \qquad (2.10)$$

Where:

$$C = \sum_{i,j}\left(A_{i,j} \times V_{i,j} \times BCEF_S \times (1 + R) \times CF_{i,j}\right) \qquad (2.11)$$

C_{t_1} = total carbon in biomass at time t_1 (ton C)

C_{t_2} = total carbon in biomass at time t_2 (ton C)

C = total carbon in biomass for time t_1 to t_2

V = merchantable growing stock volume (m^3 ha^{-1})

R = ratio of below-ground biomass to above-ground biomass

CF = carbon fraction of dry matter (ton C/ ton d.m)

$BCEF_S$ = biomass conversion and expansion factor for expansion of merchantable growing stock volume to above-ground biomass

2.9.3 Dead organic matter estimates

The transfer of carbon into and out of dead organic matter pools is difficult to estimate. Whenever a tree is harvested, the non-merchantable parts such as tree tops, branches, leaves and roots are left on the ground and transferred to dead organic matter pool. Some of the carbon is transferred out of the DOM pools as fuel wood for domestic uses, some is burnt in situ and emitted to the atmosphere, while some is decomposed and also returned to the atmosphere.

It can be assumed (IPCC Tier 1 assumption) that the average transfer rate into DOM is equal to the average transfer rate out of DOM for the year of study implying the net change is zero. The rationale is that DOM stocks, (dead wood in particular) are highly variable and site specific, and depends on forest type, age, disturbances and forest management. A more accurate estimation (Tier 2 or 3 methods) is obtained using equation 2.12 provided data for carbon flows into and out of the pool is available. This requires detailed inventories that include repeated measurements of dead wood and litter pools, and/or models that simulate dead wood and litter dynamics.

$$\Delta C_{DOM} = A \times \{DOM_{in} - DOM_{out}\} \times CF \qquad (2.12)$$

Where:

ΔC_{DOM} = carbon change in dead organic matter (ton C y^{-1})

A = area of land (ha)

DOM_{IN} = transfer of biomass into DOM pool (ton C d. m. ha^{-1} y^{-1})

DOM_{out} = decay and disturbance carbon loss out of DOM pool (ton C d. m. ha^{-1} y^{-1})

CF = carbon fraction of dry matter (ton C/ ton d.m)

2.9.4 Soil organic carbon estimates

Both organic and inorganic forms of carbon are found in forest soils but organic soils have a larger impact on forest management. Organic soils are soils with a minimum of 12 to 20 percent organic matter by mass and develop under poorly drained conditions (Brady and Weil, 1996). All other soils have relatively low amounts of organic matter and occur under moderate to well drained conditions.

The soil organic carbon stocks are computed to a default of 1 m depth (Woodbury et al., 2007) and excludes residue and litter stocks which form part of the dead organic matter pools. In undrained organic soils, inputs into SOC pools may exceed outputs from decomposition under anaerobic conditions, and considerable amounts of organic matter can accumulate over time. The carbon will readily decompose when conditions become aerobic following soil drainage. The basic method for estimating carbon emissions from organic soils is using an annual emission factor (EF, in ton ha^{-1} y^{-1}) that estimates the carbon losses due to drainage where the area of the drained organic soil is multiplied by the associated emission factor to derive an estimate of the annual carbon dioxide emissions as shown in equation 2.13.

$$\Delta C_{SO} = \sum_c (A \times EF)_c \qquad (2.13)$$

The dynamics of soil carbon are very complex and fall outside the scope of this study, therefore it will not be analysed further.

2.10 Estimating the actual carbon stock in the forest

The most direct way to estimate forest carbon stocks is to harvest all the trees in a known area, dry them and weigh the biomass but this method is impractical for country level analysis (Gibbs et al., 2007). No methodology can yet directly measure forest carbon stocks, as a result, much effort has gone into developing tools and models that can extrapolate harvest data points to larger scales based on proxies measured in the field or from remote sensing instruments (Achard et al., 2007). Two methods are reviewed on estimating actual forest stocks which are: the biome-average approach and the ground-based forest inventory data.

2.10.1 The biome-average approach

In this approach, a single representative value of forest carbon per unit area (e.g. tonnes of C per hectare) is applied to broad forest categories or biomes (Fearnside, 2000). The earliest compilations of biome averages were made years ago and have continuously been updated which makes it difficult to identify original data sources and other key information. Many contemporary estimates of forest carbon stocks are based on multiple versions or iterations of analysis and often “best guesses” are employed.

Biome averages are based on two main sources of information

- Compilations of whole-tree harvest measurement data and
- Analysis of forest inventory data archived by the United Nations Food and Agricultural Organization (FAO)

Compilations of whole-tree harvest measurement data provide direct estimates of the actual forest volume or biomass at a particular site (Gibbs et al., 2007). It is highly accurate for a specific location and cover only a tiny portion of the forest. As such it could be highly biased and provide only rough approximations of forest carbon stocks over larger spatial scales.

Forest inventory data on the other hand can provide high quality information for a particular region but existing inventories were generally not collected using sampling schemes appropriate for the biome scale (Gibbs et al., 2007).

Biome averages, however, are freely and immediately available. They currently provide the only source of globally consistent forest carbon information and despite the uncertainties, biome averages continue to be the most routinely used source of forest carbon stock data. Further, this approach provides an important starting point for a country to assess the relative magnitude of their emissions from deforestation and degradation.

2.10.2 Ground-based forest inventory data

This approach involves the measurement of diameter at breast height (DBH) and tree height. The measurements of diameter at breast height alone or in combination with tree height can be converted to estimates of forest carbon stocks using allometric relationships. The allometric equations relate these measured forest data to harvest measurements and exist for most plantation forests.

The development of allometric relationship is time-consuming and expensive. This is because it requires destructive harvesting of a large number of trees. The advantage of this approach is that allometric equations are based on a large number of trees and spans a wide range of diameters. This method is used when calculating carbon stocks using higher Tiers i.e. Tier 2 and/or Tier 3. Table 2.3 shows the benefits and limitations of the available methods to estimate national-level forest carbon stocks.

Table 2.3: Benefits and limitations of available methods to estimate national-level forest carbon stocks (Gibbs et al., 2007).

Method	*Description*	*Benefits*	*Limitations*
Biome averages	Estimates of average forest carbon stocks for broad forest categories based on a variety of input data sources	Immediately available at no cost. Data refinements could increase accuracy. Globally consistent.	Fairly generalized. Data sources not properly sampled to describe large areas.
Forest inventory	Relates ground-based measurements of tree diameters or volume to forest carbon stocks using allometric relationships	Generic relationships readily available. Low-tech method widely understood. Can be relatively inexpensive as field-labour is largest cost.	Generic relationships not appropriate for all regions. Can be expensive and slow. Challenging to produce globally consistent results.
Optical remote sensors	Uses visible and infrared wavelengths to measure spectral indices and correlate to ground-based forest carbon measurements	Satellite data routinely collected and freely available at global scale. Globally consistent.	Limited ability to develop good models for tropical forests. Spectral indices saturate at relatively low C stocks. Can be technically demanding
Very high-res. airborne optical remote sensors	Uses very high resolution images to measure tree height and crown area and allometry to estimate carbon stocks	Reduces time and cost of collecting forest inventory data. Reasonable accuracy. Excellent ground verification for deforestation baseline.	Only covers small areas. Can be expensive and technically demanding. No allometric relations based on crown area are available
Radar remote sensors	Uses microwave or radar signal to measure forest vertical structure	Satellite data are generally free. New systems launched in 2005 expected to provide improved data. Can be accurate for young or sparse forest.	Less accurate in complex canopies of mature forests because signal saturates. Mountainous terrain also increases errors. Can be expensive and technically demanding
Laser remote sensors	LiDAR uses laser light to estimates forest height/vertical structure	Accurately estimates full spatial variability of forest carbon stocks. Potential for satellite-based system to estimate global forest carbon stocks.	Airplane-mounted sensors only option. Satellite system not yet funded. Requires extensive field data for calibration. Can be expensive and technically demanding

The sections above presented the literature review on material flow analysis and its application in the South African forestry sector. The material flow analysis tool was also compared with the Life Cycle Assessment tool and the IPCC guidelines for estimating forest carbon stocks were reviewed. The next section presents other studies on Material Flow Analysis of the forest industry and Material flow analysis using other materials and systems.

2.11 Other Material Flow Analysis studies

This section reviews other Material Flow Analysis studies, the problems they had, and the results drawn from these studies.

2.11.1 Studies on the forest industry

Korhonen et al. (2001) did a study on the forest industry ecological system where the flow of matter (biomass), nutrients, energy and carbon was analysed for the national forest industry of Finland in 1997. In this study, the emphasis was on the industrial ecology of the forest industry operation and how it could be enhanced. The flow of matter (biomass) is illustrated in Figure 2.8.

Figure 2.8 describes the main wood resource (biomass) flows in the Finnish forest industry and shows that the annual harvest of forests is less than the annual growth of the forests. The forest ecosystem bounds atmospheric carbon dioxide to wooden biomass and the biomass is utilised for products and for energy production and finally the carbon is released back to the atmosphere from energy production or as landfill gas from decay of products. The annual carbon uptake from the atmosphere to the forest exceeds the drain due to forest cuttings and natural processes, hence the forest ecosystem serves as a carbon sink. Carbon is released through harvesting and transferred to products (wooden material) or is burned and released as carbon dioxide to the atmosphere. About 60 % of the carbon inflow is locked up as products and will be released one year to several decades later back to the atmosphere from incineration of the products or from landfills when the product decays. Forty % of the carbon inflow is used in energy production and is released as carbon dioxide to the atmosphere. The saw mill waste, (wood waste such as bark and dust) are used in the production of energy, and waste from the pulp mills such as black liquor, are also utilised as fuel for energy production. Hence less than 2 % of the harvested wooden material ends up as waste flows to landfills.

The annual cutting and annual growth of forest is the most important industrial ecosystem feature with regard to the flow of carbon in the forest ecosystem. The study includes carbon dioxide emissions from fossil-fuel, electricity generation and transportation activities and also flows from imports and exports. This gives a comprehensive analysis for the entire sector chain. A comprehensive material flow analysis of the South African forestry industry needs to include the paper and pulp sector, import and export flows, as well as carbon dioxide emissions from fossil-fuel, electricity generation and transportation activities.

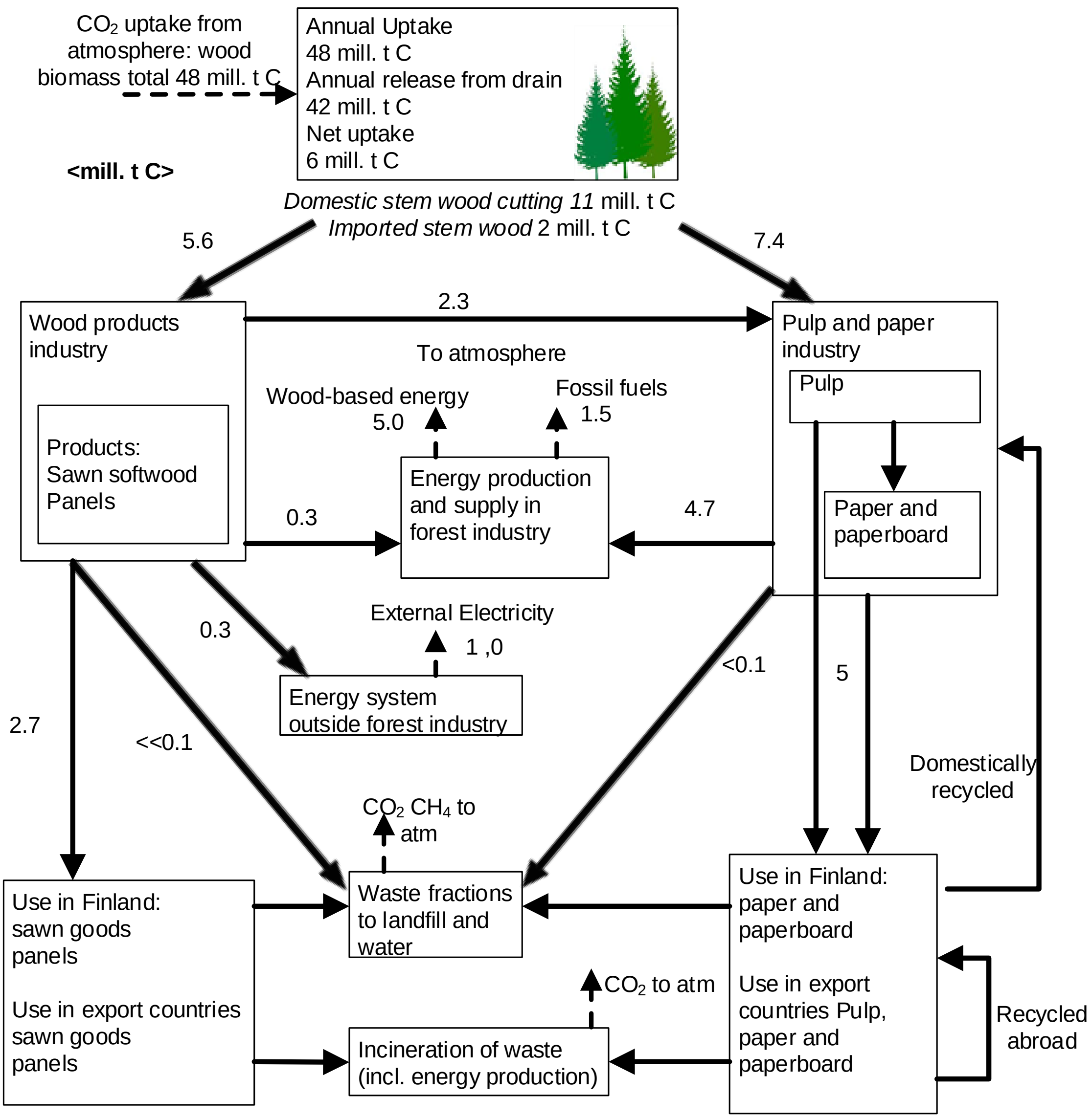

Figure 2.8: Carbon flows in Finnish forest industry in 1997 (Korhonen et al., 2001)

Korhonen et al. (2001) also did a study on the flow of energy in the Finnish forest industry shown in Figure 2.9, and found that about 70 % of fuels used in the Finnish forest industry are from industrial wood waste and waste liquor. The use of waste liquor as fuel recovers the pulping chemicals back to the pulping process. Therefore there is little need for costly external chemical input, and the harmful output from the pulping process is reduced. About 94 % of the fuels in the Finnish forest industry are used in combined heat and power plants (CHP). The heat produced from electricity generation is used to produce process heat and not discarded and this reduces the consumption of external primary energy by about 30 %.

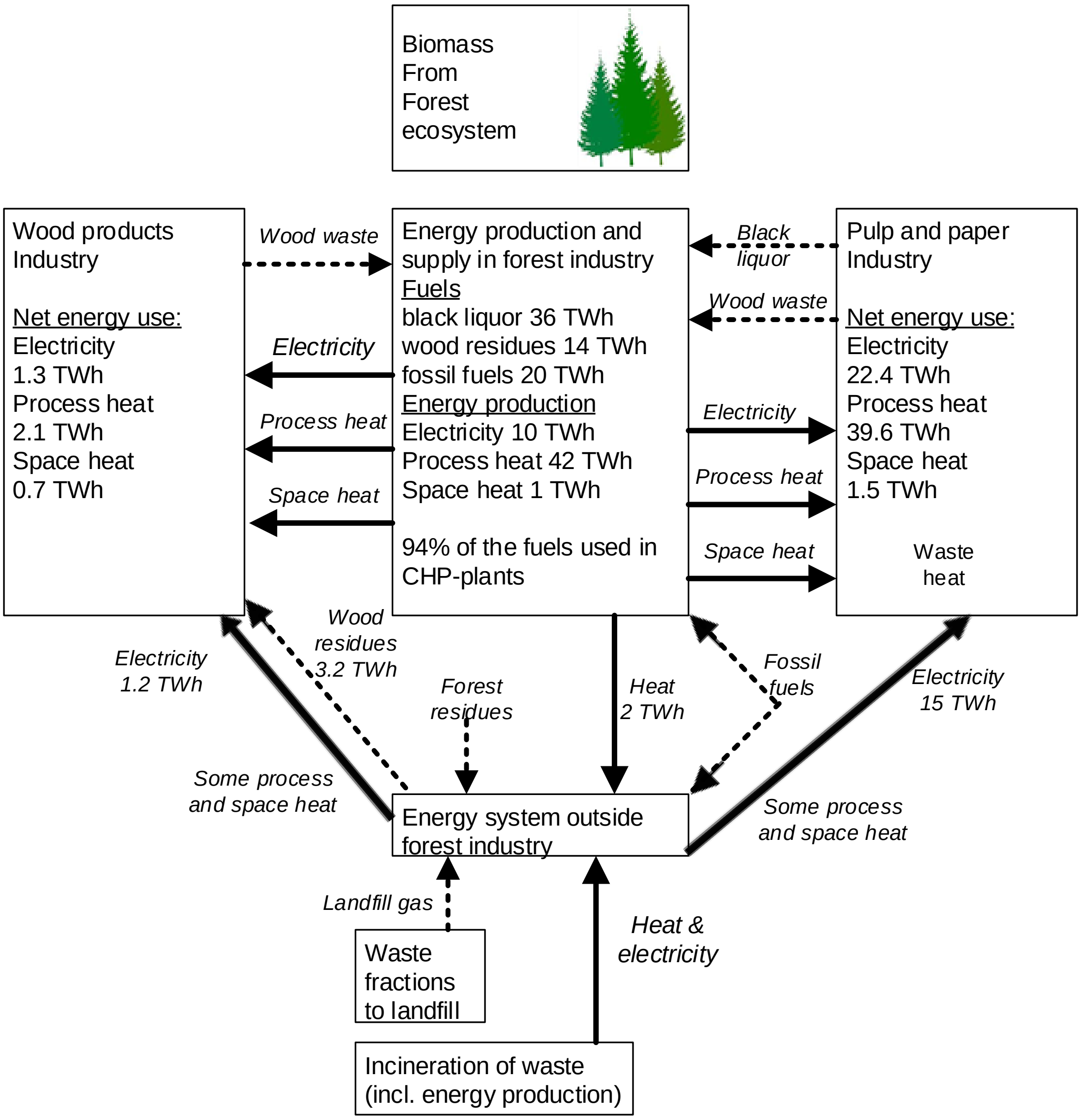

Figure 2.9: Flow of energy in the Finnish forest industry in 1997 where TWh is terawatt hours (Korhonen et al., 2001)

Local integrates called “Forest industry regional integrates” have been adopted in Finland. This is a local cooperation network based on waste material and energy flow utilization. It is a collaboration and cooperation network between industries which are in close proximity to each other. The local integrate consists of the forest industry (or harvesting department), a saw mill, a pulp mill, a paper mill, and a combined heat and power (CHP) plant. The forest or harvesting department provide wood to the pulp and paper mill, the pulp and paper mill provide the power plants with bark, waste liquor and saw mill waste for fuel and the power plants in turn provide the forest pulp and paper mill with heat and electricity.

2.11.2 Studies on other materials (plastic waste management)

Brunner and Rechberger (2004) performed a case study showing the application of material flow analysis in waste management, in particular on plastic waste management. Plastic materials and polymers such as polyvinyl chloride (PVC), polyethylene (PE) and Polyamide are among the most important man made materials and are used in many applications and activities. Examples where plastics are used, include in cars, for furniture, clothes, packaging and many other applications. Most of these plastics are made from fossil fuels and they are usually a mixture of polymers and contain additives such as stabilizers, softeners, pigments and fillers to improve their properties.

In the study, plastic flows and stocks in Austria were analysed and the focus was on plastic-waste management, emphasizing plastic waste as energy resources and as source of hazardous materials. This is illustrated in Figure 2.10. According to Brunner and Rechberger (2004) the figure was prepared using data from plastic manufacturers, waste management, and other sources in Austria.

From Figure 2.10 a total of 1.1 mill. t plastic material was bought and a large portion (0.85 mill. t) was used to produce goods with long residence times such as floor liners, window frames, and car parts. These goods with long residence times were integrated into the "anthropogenic stock" which was allocated to the process "consumption." The rest of the plastic was used for the production of packaging materials and other consumer goods with short residence times.

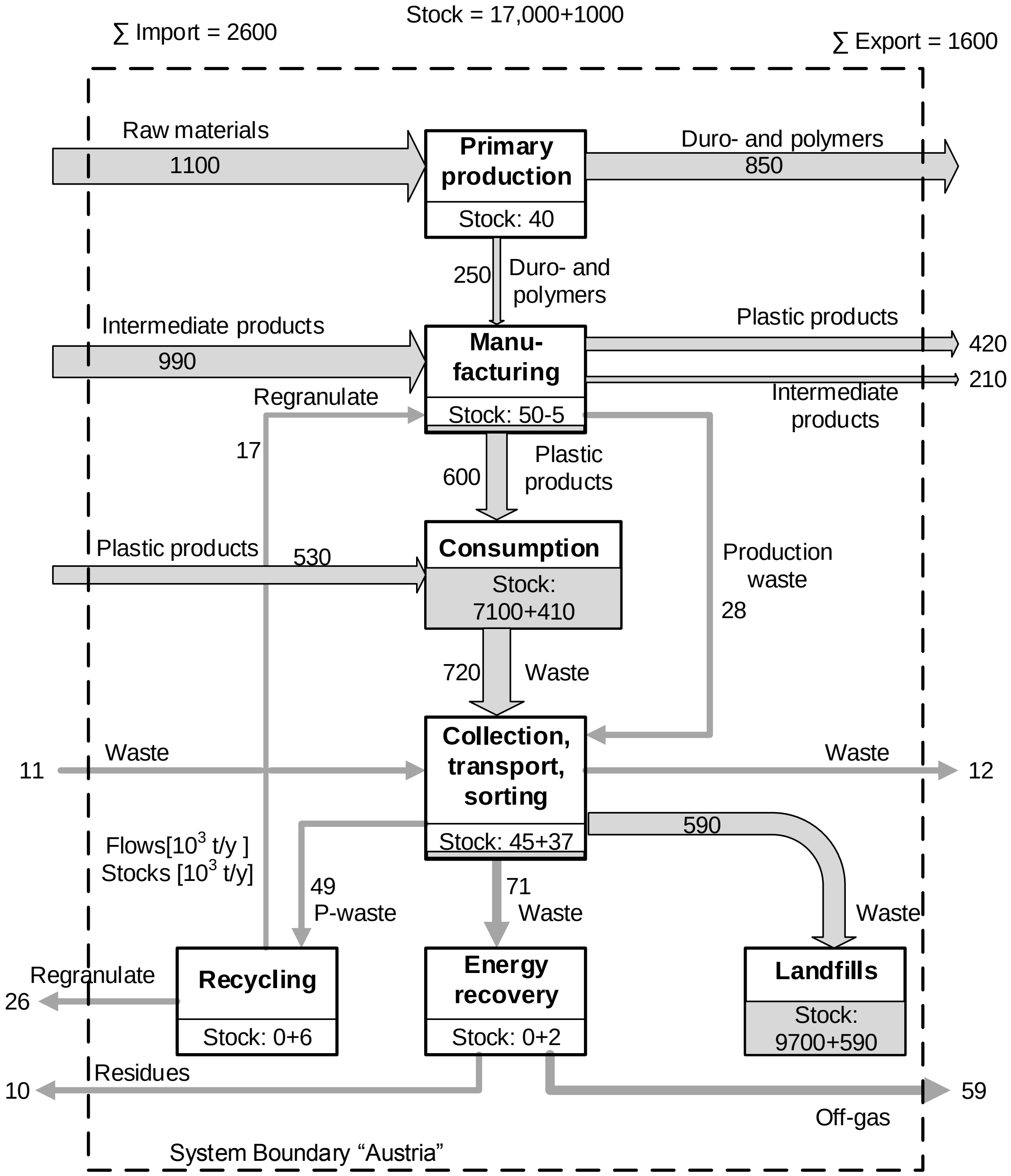

Figure 2.10: Plastic flows in Austria (Brunner and Rechberger, 2004).

Focussing on process "consumption" the net flow (input minus output) was 410 kt/year. 720 kt/year of plastic left the process as waste and a large portion (590 kt/year) was disposed of in landfills while the rest was recycled or burned for energy production. Only 49 kt/year out of 759 kt/year of all the plastic was recycled giving a recycle rate of just under 7 % for Austria. 71 kt/year are burned for energy production and the rest is disposed of in landfills which is a large waste of energy as one ton plastic corresponds roughly to one ton of fossil fuel.

This study on plastic waste management shows the benefits of Material Flow Analysis in resource management as a total country wide plastic balance was done showing the important flows and stocks of plastic which could help set the right priorities in resource management. The large and useful stock of plastic waste to landfill was identified which could be used for energy production and the potential hazards due to the toxic constituents of plastic was also identified and will have to be treated in the future.

This section provided a summary of other Material Flow Analysis studies on the forest industry and also on other materials (plastic waste management). The next chapter presents the methodology adopted in this study which is a combination of the IPCC Tier 1 and Tier 2 methods.

3. METHODOLOGY

This chapter presents the sources for data gathering and the mass balancing method used to evaluate the carbon flows and stocks within, into and out of the South African plantation forests.

3.1 Defining the problem, system and boundaries

The purpose is to develop a methodology to evaluate the carbon flows and stocks within, into and out of the South African forest. Further, to investigate the significance of the findings for the management of resource and the environment.

The system is defined according to Figure 3.1 which is a modification of the generalised carbon cycle within the forest, showing the flows of carbon into and out of the system as well as between the pools mentioned in Figure 2.7 of chapter 2. The total forest is divided into twelve forest regions consistent with the report on commercial timber resources and primary roundwood processing in South Africa (DAFF, 2011). The regions are based on political, physical, silvicultural and economic considerations and are listed in Table 3.1:

Table 3.1: Forestry economic zones

Northern Regions	Limpopo Province Mpumalanga North Mpumalanga Central Districts Mpumalanga South
Middle Regions	KwaZulu-Natal Maputaland KwaZulu-Natal Zululand KwaZulu-Natal Midlands KwaZulu-Natal North KwaZulu-Natal South
Southern Regions	Eastern Cape Southern Cape Western Cape

Spatial boundaries are the boundaries on the forest plantations in each of the forest regions. The boundary in time is a period of one year and the base year is 2011 as it is the year with the latest available data resources. The carbon stock for end of 2010 (or the beginning of 2011) was also determined and this enabled the calculation of the change in forest carbon stock between 2010 and 2011.

The input into the system is the net inflow of carbon sequestered in the forest due to tree growth while the outputs include carbon from harvesting and carbon emitted to the atmosphere from disturbances. The harvested wood includes sawlogs and veneerlogs, poles, mining timber, pulpwood, charcoal, firewood and other woods. Disturbances include damage from fires, weather, diseases, insect infestations and animals.

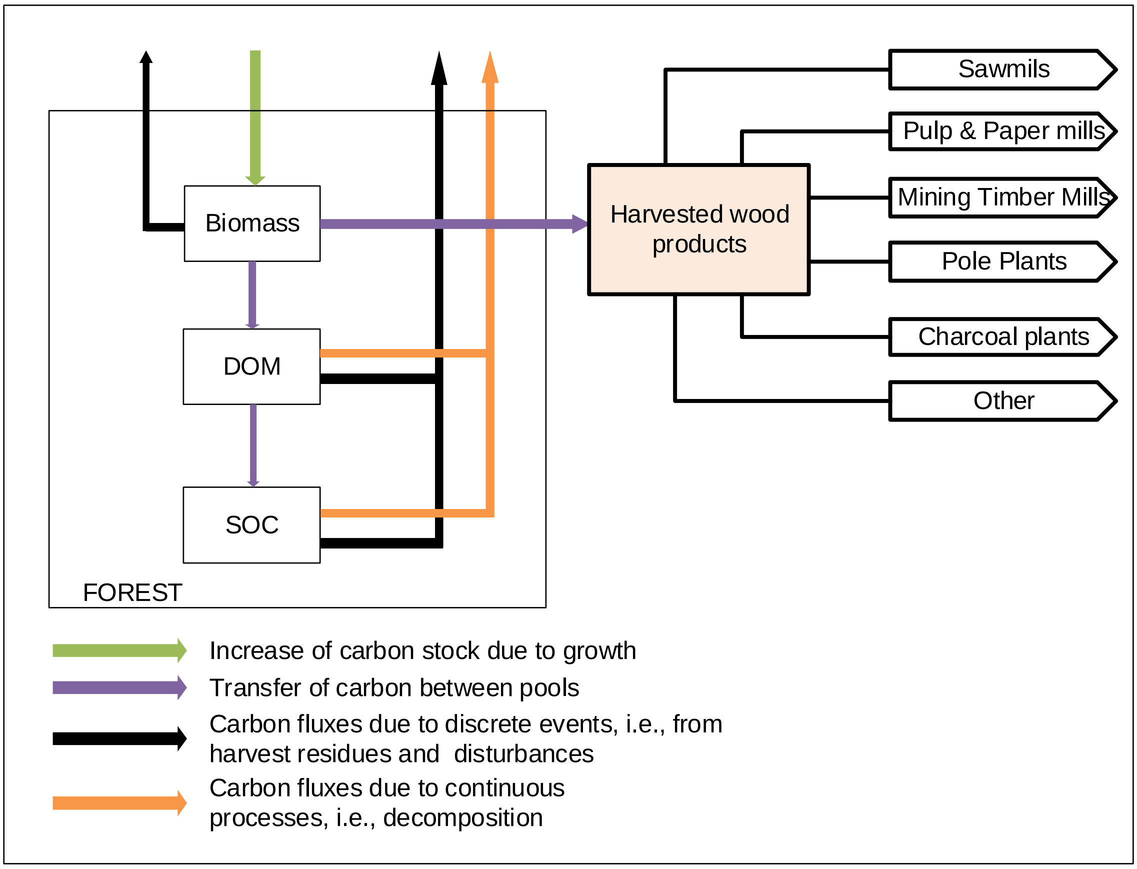

Figure 3.1: The system under investigation

There are also flows out of the forest from continuous process of decomposition, but this is considered negligible. Further, the flows within the system, (flows in the dead organic matter pool and the soil organic carbon pool) are also assumed to be negligible. The South African Forestry database does not report values on these flows and it is assumed that the error from these flows is of little relevance for the conclusions of the overall balance of the system (IPCC Tier 1 assumption). This is further supported by the fact that the biomass pool is the largest forest pool and the most directly impacted from forest activities. Moreover this assumption is based on the Tier 1 IPCC Guidelines for estimating greenhouse gas inventories assumption on calculating carbon stock changing in dead organic matter pools which assumes that the carbon stock changes per year in the dead organic pool is zero.

3.2 Determination of mass flows and stocks

This section shows how the input and output flows and the forest carbon stocks are calculated.

3.2.1 Essential data and source

The essential data needed for the calculations are listed below:

- Plantation area by species, management objective and forest zone (Source: DAFF, 2011)
- Rotation ages by species, management objective and forestry zone (Source: DAFF, 2011)
- Mean Annual Increments (MAI) per species, product and forestry zone (Source: Forestry South Africa)
- Growth curves per species (Source: Godsmark (2013))
- Age class distribution per species and forestry zone (Source: DAFF, 2011)
- Timber harvested from plantations by species and forest zone (Source: DAFF, 2011)
- Plantation areas damaged (pests, diseases and fire) by wood type and forest zones (Source: DAFF, 2011)
- Industry conversion factors for round wood (Source: Forestry South Africa)

Mean annual increment (MAI) is defined here as the merchantable stand volume at harvesting divided by the stand age (rotation length) (Ugalde et al., 2001).

3.2.2 Calculating output flows

The following databases are used to calculate the output flow of carbon from the forest:

- Timber harvested from plantations by species and forest zone (Table A3)
- Plantation areas damaged by wood type and forest zones (Table A4)
- Industry conversion factors for roundwood (Table B2)
- The basic wood density for hardwood and for softwood (**Appendix B**)
- The carbon fraction of dry matter (**Appendix B**)

There are two major carbon outputs from the forest, namely, carbon due to harvesting and disturbances. As mentioned earlier, the harvested wood include sawlogs and veneerlogs, poles, mining timber, pulpwood, charcoal and firewood and other woods, while the disturbances include damage from fires, weather, diseases, insect infestations and animals. The data reported for timber harvested from plantations is in multiple units, (i.e. ton C and m^3) on a wet basis. It is important to convert it all to one unit consistent with the input unit. Industry conversion factors are used to convert from wet ton to volume and the basic wood density and the carbon fraction of dry matter is used to convert the volume to mass in ton C d.m. y^{-1}.

The output due to disturbances is calculated using equation 2.9 mentioned in Chapter 2:

$$L_{disturb} = [A_{disturb} \times B_W \times (1 + R) \times CF \times fd] \quad (2.9)$$

The average above-ground biomass in land affected by disturbance (B_W in ton/ha) is the growing stock in ton C d.m divided by the plantation area. R is the ratio of the below-ground to above-ground biomass. Other outputs from the forest, for example, from continuous process of decomposition are considered negligible.

It should be noted that some of the wood harvested for pulpwood are debarked at the forest during harvest and there is no data with the quantity of carbon in the bark, hence the harvested carbon is an underestimate (uncertainty of ~ 11.8 to%) of the actual carbon harvested from the forest (Wright, 1994).

3.2.3 Calculating forest carbon stocks

The following databases are used to calculate the carbon stocks:

- Growth curves per species (Table A1)
- Age class distribution per species and forestry zone (Tables A2, A5, A6 and A7)
- The basic wood density for hardwood and for softwood (**Appendix B**)
- The carbon fraction of dry matter (**Appendix B**)

The growth curves per species is shown in Table A1 of **Appendix A**. The *Eucalyptus grandis* growth curve is plotted and shown in Figure 3.2.

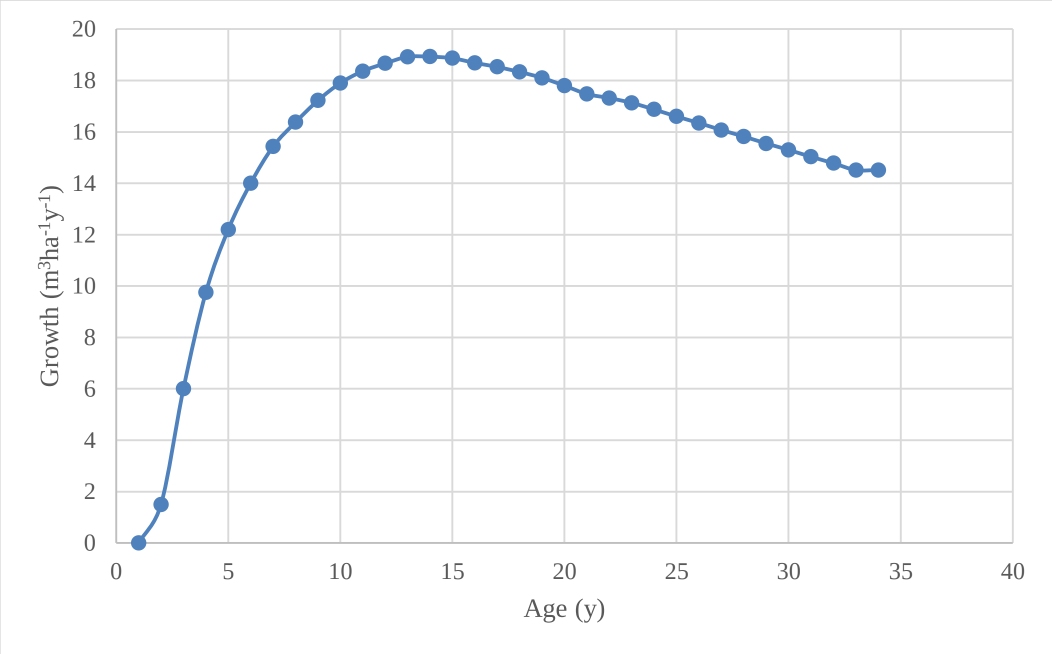

Figure 3.2: Growth curve for *Eucalyptus grandis* (Godsmark, 2013).

The yield, also known as the specific volume in m^3/ha is simply an integration of the growth curve. A number of numerical methods could be used for the integration but the trapezoid rule was used to calculate the yield.

The carbon stock is a multiplication of the yield (m^3/ha), tree age (y) and the area (ha) per age category. The below-ground biomass is obtained using the ratio R and is added to the above-ground stock to get the total carbon stock in the forest. See **Appendix B** for a sample calculation on how to calculate the forest carbon stocks.

3.2.4 Calculating input flows

The input flows correspond to the growth of carbon in the forest. The input calculations could be done with either the *Gain-Loss Method* or the *Stock-Difference Method.* In this study, the *Stock-Difference Method* was used to calculate the input flows.

3.2.4.1 The Stock-Difference Method for input flows

Once the carbon stocks for 2010 and 2011 are calculated (see **Appendix B** for sample calculation) and recorded as shown in Table 4.6, the *Stock-Difference Method* can be applied to calculate the carbon stock change between 2010 and 2011 using equation 2.10 mention in the literature review.

$$\Delta C_B = \frac{C_{t_2} - C_{t_1}}{t_2 - t_1} \quad (2.10)$$

The mass balance principle is applied to calculate the input flow once the carbon stock change and all the output flows are known as shown in equation 3.1.

$$Input\ flow = Output\ flow + Carbon\ stock\ difference \qquad (3.1)$$

3.2.4.2 The Gain-Loss Method for input flows

The input calculations may also be calculated using the *Gain-Loss Method*. The databases used are:

- Plantation area by species, management objective and forest zone (Source: DAFF, 2011)
- Rotation ages by species, management objective and forestry zone (Source: DAFF, 2011)
- MAI per species, product and forestry zone (Source: Godsmark (2013))
- The basic wood density for hardwood and for softwood (**Appendix B**)
- The carbon fraction of dry matter (**Appendix B**)

The forest carbon growth could be calculated using the mean annual increment (MAI) for each forest type and zone and the area of each forest sub-category. The carbon flows (biomass growth and harvested wood) are usually measured in terms of merchantable volume or above-ground biomass, implying they are an underestimate of the actual carbon flows. The below-ground biomass is usually added to the calculation by using the below-ground to above-ground biomass ratio (R). This gives a better estimate of the carbon flows. Refer to section 2.9.1 for further details on estimating input carbon flows using the *Gain-Loss Method*.

The total volume growth of the plantation in m^3/y is therefore a combination of equations 2.5 and 2.6 which gives equation 3.2.

$$G = \sum_{i,j}\left(A_{i,j} \times MAI_{i,j} \times [1 + R]\right) \qquad (3.2)$$

The basic wood density and the carbon fraction of dry matter are used to convert the volume growth to mass growth in ton C d.m. y^{-1}. It is important to note that the density of wood is different for the different species so this calculation must be done for each species and the sum is the total carbon dry mass.

3.3 Data uncertainty

The calculated carbon stocks are usually an underestimate of the actual carbon stocks as the calculations are achieved using merchantable volume only and the root volume using the value R. There is however more carbon which is found in the branches, leaves and tree tops of the forest.

Brunner and Rechberger (2004) used the Gauss's Law of error propagation to evaluate the propagation of uncertainties through an MFA system. Here, a function is expanded into a Taylor series and cut off after the first order term, giving a linear approximation of the function for a certain development point. Good results are achieved with a small distance from the development point, hence it is possible to determine approximately the expected value and deviation of the function's results. The deviation is calculated using equation 3.3.

$$Y = f(X_1, X_2, \dots, X_n)$$

$$Var(Y) \approx \sum_{i=1}^{n}\left(Var(X_i) \,.\, \left[\frac{\partial Y}{\partial X_i}\right]_{X=\mu}^{2}\right) + 2\sum_{j=1}^{n}\sum_{j=i+1}^{n}\left(Cov[X_i\,, X_j] \,.\, \left[\frac{\partial Y}{\partial X_i}\right]_{X=\mu} \cdot \left[\frac{\partial Y}{\partial X_j}\right]_{X=\mu}\right) \tag{3.3}$$

Where

$\mu_i, E(X_i) = mean\ value\ of X_i$

$\sigma_i = standard\ deviation\ of X_i$

$\sigma_i^2, Var(X_i) = Variance\ of X_i$

$\sigma_{ij}, Cov(X_i, X_j) = covariance\ of X_i\ and\ X_j$

Reasonable results are determined only if the random variables are normally distributed and if the uncertainties are small. Gauss's Law of error propagation is used in equation 3.1 to estimate the error in the input and the results are shown in Figures 4.1 to 4.12 of Chapter 4.

This chapter presented the methodology used in this study to assess the forest carbon stock in South Africa. The following chapter presents the results obtained using the above method for all the forest regions in South Africa.

4. RESULTS

This chapter shows the results obtained for each of the forest regions in South Africa. All numbers are in ton carbon dry mass and the figures are rounded to four significant figures, therefore totals of number lists may show minor rounding differences.

4.1 Total forest carbon flow for South Africa

The mass balance for the total carbon flows in South African plantation forest is shown in Figure 4.1.

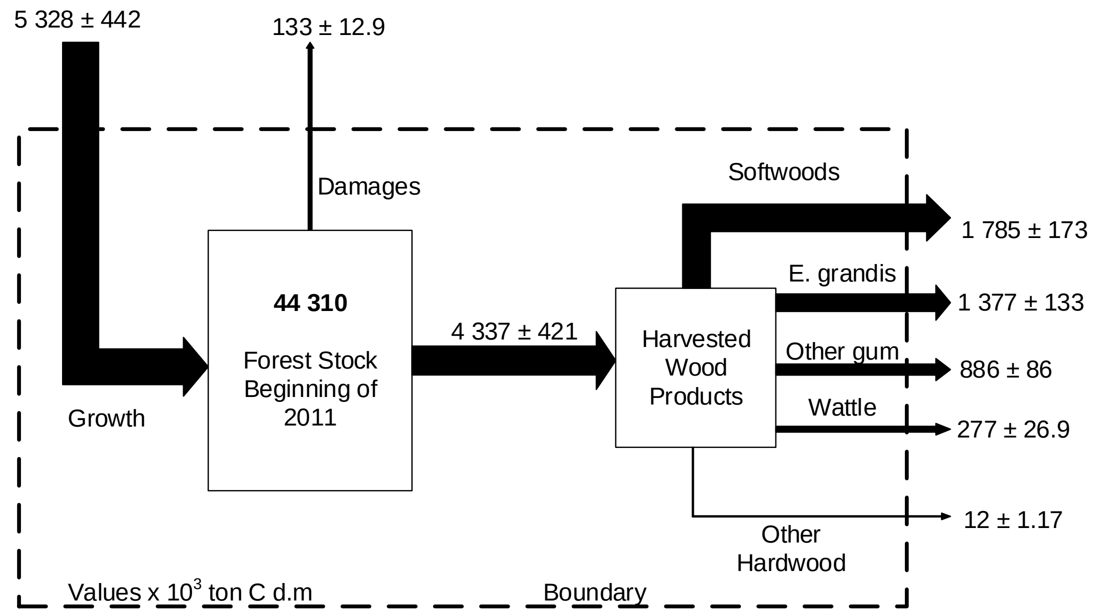

Figure 4.1: Mass balance - Total carbon flows for South African plantation forests

The total input into the forest is 5 328 000 ton C d.m and the total output is 4 470 000 ton C d.m. There was an overall increase in forest carbon stock of 857 300 ton C d.m for the 2011 calendar year.

Table 4.1 shows the biomass calculated for each forest region in ton C per hectare for 2011 whereas Table 4.2 shows the productivity for each region which corresponds to the total carbon sequestered in each region. Finally, Tables 4.3 to 4.5 shows the percentage of wood harvested by species, wood harvested by management purposes and the covered and uncovered plantation area in each region respectively.

Table 4.1: Biomass for each forest region (2011 values)

Region	Stock [t C.dm] x 10^3		Biomass [t C.dm/ha]	
	Softwood	Hardwood	Softwood	Hardwood
Limpopo Province	1 835	858	69	45
Mpumalanga North	7 803	2 250	52	33
Mpumalanga Central Districts	926	208	50	44
Mpumalanga South	5 234	3 307	45	26
KZN Maputaland	207	90	33	18
KZN Zululand	241	1 255	58	18
KZN Midlands	2 108	2 984	47	21
KZN North	783	1 264	46	18
KZN South	2 515	1 750	45	29
Eastern Cape	4 539	678	52	35
Southern Cape	3 152	191	66	102
Western Cape	915	72	83	135
R.S.A	30 260	14 910	52	44

Table 4.2: Production of biomass (Carbon sequestration) for each forest region in 2011

Region	Growth [t C.dm] x 10^3	Area [ha] x 10^3	Productivity [t C.dm/ha]
Limpopo Province	236	46	5.2
Mpumalanga North	1 224	218	5.6
Mpumalanga Central Districts	94	23	4.0
Mpumalanga South	597	244	2.4
KZN Maputaland	-	11	-
KZN Zululand	711	73	9.7
KZN Midlands	1 074	185	5.8
KZN North	252	85	2.9
KZN South	719	117	6.1
Eastern Cape	250	107	2.3
Southern Cape	158	49	3.2
Western Cape	52	12	4.5
R.S.A	5 328	1 170	4.6

Table 4.3: Percentage of wood harvested by species in 2011 (DAFF 2011)

Wood species	Total harvested [t C.dm] x 10^3	[%]
Pinus	1 785	41.2
E. grandis	1 377	31.7
Other Eucalyptus species	886	20.4
Wattle	277	6.39
Other Hardwoods	12	0.28
Total	4 337	100

Table 4.4: Wood harvested by management purpose and by region in 2011 (DAFF 2011)

Region	Sawlogs & Veneerlogs	Poles	Mining Timber	Pulpwood	Charcoal & firewood	Other	Total	
				[t C.dm] x 10^3				[%]
Limpopo Province	83	18	17	3	8	7	135	3.12
Mpumalanga North	341	14	161	253	2	5	776	17.9
Mpumalanga Central Districts	2	0	0	86	1	0	88	2.03
Mpumalanga South	139	4	14	425	4	6	591	13.6
KZN Maputaland	0	0	0	0	0	0	0	0
KZN Zululand	6	0	0	509	0	0	514	11.8
KZN Midlands	59	9	0	920	3	9	998	23.0
KZN North	10	1	5	164	21	1	202	4.66
KZN South	68	8	0	541	1	0	619	14.3
Eastern Cape	146	31	0	63	31	1	273	6.28
Southern Cape	99	12	0	0	0	0	110	2.54
Western Cape	27	4	0	0	0	0	31	0.71
R.S.A	980	101	196	2 964	70	29	4 338	1.0

Table 4.5: Covered and uncovered areas in the regions in 2011

Region	Covered Area	Uncovered Area [ha]	Total Area
Limpopo Province	45 610	2 670	48 280
Mpumalanga North	217 900	15 900	233 800
Mpumalanga Central Districts	23 290	2 180	25 470
Mpumalanga South	244 200	15 510	259 700
KZN Maputaland	11 200	5 829	17 030
KZN Zululand	73 060	3 986	77 050
KZN Midlands	185 000	10 200	195 200
KZN North	85 380	5 690	91 070
KZN South	117 000	5 876	122 800
Eastern Cape	106 800	15 340	122 100
Southern Cape	49 400	14 910	64 310
Western Cape	11 600	4 818	16 420
R.S.A	1 170 000	102900	1 273 000

The sections which follow, show the individual mass balances for each forest region in South Africa.

4.2 Results for the Limpopo forest region

The mass balance for the Limpopo forest region is shown in Figure 4.2.

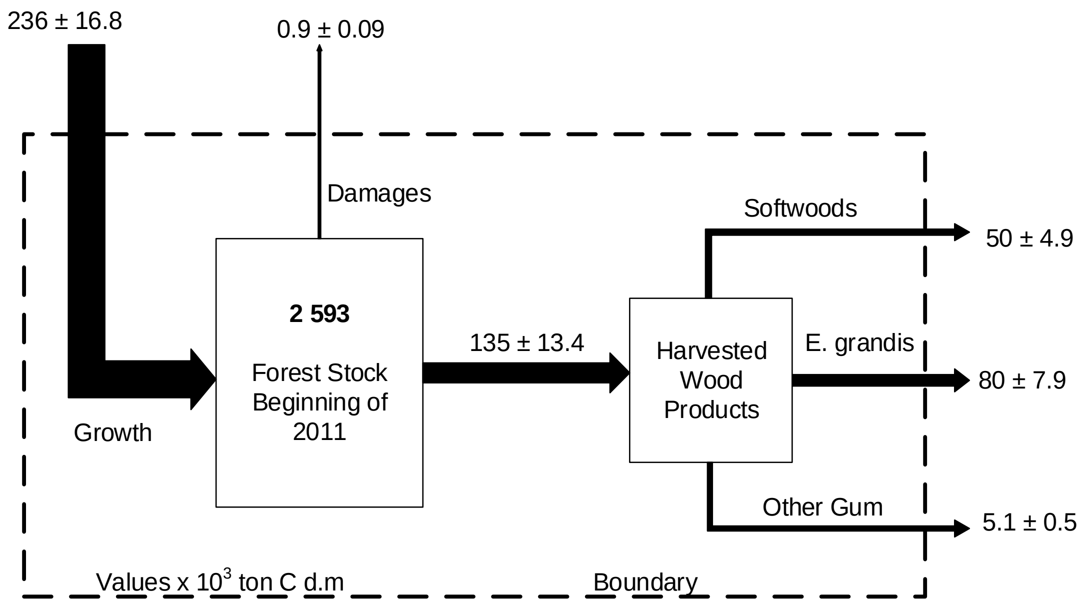

Figure 4.2: Mass balance for the Limpopo forest region

4.3 Results for Mpumalanga North

The mass balance for the Mpumalanga North forest region is shown in Figure 4.3

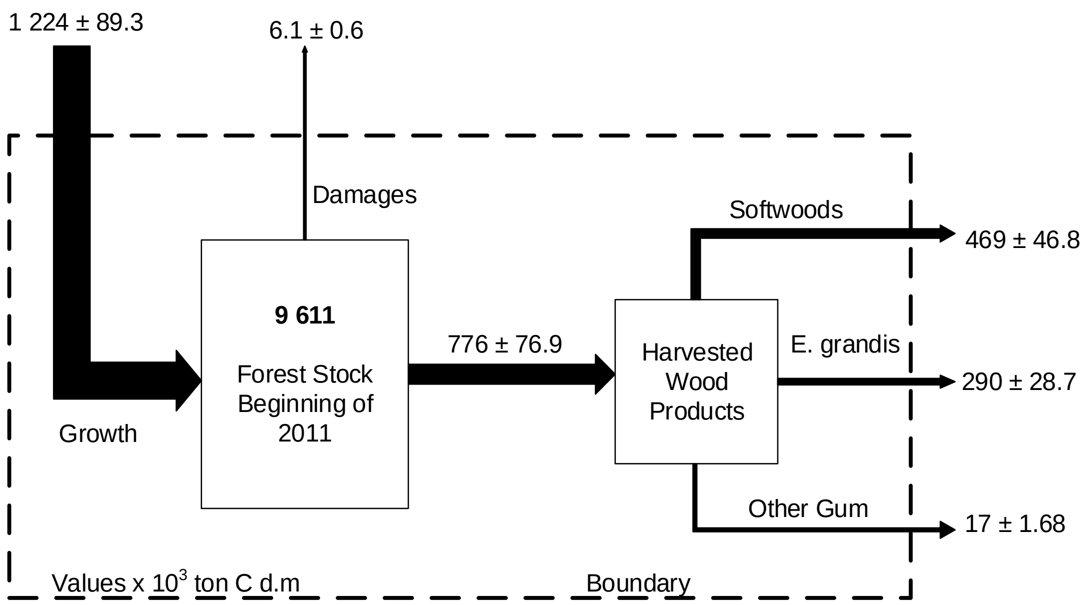

Figure 4.3: Mass balance for Mpumalanga North

4.4 Results for Mpumalanga Central Districts

The mass balance the Central Districts forest region is shown in Figure 4.4.

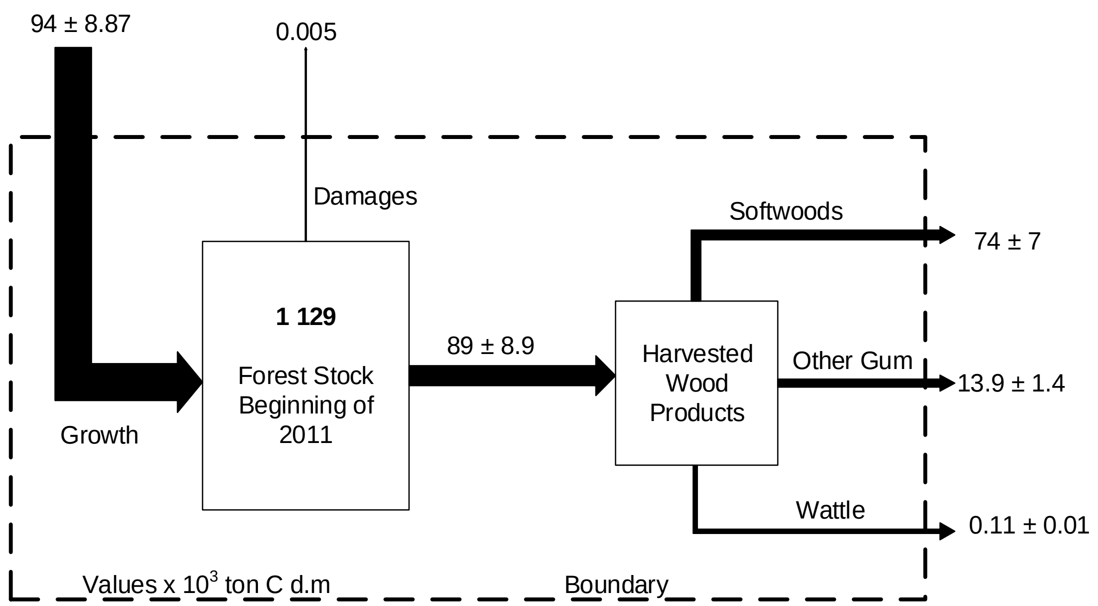

Figure 4.4: Mass balance for Central Districts

4.5 Results for Mpumalanga South

The mass balance for the Mpumalanga South forest region is shown in Figure 4.5.

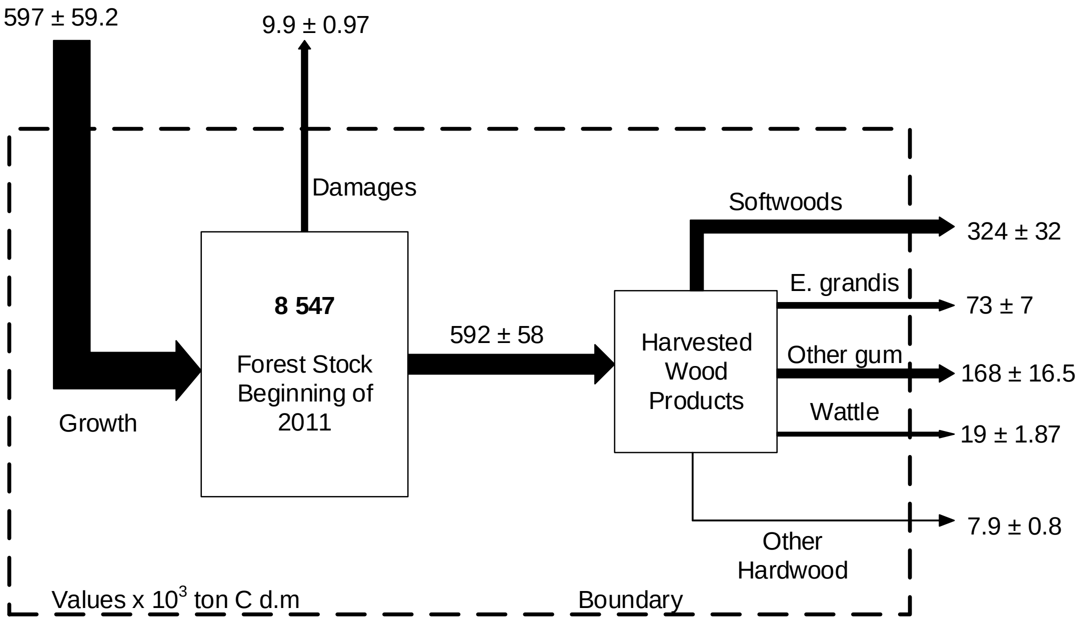

Figure 4.5: Mass balance for Mpumalanga South

4.6 Results for KwaZulu-Natal Maputaland

There were no harvests recorded in the Maputaland region in both 2010 and 2011. However there was growth in the forest hence an increase in forest carbon stock would be expected. The carbon stock however for 2011 was calculated at 297 000 ton C d.m which is less than that calculated in 2010 which was 336 000 ton C d.m. This suggests some trees were harvested yet not recorded. Further comparing Table A2.5 and Table A5.5 in **Appendix A**, a larger portion of the total area is left unplanted in 2011 than in 2010; also the forest area for *Pinus elliottii* trees of 34+ years is less in 2011 than in 2010; and finally there is no recorded forest area for 16, 17 and 19 year *Eucalyptus grandis* trees in 2011 compared to 2010.

4.7 Results for KwaZulu-Natal Zululand

The mass balance for the Zululand forest region is shown in Figure 4.6.

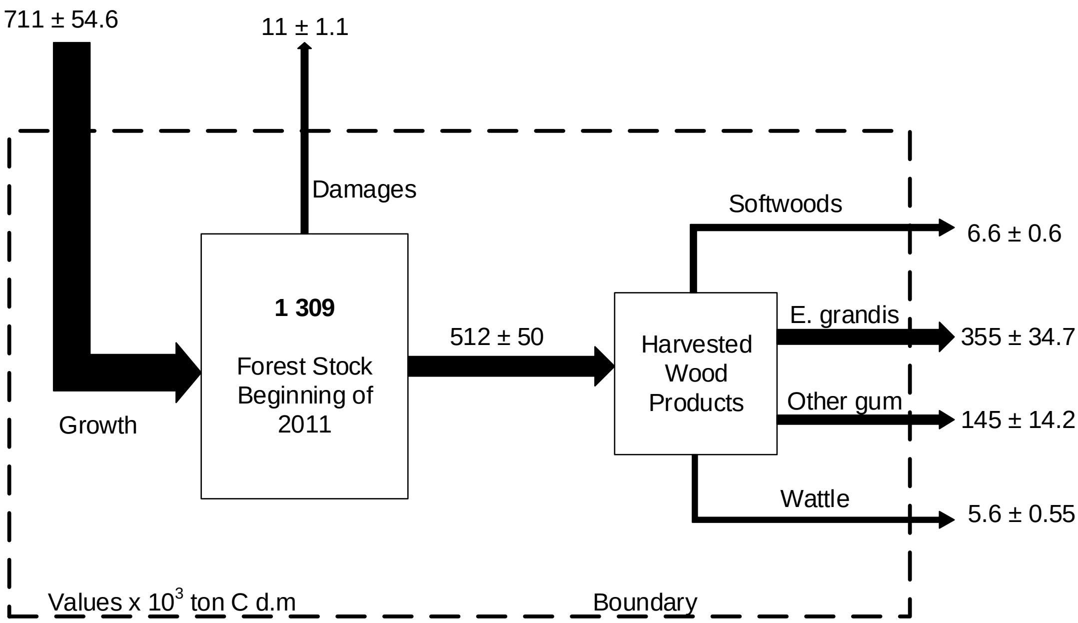

Figure 4.6: Mass balance for Zululand

4.8 Results for KwaZulu-Natal Midlands

The mass balance for KwaZulu-Natal Midlands is shown in Figure 4.7.

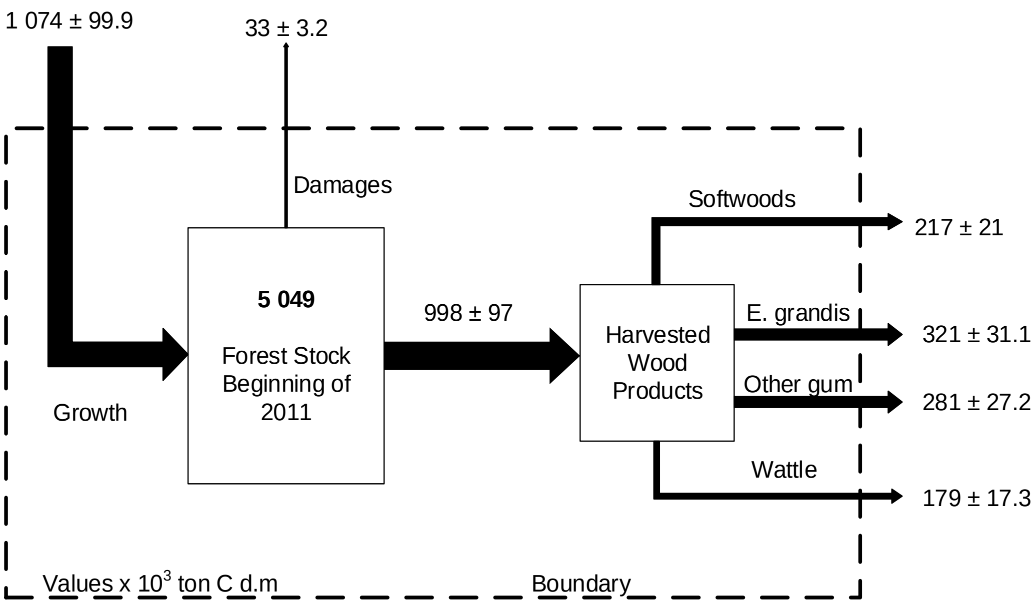

Figure 4.7: Mass balance for KZN Midlands

4.9 Results for Northern KwaZulu-Natal

The mass balance for Northern KwaZulu-Natal is shown in Figure 4.8.

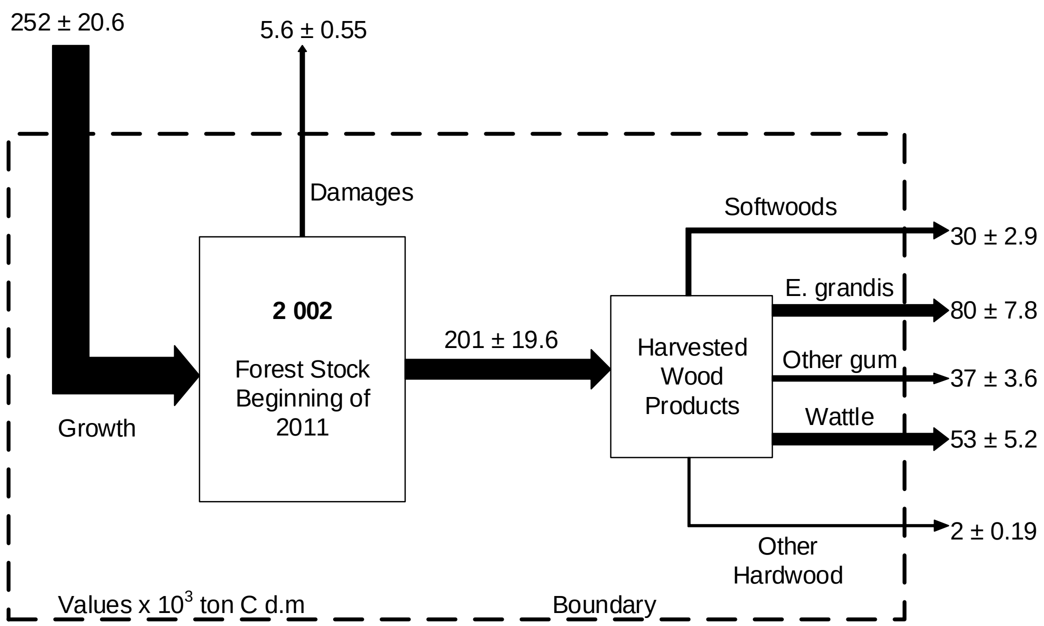

Figure 4.8: Mass balance for Northern KZN

4.10 Results for Southern KwaZulu-Natal

The mass balance for Southern KwaZulu-Natal is shown in Figure 4.9.

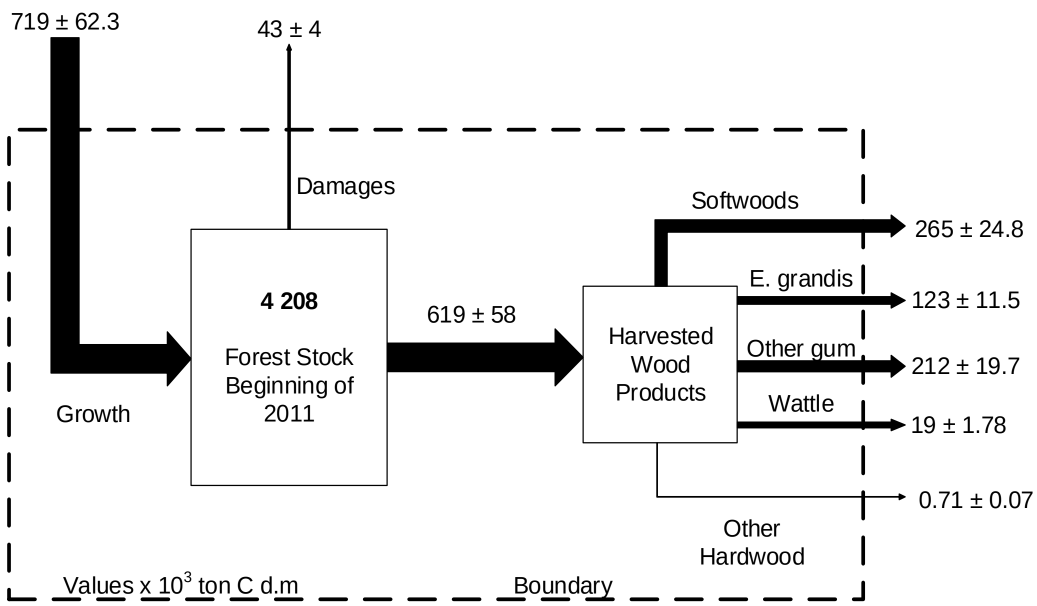

Figure 4.9: Mass balance for Southern KZN

4.11 Results for Eastern Cape

The mass balance for the Eastern Cape forest region is shown in Figure 4.10.

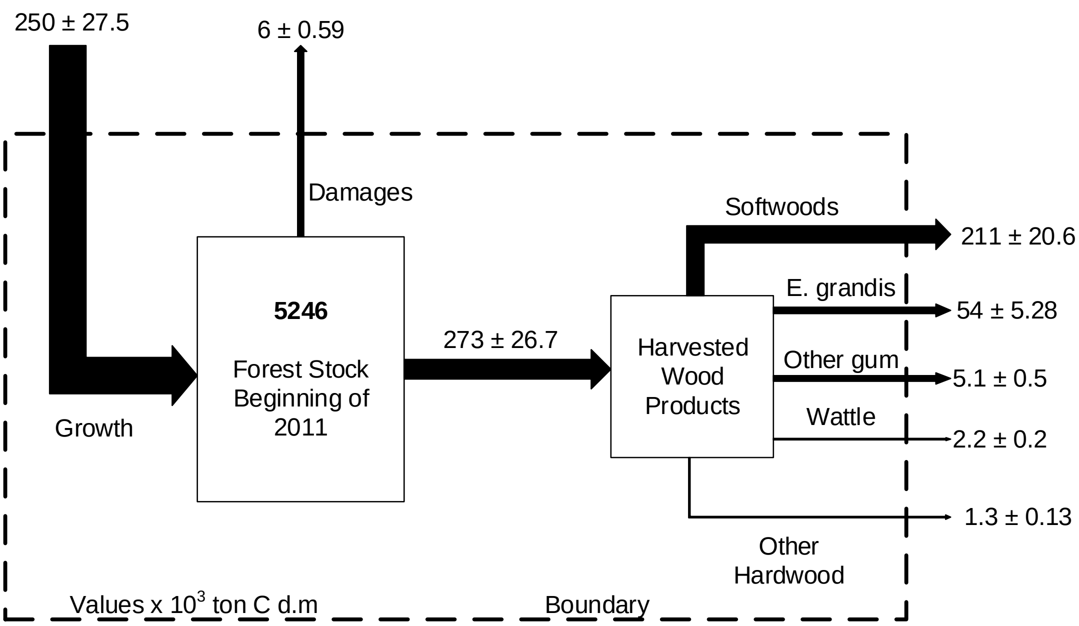

Figure 4.10: Mass balance for Eastern Cape

4.12 Results for Southern Cape

The mass balance for the Southern Cape forest region is shown in Figure 4.11.

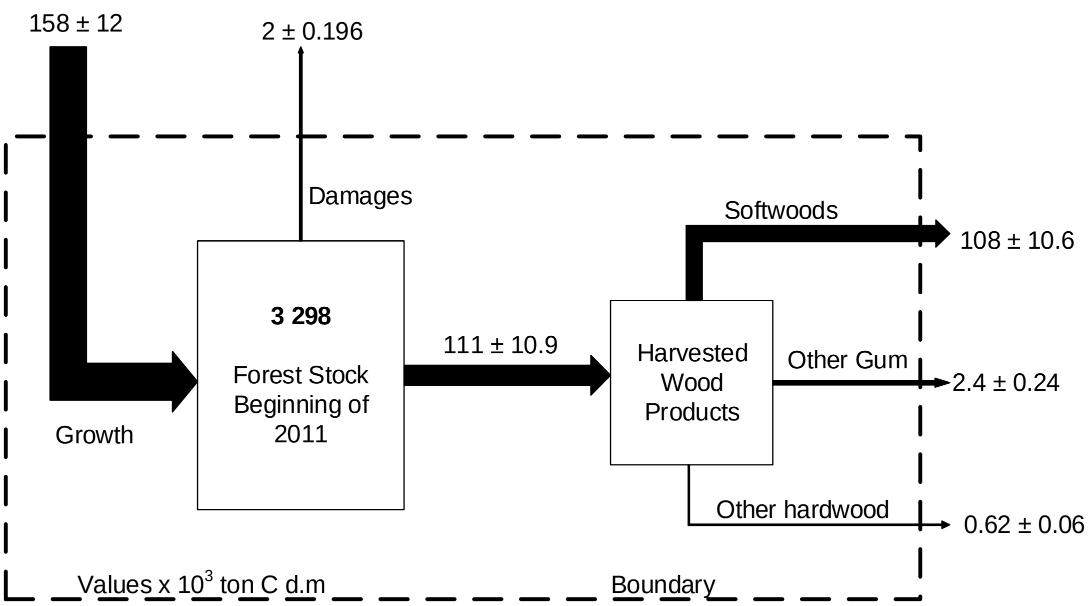

Figure 4.11: Mass balance for Southern Cape

4.13 Results for Western Cape

The mass balance for the Western Cape forest region is shown in Figure 4.12.

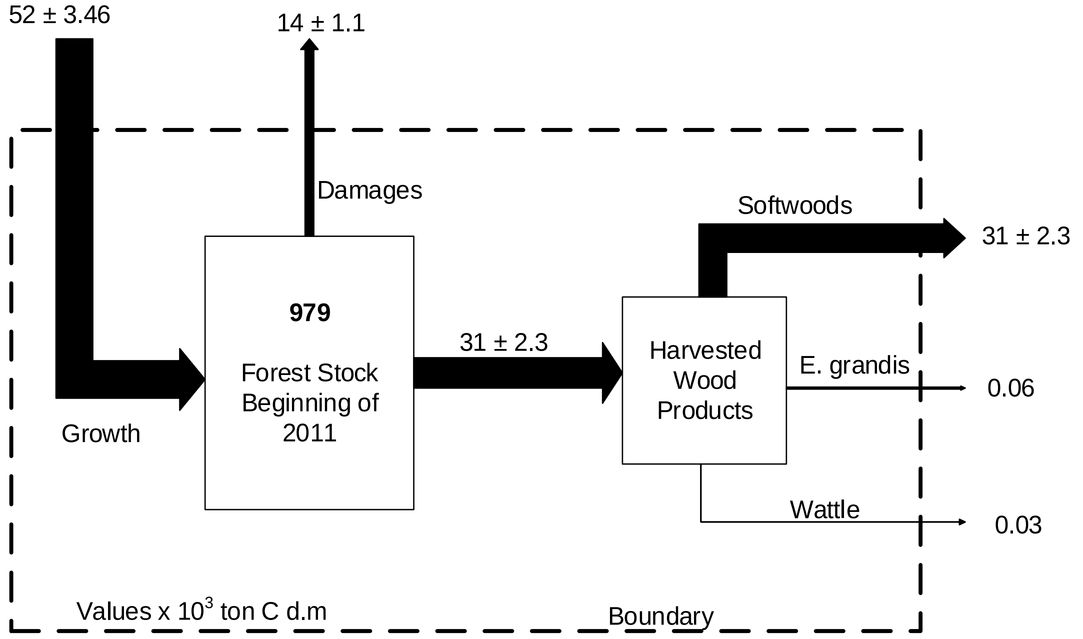

Figure 4.12: Mass balance for Western Cape

Table 4.6: Mass balance results summary for all regions

Region	Input [t C.dm] x 10^3	Harvest [t C.dm] x 10^3	Disturbance [t C.dm] x 10^3	Stock [t C.dm] 2010 x 10^3	Stock [t C.dm] 2011 x 10^3	stock change [t C.dm] x 10^3	stock change [%]
Limpopo Province	236	135	1	2 593	2 692	100	3.85
Mpumalanga North	1 224	776	6	9 611	10 050	441	4.59
Mpumalanga Central Districts	94	89	0	1 129	1 134	6	0.50
Mpumalanga South	597	592	10	8 547	8 542	-5	-0.06
KZN Maputaland	-	-	-	336	297	-39	-11.6
KZN Zululand	711	512	11	1 309	1 497	187	14.3
KZN Midlands	1 074	998	33	5 049	5 092	43	0.85
KZN North	252	202	6	2 002	2 047	45	2.23
KZN South	719	619	43	4 208	4 265	57	1.35
Eastern Cape	250	273	6	5 246	5 216	-29	-0.56
Southern Cape	158	111	2	3 298	3 343	45	1.36
Western Cape	52	31	14	979	986	8	0.77
R.S.A	5 328	4 337	133	44 310	45 160	857	1.94

This chapter presented the carbon flows and stocks in the various forest regions in a clear, understandable and transparent way (i.e. figures and tables). The results obtained are summarised in Table 4.6 and discussed further in chapter 5.

5. DISCUSSION AND INTERPRETATION OF RESULTS

This chapter discusses the results obtained in the previous chapter. In particular, the results are used to show how MFA serves to provide early recognition of environmental loadings and/or depletions, and to predict how stocks will change if inputs and/or outputs are changed.

5.1 South Africa as a whole

In this study the 2011 time series data on material stocks within the South African forest and forestry sector was collected and this was presented in Chapter 4. Forest management requires trees to be harvested from the forest and new ones planted every year. Harvesting leads to carbon removals from the forest and this forms part of the carbon output from the forest. Another output is from carbon losses to the atmosphere due to damage from fires and/or insect infestations.

Figure 4.1 and Tables 4.3 and 4.4 show the quantity of carbon removed from the forest as outputs. The total output from the forest sums up to 4 470 000 t C.dm for the year 2011, and of this, 4 337 000 t C.dm is from harvesting and the rest from damage. The flows affect the forest carbon stock and hence to be carbon neutral, new trees have to be planted every year or else the forest stock will be depleted. The tree growth from new and old trees together forms the total input into the forest.

The input is usually represented as the productivity or quantity of carbon sequestered per unit area per year. Table 4.2 shows the productivity per region for 2011 and from this table it can be shown that KwaZulu-Natal Zululand is the most productive region with 9.7 t C.dm/ha per year while Mpumalanga South is the least productive with only 2.4 t C.dm/ha per year.

The total forest land area in South Africa in 2011 was 1.27 million ha and of this, the covered area was 1.17 million ha with the rest of the area temporarily unplanted (uncovered) as shown in Table 4.5. Brown (2002) estimated the above-ground biomass for softwood and hardwood in the Eastern USA which has a similar subtropical climate and plantation tree species to South Africa and found that most softwood forests have above-ground biomass in the range 25 to 75 t C.dm/ha and most hardwood forest have above-ground biomass in the range 38 to 90 t C.dm/ha. The calculations done in this study reveal the biomass for all South African softwood plantations to be 52 t C.dm/ha and 44 t C.dm/ha for hardwood as shown in Table 4.1. These values fall within the range proposed by Brown (2002).

Furthermore the carbon sequestered, or the productivity for the South African forest in 2011 is 4.6 t C.dm/ha per year. Brown (2002) study also denotes similar productivity in subtropical forest with the range 1.3 to 5.0 t C.dm/ha per year for softwood and 1.5 to 3.8 t C.dm/ha per year for hardwood.

The total input into the South African forests corresponding to tree growth is 5 328 000 t C.dm for the year 2011. Applying the mass balance principle shows an increase in the forest carbon stock of 857 000 t C.dm between 2010 and 2011 which corresponds to a 1.94 % stock increase. This suggest good forest management practice in the South African forestry sector in the year 2011 as more carbon is being grown than being harvested or released to the atmosphere. All things being equal, the stocks should increase steadily each year, which is positive as the increasing carbon stock provides climate mitigation effects with more carbon being stored in the forest.

5.1.1 Carbon Offsets

The total carbon sequestered by plantation forests in 2011 equals 5.328 million t C.dm which corresponds to 0.103 t C.dm per capita using the 2011 South African population of 51.77 million (StatsSA, 2012). The total carbon dioxide emissions from industry in South Africa in 2011 was 322.7 million tons CO_2, which is equivalent to 88 million ton C or 1.7 tons C per capita (SAPPI, 2012). Eskom was the largest contributor to the CO_2 emissions with 230 million tons of CO_2e followed by Sasol with 61.2 million tons of CO_2e, then Arcelor Mittal South Africa (11.9 million tons of CO_2e), Pretoria Portland Cement (4.8 million tons of CO_2e), BHP Billiton (3.1 million tons of CO_2e), Evraz Highveld Steel and Vanadium (2.8 million tons of CO_2e), Anglo American (2.7 million tons of CO_2e), Sappi (2.7 million tons of CO_2e), Harmony Gold (1.5 million tons of CO_2e), Mondi (1 million tons of CO_2e) and Gold Fields (1 million tons of CO_2e) (SAPPI, 2012).

The total carbon offset of all industrial sector carbon emissions in South Africa considering 5.328 million t C.dm was sequestered in the forest was therefore 6.1 %. In chapter 2 it was mentioned that 83 % of the plantation area was owned by the private sector, which is mainly Sappi and Mondi. Eighty three % of the total carbon sequestered is 4.42 million t C.dm. (It is assumed that the mix of trees and climates are the same for the 83% as for the 100%). The total carbon dioxide emissions by Sappi and Mondi combined is 3.7 million tons of CO_2e, which converts to 1.01 million ton C. Comparing the carbon sequestered and the carbon emitted, the net change is positive (3.41 million t C.dm) which implies there is a net carbon dioxide absorption. When plantations and the pulping and paper making process are considered as an integrated entity, i.e. taking into account process emissions and plantation absorptions, the net result is GHG absorption (SAPPI, 2013). In South Africa, the government has proposed a carbon tax of R120 per ton of CO_2 emitted from non-renewable energy sources. Since Mondi and Sappi combined have a net carbon dioxide absorption, a tax offset mechanism should/could be implemented to recognise the sequestration effects of these company owned plantations.

5.1.2 Sensitivity to changes

The flows into and out of the forest affect the forest carbon stock, as an increase in the input will increase the stock if the output stays constant and vice versa, where an increase in output will decrease the forest carbon stock provided the input remains constant. Figure 5.1 shows the effect of increasing the harvest (output) in the forest keeping the input and damage flows constant (based on the flows for 2011).

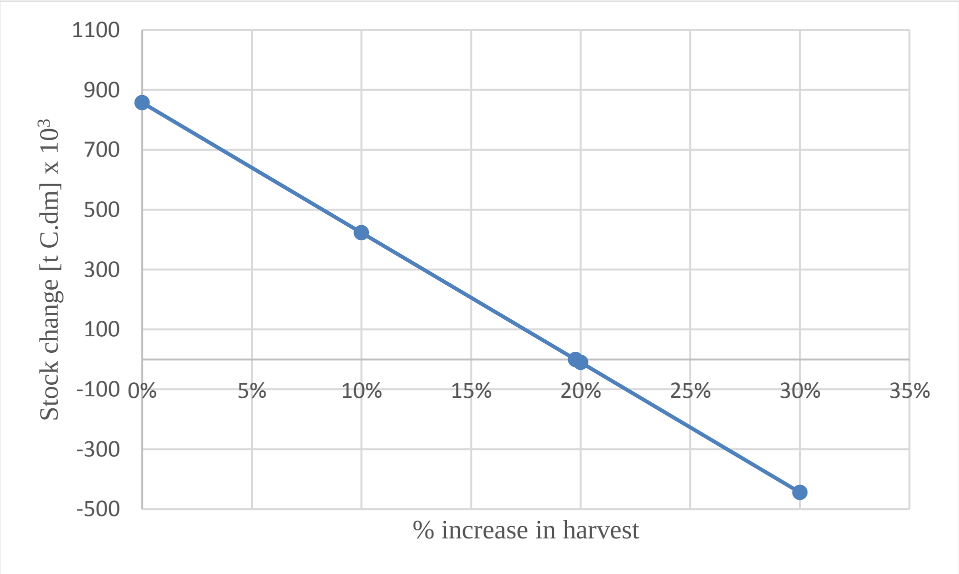

Figure 5.1: Effect of increasing the harvest - Total for South Africa

Based on the 2011 flows, the following was noted:

> Assuming there is no change in the input nor in the amount lost due to damages, a 19.8 % increase in harvest will make the South African forest industry carbon neutral as total input will equal the total output and the stock change will be zero. Any further increase in the harvest will lead to an unsustainably managed forest system whereby the forest stock is slowly being depleted. If there is no change in input or the amount of wood harvested, only a 645 % increase in damages will make the forest carbon neutral which is highly unlikely.

The sensitivity to an increase in harvest is analogous to the sensitivity to a decrease in growth (input) and would lead to the same consequence. Whereas over a 100 % increase in the damages/disturbances will cause a significant change in the forest carbon stock, implying the entire South African forest region is not sensitive to damage flow changes. Table 5.1 shows the percentage threshold values in input, harvest and disturbances for carbon neutrality per region.

The material balance on carbon around the entire South African forest industry in 2011, suggests good forest management practices with overall carbon positivity. The next sections discuss the material balances around each forest region.

5.2 Regions with increasing carbon stocks in 2011

The carbon stocks in the following regions increased from 2010 to 2011 and their material balances are shown in Chapter 4:

- Limpopo Province
- Mpumalanga North
- Mpumalanga Central Districts
- KZN Zululand
- KZN Midlands
- KZN North
- KZN South
- Southern Cape
- Western Cape

Applying the mass balance principle to each of these regions showed an overall increase in forest carbon stock for each region and this is summarised in Table 4.6.

5.2.1 Carbon balance in the Limpopo forest region

The material balance of carbon in the Limpopo forest region is shown in Figure 4.2. The total harvest from the region was 135 000 t C.dm and this forms only 3.12 % of the total harvest for South Africa (see Table 4.4). The loss of carbon to the atmosphere via damages was 957 t C.dm and together with the harvest, the total output from the Limpopo forest region summed up to 135 900 t C.dm.

The total tree growth in the region (total input) was 236 000 t C.dm, and applying the mass balance principle shows an overall increase in forest carbon stock of 100 000 t C.dm, hence the region was carbon positive in 2011. The total forest area in the Limpopo region is 48 280 ha but only 45 610 ha was covered by trees as shown in Table 4.5. In this forest region, the above-ground biomass for softwood was 69 t C.dm/ha and 45 t C.dm/ha for hardwood and the productivity of the region was 5.2 t C.dm/ha for the base year 2011. These values fall within the range of forest with similar subtropical climate and tree type as suggested by Brown (2002).

Figure 5.2 shows the effect of increasing the harvest in the Limpopo forest keeping the input and damage flows constant.

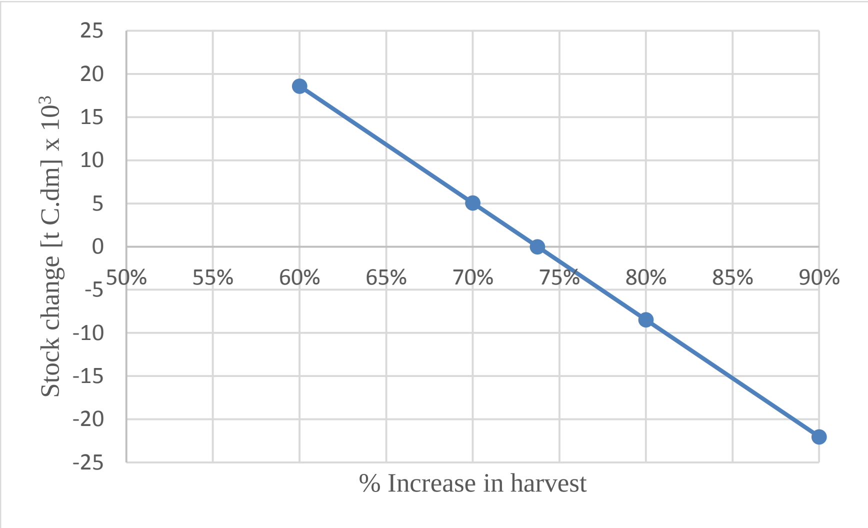

Figure 5.2: Effect of increasing the harvest in the Limpopo forest region

Only a 73.7 % increase in harvest will make the Limpopo forest region carbon neutral and any further increase will make the region carbon negative. 73.7 % increase in harvest in the Limpopo forest region correspond to 99 800 t C.dm which falls outside the error range for the region. This forest region disproves the hypothesis as forest management practices and activities for the base year 2011 increased the forest carbon stocks in the region. This implies the region was well managed and the forest carbon stock in the region will keep increasing if the forest management practice is maintained.

5.2.2 Carbon balance in Mpumalanga North

The carbon balance in Mpumalanga North forest region is shown in Figure 4.3. The total harvest from the region was 776 000 t C.dm and this forms 17.9 % of the total harvest for South Africa (see Table 4.4). The loss of carbon to the atmosphere via damages was 6 100 t C.dm and together with the harvest, the total output from Mpumalanga North forest region was 782 000 t C.dm.

The total tree growth in the region was 1 224 000 t C.dm, and applying the mass balance principle shows an overall increase in forest carbon stock of 441 000 t C.dm, corresponding to a 4.59 % increase in stock in 2011. The total forest area in this region is 233 800 ha with only 217 900 ha covered by trees as shown in Table 4.5. The region has above-ground biomass for softwood of 52 t C.dm/ha and 33 t C.dm/ha for hardwood with a productivity of 5.6 t C.dm/ha for the base year 2011.

The tree growth in this region offset the total carbon dioxide emission in South Africa by 1.39 %, increasing the regions carbon stock in the process. The sensitivity to harvest is shown in Figure 5.3. The sensitivity to an increase in harvest is analogous to the sensitivity to a decrease in growth (input) and would lead to the same consequence in the region. Whereas over a 100 % increase in the damages/disturbances will cause a significant change in the region, implying the region is not sensitive to damage flow changes.

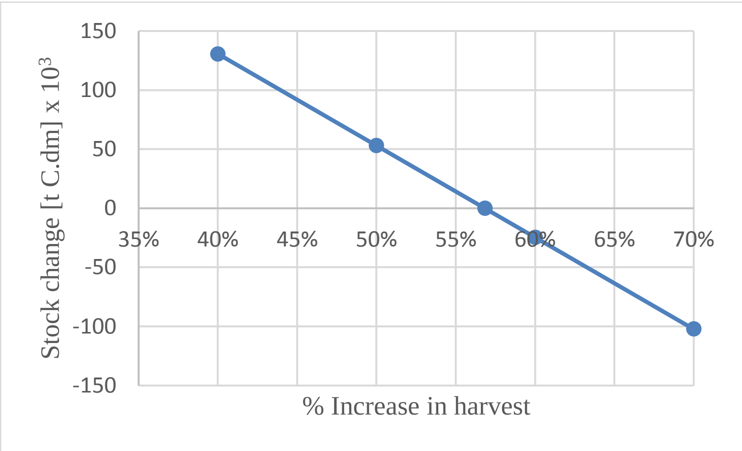

Figure 5.3: Effect of increasing the harvest in the Mpumalanga North forest region

This region is not very sensitive to changes in harvest as it will require a 56.8 % increase in harvest for the region to have a stock change of zero. 56.8 % increase in harvest in the Mpumalanga North forest region correspond to 441 300 t C.dm which falls outside the error range of ± 77 000 t C.dm for the region. This forest region also disproves the hypothesis as the forest management practices and activities increased the forest carbon stock in the region for the base year 2011.

5.2.3 Carbon balance in Mpumalanga Central Districts

The carbon balance in Mpumalanga Central Districts forest region is shown in Figure 4.4. The total harvest from the region was 88 000 t C.dm and this forms only 2.03 % of the total harvest for South Africa (see Table 4.4). The loss of carbon to the atmosphere via damages was 5.0 t C.dm which is negligible.

The total tree growth in the region was 94 000 t C.dm, and applying the mass balance principle shows an overall increase in forest carbon stock of 6 000 t C.dm, corresponding to a 0.5 % increase in stock in 2011. The total forest area in this region is 25 470 ha with only 23 290 ha covered by trees as shown in Table 4.5. The region has above-ground biomass for softwood of 50 t C.dm/ha and 44 t C.dm/ha for hardwood with a productivity of 4.0 t C.dm/ha for the base year 2011.

The tree growth in this region offset the carbon dioxide emission by 0.11 %, increasing the regions carbon stock in the process. The sensitivity to harvest is shown in Figure 5.4.

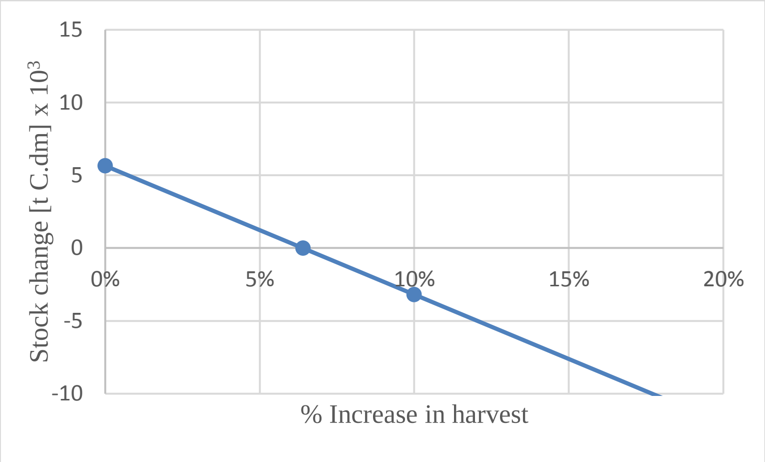

Figure 5.4: Effect of increasing the harvest in the Central Districts forest region

This region is more sensitive to changes in harvest compared to Limpopo and Mpumalanga North forest regions. It requires a 6.4 % increase in harvest for the region to have a stock change of zero. The error range in harvest in Mpumalanga Central Districts forest region is ± 8 850 t C.dm, and the sensitivity to harvest has a threshold of 6.4 % corresponding to 5 660 t C.dm. The threshold value falls within the error range for the harvest, therefore this forest region is extremely sensitive to changes in the flows in or out of the forest and any increase in harvest or decrease in tree growth will deplete the forest carbon stock in the region. It is therefore recommended that more trees be planted (tress with greater mean annual increments (MAI) or hybrid trees) and the number of trees harvested be reduced.

This region somewhat proves the hypothesis that the forest carbon stock is being depleted annually as a result of forest management activities and continuous usage of forest products.

5.2.4 Carbon balance in KZN Zululand

The carbon balance in KZN Zululand forest region is shown in Figure 4.6. The total harvest from the region was 514 000 t C.dm and this forms 11.8 % of the total harvest for South Africa (see Table 4.4). The loss of carbon to the atmosphere via damages was 11 000 t C.dm and together with the harvest, the total output from KZN Zululand forest region was 525 000 t C.dm.

The total tree growth in the region was 711 000 t C.dm, and applying the mass balance principle shows an overall increase in forest carbon stock of 187 000 t C.dm, corresponding to a 14.3 % increase in stock in 2011. The total forest area in this region is 77 050 ha with only 73 060 ha covered by trees as shown in Table 4.5. The region has above-ground biomass for softwood of 58 t C.dm/ha and 18 t C.dm/ha for hardwood with a productivity of 9.7 t C.dm/ha for the base year 2011.

KZN Zululand is the most productive region of the twelve regions and it has the largest percentage increase in forest carbon stock. The tree growth in this region offset the carbon dioxide emission by 0.81 %. The sensitivity to harvest is shown in Figure 5.5.

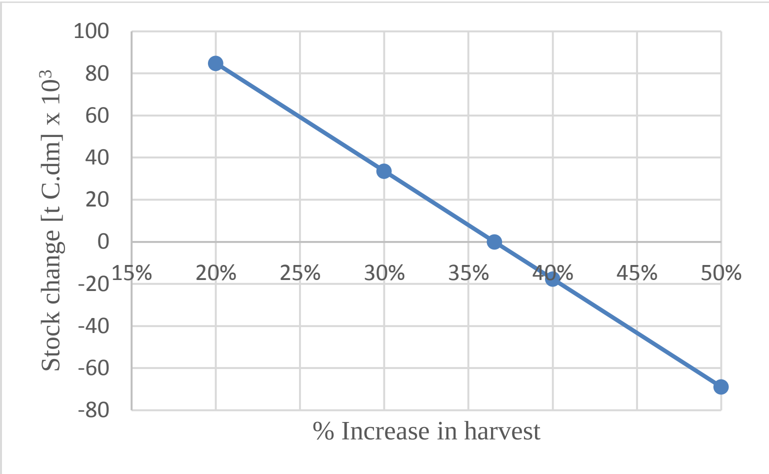

Figure 5.5: Effect of increasing the harvest in the KZN Zululand forest region

This region is not very sensitive to changes in harvest as it will require a 36.5 % increase in harvest for the region to have a stock change of zero. 36.5 % increase in harvest in the KZN Zululand forest region correspond to 187 200 t C.dm which falls outside the error range of ± 50 000 t C.dm for the region. This forest region disproves the hypothesis as the forest management practices and activities for the base year 2011 increased the forest carbon stock of the region

5.2.5 Carbon balance in KZN Midlands

The carbon balance in KZN Midlands forest region is shown in Figure 4.7. The total harvest from the region was 998 000 t C.dm and this forms only 23 % of the total harvest for South

Africa (see Table 4.4). The loss of carbon to the atmosphere via damages was 33 000 t C.dm and together with the harvest, the total output from KZN Midlands forest region was 1 031 000 t C.dm.

The total tree growth in the region was 1 074 000 t C.dm, and applying the mass balance principle shows an overall increase in forest carbon stock of 43 000 t C.dm, corresponding to a 0.85 % increase in stock in 2011. The total forest area in this region is 195 200 ha with only 185 000 ha covered by trees as shown in Table 4.5. The region has above-ground biomass for softwood of 47 t C.dm/ha and 21 t C.dm/ha for hardwood with a productivity of 5.8 t C.dm/ha for the base year 2011.

The tree growth in this region offset the carbon dioxide emission by 1.22 %, increasing the regions carbon stock in the process. The sensitivity to harvest is shown in Figure 5.6.

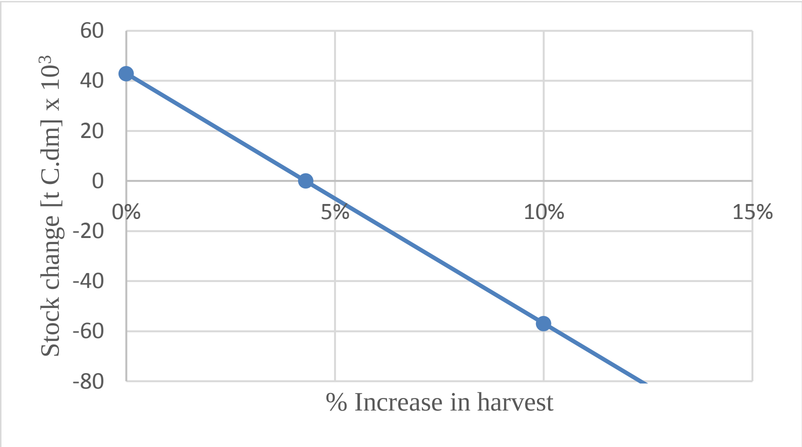

Figure 5.6: Effect of increasing the harvest in the KZN Midlands forest region

This region is the most sensitive of the twelve regions to changes in harvest. It requires only 4.3 % increase in harvest for the region to have a stock change of zero. The error range in harvest in KZN Midlands forest region is ± 96 700 t C.dm, and the sensitivity to harvest has a threshold of 4.3 % corresponding to 42 900 t C.dm. The threshold value falls within the error range for the harvest, therefore this forest region is extremely sensitive to changes in the flows in or out of the forest and any increase in harvest or decrease in tree growth will deplete the forest carbon stock in the region. It is therefore recommended that more trees be planted (tress with greater mean annual increments (MAI) or hybrid trees) and fewer trees be harvested.

This region also somewhat proves the hypothesis that the forest carbon stock is being depleted annually as a result of forest management activities and continuous usage of forest products.

5.2.6 Carbon balance in KZN North

The carbon balance in KZN North forest region is shown in Figure 4.8. The total harvest from the region was 202 000 t C.dm and this forms 4.66 % of the total harvest for South Africa (see Table 4.4). The loss of carbon to the atmosphere via damages was 5 600 t C.dm and together with the harvest, the total output from KZN North forest region was 208 000 t C.dm.

The total tree growth in the region was 252 000 t C.dm, and applying the mass balance principle shows an overall increase in forest carbon stock of 45 000 t C.dm, corresponding to a 2.23 % increase in stock in 2011. The total forest area in this region is 91 070 ha with only 85 380 ha covered by trees as shown in Table 4.5. The region has above-ground biomass for softwood of 46 t C.dm/ha and 18 t C.dm/ha for hardwood with a productivity of 2.9 t C.dm/ha for the base year 2011. The tree growth in this region offset the carbon dioxide emission by 0.29 %. The sensitivity to harvest is shown in Figure 5.7.

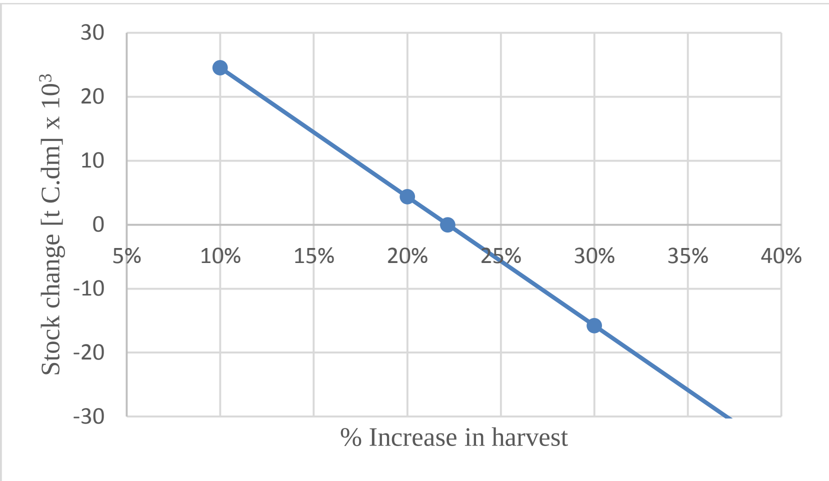

Figure 5.7: Effect of increasing the harvest in the KZN North forest region

This region is not very sensitive to changes in harvest as it will require a 22.2 % increase in harvest corresponding to 44 670 t C.dm for the region to have a stock change of zero. The sensitivity threshold value falls outside the error range (± 19 660 t C.dm) supporting the fact that the region is not very sensitive to changes in flows. This forest region disproves the hypothesis as the forest management activities increased the forest carbon stock instead of depleting the stock.

5.2.7 Carbon balance in KZN South

The carbon balance in KZN South forest region is shown in Figure 4.9. The total harvest from the region was 619 000 t C.dm and this forms only 14.3 % of the total harvest for South Africa (see Table 4.4). The loss of carbon to the atmosphere via damages was 43 000 t C.dm and together with the harvest, the total output from KZN South forest region was 662 000 t C.dm.

The total tree growth in the region was 719 000 t C.dm, and applying the mass balance principle shows an overall increase in forest carbon stock of 57 000 t C.dm, corresponding to a 1.35 % increase in stock in 2011. The total forest area in this region is 122 800 ha with only 117 000 ha covered by trees as shown in Table 4.5. The region has above-ground biomass for softwood of 45 t C.dm/ha and 29 t C.dm/ha for hardwood with a productivity of 6.1 t C.dm/ha for the base year 2011.

The tree growth in this region offset the carbon dioxide emission by 0.82 %, increasing the regions carbon stock in the process. The sensitivity to harvest is shown in Figure 5.8.

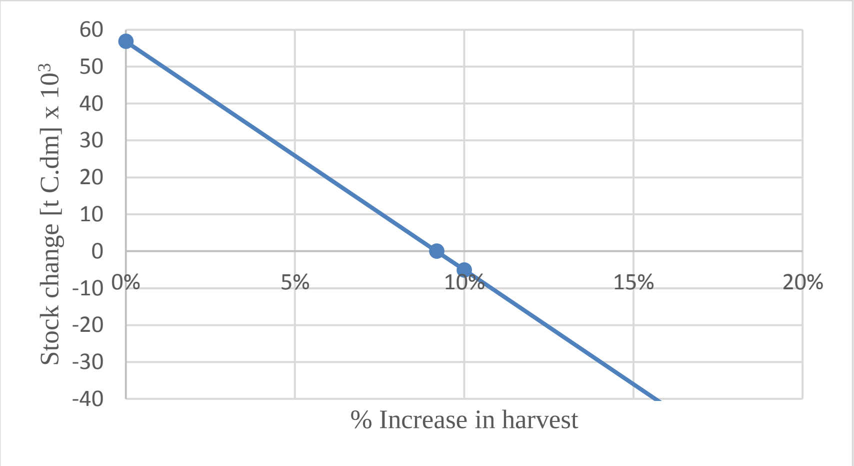

Figure 5.8: Effect of increasing the harvest in the KZN South forest region

This region is sensitive to carbon flow changes and requires 9.18 % increase in harvest for the region to have a stock change of zero. The error range in harvest in the KZN South forest region is ± 58 000 t C.dm, and the harvest sensitivity threshold has a value of 56 800 t C.dm which falls within the error range for the region. The KZN South forest region is therefore very sensitive to changes in the flows in or out of the forest and any increase in harvest or decrease in tree growth will deplete the forest carbon stock in the region. It is therefore recommended that more trees be planted, tress with greater mean annual increments and decrease the quantity of trees harvested.

This region also somewhat proves the hypothesis that the forest carbon stock is being depleted annually as a result of forest management activities and continuous usage of forest products because worse case scenarios deplete the stock.

5.2.8 Carbon balance in Southern Cape

The carbon balance in Southern Cape forest region is shown in Figure 4.11. The total harvest from the region was 110 000 t C.dm and this forms 2.54 % of the total harvest for South Africa (see Table 4.4). The loss of carbon to the atmosphere via damages was 2 000 t C.dm and together with the harvest, the total output from Southern Cape forest region was 112 000 t C.dm.

The total tree growth in the region was 158 000 t C.dm, and applying the mass balance principle shows an overall increase in forest carbon stock of 45 000 t C.dm, corresponding to a 1.36 % increase in stock in 2011. The total forest area in this region is 64 300 ha with only 49 400 ha covered by trees as shown in Table 4.5. The region has above-ground biomass for softwood of 66 t C.dm/ha and 102 t C.dm/ha for hardwood with a productivity of 3.2 t C.dm/ha for the base year 2011.

The tree growth in this region offset the carbon dioxide emission by 0.18 %, increasing the regions carbon stock in the process. The sensitivity to harvest is shown in Figure 5.9.

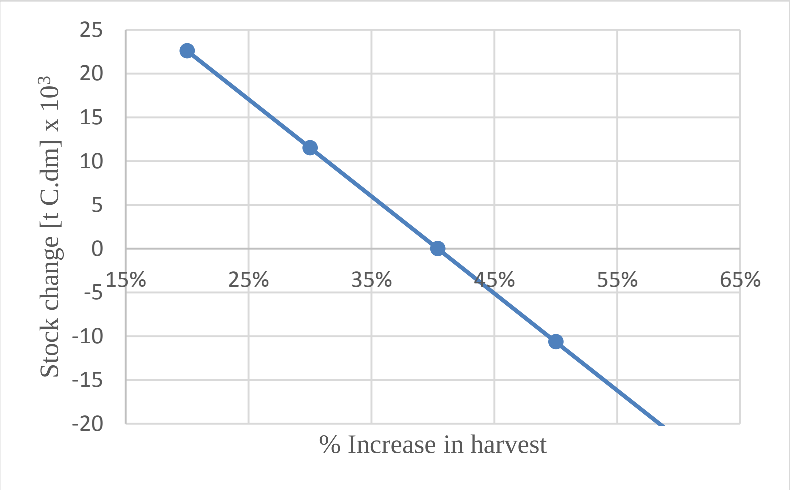

Figure 5.9: Effect of increasing the harvest in the Southern Cape forest region

This region is not very sensitive to changes in harvest as it will require a 40.4 % increase in harvest for the region to have a stock change of zero. 40.4 % increase in harvest in the Southern Cape forest region correspond to 44 800 t C.dm which falls outside the error range of ± 10 900 t C.dm for the region. The hypothesis fails in this forest region as forest management practices and activities for the base year 2011 increased the forest carbon stock in the region.

5.2.9 Carbon balance in Western Cape

The carbon balance in Western Cape forest region is shown in Figure 4.12. The total harvest from the region was 31 000 t C.dm and this forms 0.71 % of the total harvest for South Africa (see Table 4.4). The loss of carbon to the atmosphere via damages was 14 000 t C.dm and together with the harvest, the total output from Western Cape forest region was 45 000 t C.dm.

The total tree growth in the region was 52 000 t C.dm, and applying the mass balance principle shows an overall increase in forest carbon stock of 8 000 t C.dm, corresponding to a 0.77 % increase in stock in 2011. The total forest area in this region is 16 400 ha with only 11 600 ha covered by trees as shown in Table 4.5. The region has above-ground biomass for softwood of 83 t C.dm/ha and 135 t C.dm/ha for hardwood with a productivity of 4.5 t C.dm/ha for the base year 2011.

The tree growth in this region offset the carbon dioxide emission by 0.06 %, increasing the regions carbon stock in the process. The sensitivity to harvest is shown in Figure 5.10.

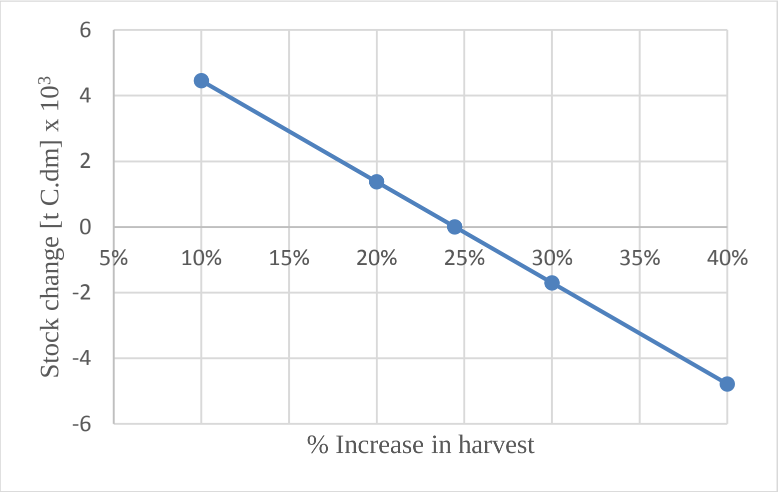

Figure 5.10: Effect of increasing the harvest in the Western Cape forest region

This region is not very sensitive to changes in harvest as it will require a 24.5 % increase in harvest for the region to have a stock change of zero. 24.5 % increase in harvest in the Western Cape forest region correspond to 7 500 t C.dm which falls outside the error range of ± 2 300 t C.dm for the region. The hypothesis fails in this forest region as forest management practices and activities for the base year 2011 increased the forest carbon stocks in the region.

5.3 Regions with decreasing carbon stocks in 2011

The carbon stocks in the following regions decreased from 2010 to 2011 and a summary of their material balances is shown in Table 4.6:

- Mpumalanga South
- Maputaland
- Eastern Cape

5.3.1 Carbon balance in Mpumalanga South

The carbon balance in Mpumalanga South forest region is shown in Figure 4.5. The total harvest from the region was 591 000 t C.dm and this forms 13.6 % of the total harvest for South Africa. The loss of carbon to the atmosphere via damages was 10 000 t C.dm and together with the harvest, the total output from Mpumalanga South forest region was 601 000 t C.dm.

The total tree growth in the region was 597 000 t C.dm, and applying the mass balance principle shows an overall decrease in forest carbon stock of 5 000 t C.dm. for the base year 2011. The total forest area in this region is 259 700 ha with only 244 200 ha covered by trees as shown in Table 4.5. The region has above-ground biomass for softwood of 45 t C.dm/ha and 26 t C.dm/ha for hardwood with a productivity of 2.4 t C.dm/ha for the base year 2011.

The hypothesis has been proven for this forest region as the forest management activities and practices led to depletion of forest carbon stock. Further Mpumalanga South forest region is highly sensitive to flow changes with a harvest threshold value of 5 000 t C.dm (0.84 %) which falls within the error range of ± 58 200 t C.dm for the forest region. It is recommended to plant more trees with a faster growth rate or greater mean annual increment and to decrease harvest in the Mpumalanga South forest region in order to increase the region's forest carbon stock.

The output flow to a large extent depends on the quantity of wood harvested and in this forest regions which is very sensitive to flow changes, carbon stocks may increase or decrease from year to year depending on how many hectares become harvestable in that particular year. Looking at the mass balance in Figure 4.5, less carbon is removed from the forest due to harvesting than is being grown. The forest stock decreases however as a result of carbon release via damage (fires, insects etc.) For carbon neutrality to be achieved, the Mpumalanga South forest should be managed and maintained with care to avoid wild fires which will lead to an increase in carbon emissions in the forest.

5.3.2 Carbon balance in Maputaland

There was no reported harvesting done in the Maputaland forest region but it was calculated that the forest stock decreased. There is however, growth in the trees so an increase in forest stock should be expected. Looking at Table A2.5 and Table A5.5 in **Appendix A**, we see that there is a large portion of the forest area left unplanted in 2011 than in 2010, whereas the total area in each year is roughly same. This explains the calculated decrease in carbon stock as there are less trees standing in 2011 than in 2010. It is assumed that some trees were harvested or destroyed by fires or insects and these data were not recorded in the national forestry database. This is further supported by the fact that the forest area for *Pinus elliottii* trees of 34+ years is less in 2011 than in 2010 and there is no recorded forest area for 16, 17 and 19 year *Eucalyptus grandis* trees in 2011 compared to 2010.

For an increase in the forest stock in the Maputaland forest region, the only remedy will be to plant more trees in the region or plant trees with greater mean annual increments such as hybrid trees or cloned trees. The calculated above-ground biomass for Maputaland forest region was 33 t C.dm/ha for softwood and 18 t C.dm/ha for hardwood.

5.3.3 Carbon balance in Eastern Cape

The carbon balance in Eastern Cape forest region is shown in Figure 4.10. The total harvest from the region was 273 000 t C.dm and this forms 6.28 % of the total harvest for South Africa. The loss of carbon to the atmosphere via damages was 6 000 t C.dm and together with the harvest, the total output from Mpumalanga South forest region was 279 000 t C.dm.

The total tree growth in the region was 250 000 t C.dm, and applying the mass balance principle shows an overall decrease in forest carbon stock of 29 000 t C.dm. for the base year 2011. The total forest area in this region is 122 100 ha with only 106 800 ha covered by trees as shown in Table 4.5. The region has above-ground biomass for softwood of 52 t C.dm/ha and 35 t C.dm/ha for hardwood with a productivity of 2.3 t C.dm/ha for the base year 2011.

The hypothesis has also been proven for the Eastern Cape forest region as the forest management activities and practices led to depletion of forest carbon stock. This region is not very sensitive to flow changes as the harvest threshold value of 29 400 t C.dm falls outside the error range of ± 26 800 t C.dm for the forest region. In 2011 more trees were just harvested than they should have for the Eastern Cape forest region. It is therefore recommended to decrease the quantity harvested in subsequent years.

5.4 Sensitivity analysis - Summary

The sensitivity analysis summary showing percentage threshold values in input, harvest and disturbances for carbon neutrality per region is shown in Table 5.1. The sensitivity to an increase in harvest is analogous to the sensitivity to a decrease in growth (input) and would lead to the same consequence in each region. Whereas over 100 % increase in the damages/disturbances will cause a significant change in the regions except for Mpumalanga South and Western Cape forest regions requiring a 50 % and 55 % increase in disturbance for the stock change to be zero respectively. Hence all the forest regions except Mpumalanga South and Western Cape are not sensitive to damages/disturbances flow changes.

Table 5.1: Sensitivity analysis summary showing percentage threshold values in Input, Harvest and Disturbances for carbon neutrality per region

Region	Sensitivity threshold [%]		
	Input (Growth)	Harvest	Disturbance
Limpopo Province	-42	73.7	10 400
Mpumalanga North	-36	56.8	7 150
Mpumalanga Central Districts	-6.0	6.4	109 400
Mpumalanga South	0.84	-0.8	-50
KZN Maputaland	-	-	-
KZN Zululand	-26	36.5	1 660
KZN Midlands	-4	4.3	129
KZN North	-18	22.2	801
KZN South	-7.9	9.2	131
E. Cape	12	-10.8	-100
S. Cape	-28	40.4	1 890
W. Cape	-14	24.5	55
R.S.A	-16	19.8	645

5.5 Connecting the carbon flows in the forest

The mass balance principle was used to calculate the net carbon dioxide uptake from the atmosphere, stored in the trees as living biomass; that is, the tree growth or total carbon input flow to the forest. The input flow must equal the output plus the carbon stock difference in the year of study, 2011. The output flow and the carbon stock difference were first calculated, then the mass balance principle was applied to calculate the input flow. It was mentioned in Section 2.9.1.1 and Section 3.2.4.2 that the input flow could be calculated using the *Gain-Loss Method*, which was then used to verify the mass balance. The input flow using the *Gain-Loss Method* was calculated at 5 410 000 t C.dm which fell within the error interval of the 5 328 000 ± 442 000 t C.dm as shown in Figure 4.1.

The total annual input for the South African forest was calculated using the mean annual increment (MAI) shown in **Appendix C**, Table C3 and the plantation area shown in Table C1. The rotational age in Table C2 was used to select the particular MAI to use in the calculation. Equation 3.2 was then applied to calculate the input flow (in m^3/y) in the forest for the base year 2011.

$$G = \sum_{i,j}\left(A_{i,j} \times MAI_{i,j} \times [1 + R]\right) \quad (3.2)$$

Finally the basic wood density (0.497 $t.m^{-3}$ for hardwood and 0.501 $t.m^{-3}$ for softwood) was then used to convert the input to ton C $d.m.y^{-1}$

5.6 Stock change over longer periods

Tables 5.2 and 5.3 show the change in carbon stock from 2007 to 2011 and from 2003 to 2011 respectively. The overall carbon stock decreased in both instances and this is as a result of a decrease in the total planted area from 1.175 million ha in 2007 to 1.17 million ha in 2011, and from 1.253 million ha in 2003 to 1.17 million ha in 2011. There is a direct relation between the forest carbon stock and the covered area, therefore if the covered area or number of trees planted per unit area is increased, so will the carbon stock.

Table 5.2: Change in carbon stock from 2007 to 2011

Region	Covered Area 2007	Covered Area 2011 [ha]	Stock [t C.dm] 2007 x 10^3	Stock [t C.dm] 2011 x 10^3	stock change [t C.dm] x 10^3	stock change %
Limpopo Province	45 320	45 610	2 480	2 692	53	2.14
Mpumalanga North	220 700	217 900	10 983	10 053	-232	-2.12
Mpumalanga Central Districts	17 600	23 290	785	1 134	87	11.12
Mpumalanga South	249 400	244 200	8 061	8 542	120	1.49
KZN Maputaland	13 470	11 200	161	297	34	21.09
KZN Zululand	75 470	73 060	1 720	1 497	-56	-3.25
KZN Midlands	185 600	185 000	5 229	5 092	-34	-0.66
KZN North	81 280	85 380	1 925	2 047	30	1.57
KZN South	100 600	117 000	3 797	4 265	117	3.09
E. Cape	109 800	106 800	5 509	5 216	-73	-1.33
S. Cape	62 040	49 400	4 300	3 343	-239	-5.56
W. Cape	13 580	11 600	1 121	986	-34	-3.00
R.S.A	1 175 000	1 170 000	46 070	45 164	-227	-0.49

Table 5.3: Change in carbon stock from 2003 to 2011

Region	Covered Area 2003	Covered Area 2011 [ha]	Stock [t C.dm] 2003 x 10^3	Stock [t C.dm] 2011 x 10^3	stock change [t C.dm] x 10^3	stock change %
Limpopo Province	58 920	45 610	2 670	2 692	6	0.22
Mpumalanga North	226 200	217 900	11 238	10 053	-296	-2.64
Mpumalanga Central Districts	18 700	23 290	955	1 134	45	4.71
Mpumalanga South	247 600	244 200	7 881	8 542	165	2.09
KZN Maputaland	16 650	11 200	690	297	-98	-14.25
KZN Zululand	116 500	73 060	3 117	1 497	-405	-13.00
KZN Midlands	188 900	185 000	5 479	5 092	-97	-1.77
KZN North	86 790	85 380	2 070	2 047	-6	-0.29
KZN South	103 700	117 000	3 932	4 265	83	2.12
E. Cape	117 900	106 800	5 245	5 216	-7	-0.14
S. Cape	55 750	49 400	3 884	3 343	-135	-3.49
W. Cape	15 110	11 600	1 287	986	-75	-5.84
R.S.A	1 253 000	1 170 000	48 448	45 164	-821	-1.69

Figure 5.11 shows the total plantation area from 1980 to 2011. There is an increase in the total plantation area from 1980 to 1997 which, all things being equal, meant the forest carbon stock increased. After 1997, the total plantation area decreased gradually, hence the carbon stock also decreased. Overall, there is a general increase in the total plantation area of 112 000 ha from 1980 to 2011, which implies the forest stock has increased since 1980.

The tail end of the graph in Figure 5.11 shows a slight increase in the plantation area. Therefore if one was to extrapolate, the plantation area should increase in the subsequent years, hence an increasing the forest carbon stock. Looking closer at 2007 and 2011, the total forest area increased but the calculated stock change was negative, i.e. the stock decreased. The decrease in the stock is as a result of less area covered by trees in 2011 than in 2007 as shown in Table 5.2.

This chapter discussed and interpreted the results obtained in this study and showed how the forest carbon stock is proportional to the number of trees planted per area and the plantation area covered by trees. The forest management activities depleted the forest carbon stock for Mpumalanga Central Districts, Mpumalanga South, KwaZulu-Natal Maputaland, KwaZulu-Natal Midlands, KwaZulu-Natal South and the Eastern Cape forest regions. The next chapter gives the conclusions and recommendations drawn from this study.

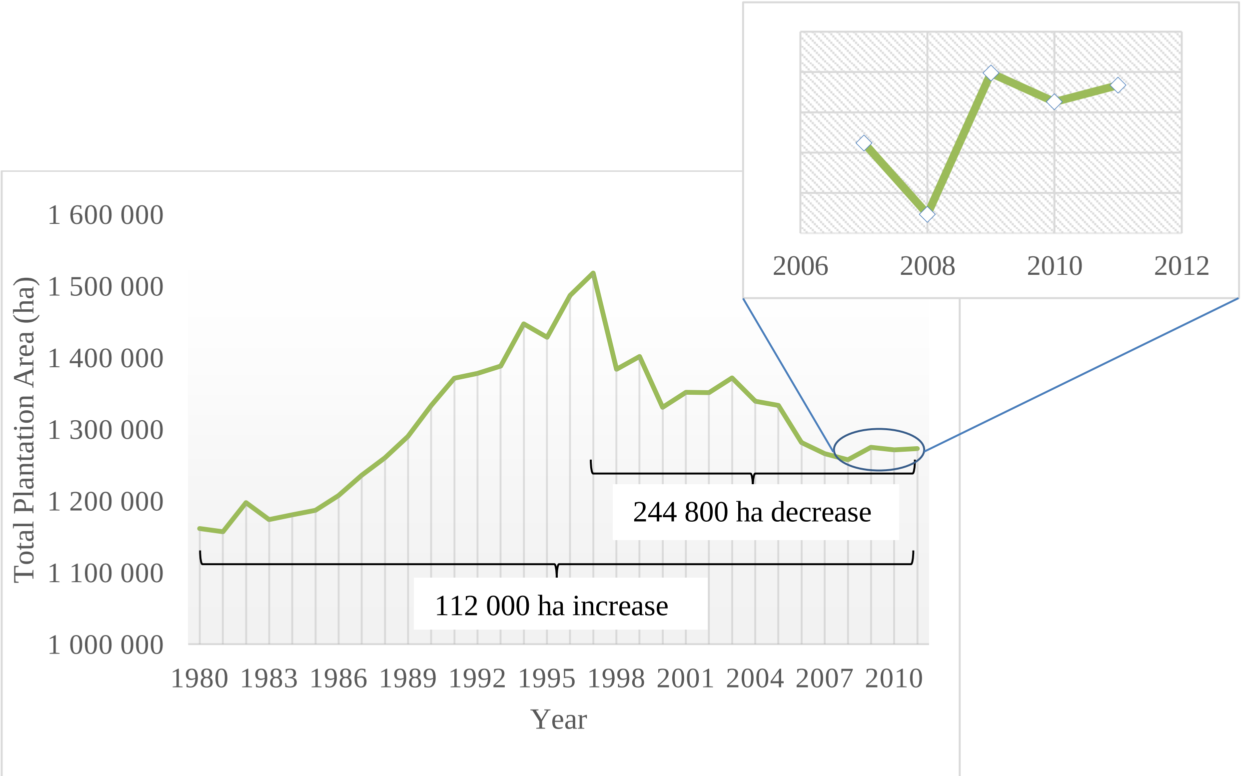

Figure 5.11: Total Plantation Area 1980 to 2011 (FSA, 2011)

Table 5.4: Comparison between the stocks in 2003, 2007 and 2011

Region	2003 Stock [t C.dm] x 10^3		2007 Stock [t C.dm] x 10^3		2011 Stock [t C.dm] x 10^3	
	Softwood	Hardwood	Softwood	Hardwood	Softwood	Hardwood
Limpopo Province	1 370	1 299	1 682	798	1 835	858
Mpumalanga North	8 535	2 704	8 967	2 016	7 803	2 250
Mpumalanga Central Districts	850	105	538	247	926	208
Mpumalanga South	4 917	2 965	5 223	2 838	5 234	3 307
KZN Maputaland	383	307	73	89	207	90
KZN Zululand	706	2 411	468	1 252	241	1 255
KZN Midlands	2 570	2 909	2 165	3 064	2 108	2 984
KZN North	785	1 285	723	1 202	783	1 264
KZN South	2 036	1 895	2 455	1 342	2 515	1 750
E. Cape	4 586	659	4 876	633	4 539	678
S. Cape	3 502	383	3 881	418	3 152	191
W. Cape	1 196	90	1 044	77	915	72
R.S.A	31 440	17 010	32 090	13 980	30 260	14 910

6. CONCLUSIONS AND RECOMMENDATIONS

In this study the time series data on carbon stocks and flows within the South African forest and forestry sector was collected and the complexity was reduced by incorporating the flows and stocks into a Material Flow Analysis using the mass balance principle. 2011 was selected as the base year as it is the year with the latest available data. It was shown the entire region is, as a whole carbon positive. Six out of the twelve forest regions were carbon positive with respect to forest management activities in the year 2011. In these regions, more trees were being grown than were being harvested, hence the forest stock gradually increased. Also it was found that these regions are not sensitive to changes in input nor output flows.

The hypothesis was proven for the other six forest regions namely Mpumalanga Central Districts, Mpumalanga South, KwaZulu-Natal Maputaland, KwaZulu-Natal Midlands, KwaZulu-Natal South and the Eastern Cape forest regions. In these regions, fewer trees were being grown and there was less carbon input into the forest than was being removed from harvesting or damages. It was found that these regions with the exception of the Eastern Cape forest region, are extremely sensitive to carbon flow changes with the carbon stock change being positive or negative with slight changes in the input or output flows. It is suggested that more trees be grown, trees with greater mean annual increments or hybrid trees be planted in these regions. Further, the quantity of wood harvested should be substantially reduced or else the forest carbon stock will be depleted year after year.

Of the 1.27 million ha of forest land in South Africa, only 1.17 million ha was covered by plantations in 2011 while the remaining 102 900 ha was temporarily unplanted. The above-ground biomass was on average 52 t C.dm/ha for softwood forest and 44 t C.dm/ha for hardwood forest in South Africa in 2011. This falls within the range of forest with similar subtropical climate and tree type. The overall productivity, or the carbon sequestered in 2011 was 4.6 t C.dm/ha with KwaZulu-Natal Zululand having the highest sequestration of carbon per ha (9.7 t C.dm/ha) while the Eastern Cape forest region had the lowest sequestration of carbon per ha (2.3 t C.dm/ha). Of the total wood harvested 41 % was softwood and the rest was *Eucalyptus grandis* and other hardwood species as shown in Table 4.3. Additionally it is apparent from Table 4.4 that pulpwood is the major product harvested from the commercial plantations in South Africa and sawlogs are also a very significant product.

The Material Flow Analysis method was used to identify the forest regions which were very sensitive to flow changes as this could help facilitate the implementation of goal-oriented decisions. Based on the 2011 data, Mpumalanga Central Districts, Mpumalanga South, KwaZulu-Natal Maputaland, KwaZulu-Natal Midlands, and KwaZulu-Natal South forest regions are very sensitive to a change in either input or output flow with their harvest threshold values falling within the error ranges in each region respectively. Whereas the least sensitive region is Limpopo forest region with the greatest percentage harvest threshold value. Discrete events such as fires or climate change also affect the forest carbon stock but their effect is only significant in forest regions which are very sensitive to flow changes and less significant in forest which are less sensitive.

The total tree growth in the forest for 2011 was 5.328 million t C.dm and with a total carbon dioxide emission for South Africa of 322.7 million ton CO_2, the forest carbon offset was estimated at 6.1 % for the base year 2011. Using 83 % of tree growth (83 % of the plantation area is owned by the private sector, particularly Sappi and Mondi) and the total carbon emitted by Sappi and Mondi, the net change in carbon is positive (3.41 million t C.dm), implying there is net greenhouse gas (GHG) absorption. This was identified after applying the Material Flow Analysis method and calculating the total input flow (tree growth) in the forest. Therefore it can be concluded that when the forest plantation absorptions together with the pulp and paper making process emissions are combined, the net result is GHG absorption.

According to Bower et al. (2011), a policy of active and responsible forest management is more effective in capturing and storing atmospheric carbon than a policy of hands-off management that precludes periodic harvests and use of wood products. The material flow model showed that the active and responsible forest management is more effective in capturing and storing carbon as the overall South African forest was carbon positive in 2011.

It is recommended that a comprehensive carbon flow analysis of the South African forestry industry needs to include the paper and pulp sector, import and export flows, as well as carbon dioxide emissions from fossil-fuel, electricity generation and transportation activities. Further, since Mondi and Sappi combined have a net carbon dioxide absorption, a tax offset mechanism should/could be implemented to recognise the sequestration effects of these company owned plantations. This study could also be expanded to include water and energy flows, nitrogen phosphorus and basic cation flows in the forest.

In this study, the time series data on material stocks and flows within the South African forest were collected and the complexity was reduced by incorporating the data into a Material Flow Analysis model. The results about the flows and stocks were presented in a clear, understandable and transparent way and the importance and relevance of these flows was evaluated. The hypothesis was proven for six out of the twelve forest regions, and five of these regions were extremely sensitive to changes in flows.

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APPENDICES

APPENDIX A – RAW DATA

This section shows the raw data used to develop the Material Flow Aanalysis model. All figures are rounded to the nearest full number therefore totals of number lists may show minor rounding differences.

2011 Data

Table A1: Growth curves per species (Godsmark, 2013)

Species	Softwoods						Hardwoods		
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle
Year									
1	0	0	0	0	0	0	0	0	0
2	0.0	0.0	1.0	0.3	0.3	0.3	1.5	1.5	0.0
3	4.3	2.5	5.3	4.0	4.0	4.0	6.0	6.0	2.7
4	6.4	4.0	7.8	6.1	6.1	6.1	9.8	9.8	5.3
5	8.0	5.2	9.7	7.6	7.6	7.6	12.2	12.2	7.0
6	9.2	6.1	11.2	8.9	8.9	8.9	14.0	14.0	8.3
7	10.3	6.9	12.5	9.9	9.9	9.9	15.4	15.4	9.1
8	11.2	7.5	13.6	10.8	10.8	10.8	16.4	16.4	9.6
9	12.1	8.1	14.6	11.6	11.6	11.6	17.2	17.2	9.9
10	12.8	8.6	15.4	12.3	12.3	12.3	17.9	17.9	10.0
11	13.4	9.1	16.2	12.9	12.9	12.9	18.4	18.4	9.9
12	14.0	9.5	16.8	13.4	13.4	13.4	18.7	18.7	9.8
13	14.5	9.8	17.4	13.9	13.9	13.9	18.9	18.9	9.5
14	15.0	10.1	17.9	14.3	14.3	14.3	18.9	18.9	9.3
15	15.6	10.4	18.3	14.8	14.8	14.8	18.9	18.9	9.0
16	15.8	10.7	18.7	15.0	15.0	15.0	18.7	18.7	8.7
17	16.1	10.9	19.0	15.3	15.3	15.3	18.5	18.5	8.4
18	16.4	11.0	19.3	15.6	15.6	15.6	18.3	18.3	8.1
19	16.6	11.2	19.5	15.8	15.8	15.8	18.1	18.1	7.7
20	16.8	11.3	19.7	15.9	15.9	15.9	17.8	17.8	7.5
21	17.0	11.4	19.8	16.1	16.1	16.1	17.5	17.5	7.2
22	17.1	11.5	19.9	16.2	16.2	16.2	17.3	17.3	6.9
23	17.3	11.5	20.0	16.2	16.2	16.2	17.1	17.1	6.7
24	17.3	11.5	20.0	16.3	16.3	16.3	16.9	16.9	6.4
25	17.4	11.5	20.0	16.3	16.3	16.3	16.6	16.6	6.2
26	17.4	11.5	20.0	16.3	16.3	16.3	16.3	16.3	6.0
27	17.4	11.5	20.0	16.3	16.3	16.3	16.1	16.1	5.8
28	17.4	11.5	19.9	16.3	16.3	16.3	15.8	15.8	5.6
29	17.4	11.5	19.9	16.2	16.2	16.2	15.6	15.6	5.4
30	17.4	11.4	19.8	16.2	16.2	16.2	15.3	15.3	5.2
31	17.4	11.4	19.7	16.1	16.1	16.1	15.0	15.0	5.1
32	17.3	11.3	19.6	16.1	16.1	16.1	14.8	14.8	4.9
33	17.3	11.3	19.5	16.0	16.0	16.0	14.5	14.5	4.8
34	17.3	11.3	19.5	16.0	16.0	16.0	14.5	14.5	4.8
34+	17.3	11.3	19.5	16.0	16.0	16.0	14.5	14.5	4.8
jungle	14.0	9.3	16.3	13.2	13.2	13.2	15.2	15.2	6.7

Table A2: Age class distribution per species and forest zone in 2011 (inventory of growing stock)
Table A2. 1: Limpopo age class distribution (DAFF, 2011)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	595	153				26	1478	418	0		
1	186	141				119	712	152	14		
2	421	199				122	652	237	4		
3	305	148				142	1054	650	12		
4	402	179		1		207	1229	430	0		
5	256	134				383	1272	467	9		
6	331	54				402	827	342	13		
7	441	132				396	978	183	5		
8	325	127				509	705	200	8		
9	527	36				309	729	164	5		
10	402	180				230	596	174	0		
11	572	169				190	631	270	0		
12	648	159		3		158	614	334	0		
13	802	381		20		167	466	304	0		
14	1144	167		20		63	494	112	3		
15	919	242	11			38	679	12			
16	741	211				43	806	7			
17	1849	334				6	626	16			
18	608	188	6			21	540	11			
19	441	204		4		105	527	0			
20	604	160				61	347	0			
21	315	125	10			48	163	1			2
22	541	242	30			56	107	0			7
23	407	101	16			28	22	1			0
24	422	108	2			52	4	4			0
25	412	176	43			44	1	0			0
26	267	382	43			24	0	0			0
27	426	97	71			14	2	6		3	0
28	139	167	62			18	0	2			7
29	118	45	50			53	0	0			0
30	91	261	43			6	10	0			9
31	82	52	67			65	0	0		7	13
32	81	236	69			14	0	0			16
33	89	123	65			0	0	0			0
34	10	66	181			0	0	0			0
34+	124	182	169			58	5	0			37
jungle	50	10	4			0	0	0			0
Total	16093	6071	942	48	0	4177	16276	4497	73	10	91

Table A2. 2: Mpumalanga North age class distribution (DAFF, 2011)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	6086	3951	499	92	84	1277	3654	260	0		
1	2493	1966	755			1076	3059	281	19		
2	3503	3002	1547			1047	4299	1587			
3	3435	3216	721			613	5159	1645			
4	2876	2617	413			546	7175	761			
5	3429	2765	812			688	6551	1007			
6	3323	2168	296			567	6909	553			
7	2823	1431	354			767	5125	310			
8	2706	1551	302			1205	3870	260			
9	2102	1230	253			817	2581	236			
10	2278	2624	253			1041	2377	228			
11	2082	1830	230			876	3352	63	8		
12	2326	2388	386			1275	768	57			
13	4411	1577	480			771	811	20			
14	4248	1746	117			665	1595	26			
15	4318	1685	268			575	1103	0			
16	2880	2414	191			300	1904	16			
17	2829	1450	82			163	390	24			
18	1754	1469	32			38	344	23			6
19	2429	1360	77			70	212	10			0
20	2265	1495	93			42	421	42			1
21	1766	1234	86			24	197	63			14
22	1970	1913	186			77	343	42			14
23	1703	1268	400			49	240	17			2
24	1638	1558	220			31	162	8			11
25	1476	1486	329			56	186	10			1
26	1311	1229	225			165	239	8			10
27	1166	964	189			55	114	1			3
28	1027	865	264			95	45	20		1	0
29	600	493	183			52	52	18			0
30	490	411	214			0	22	1			30
31	388	310	170			7	6	17			2
32	191	248	78			37	68	18			0
33	220	249	40			7	3	15			9
34	339	92	112			0	48	6			0
34+	460	198	134			24	214	120	6		
jungle	110	10	20			0	67	32			
Total	79451	56463	11011	92	84	15098	63665	7805	33	1	103

Table A2. 3: Central Districts age class distribution (DAFF, 2011)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	1325	392				42	201	220			
1	649	0				120	0	8	59		
2	1100	0				45	0	188			
3	468	0				68	0	176			
4	767	0				209	0	199			
5	918	0				251	51	473			
6	686	0				98		816			
7	651	27				56		547	39		
8	505	0				102	53	263			
9	356	0				93	32	499			
10	280	0				98		311			
11	432	0				51		137			
12	203	5				207		51			
13	871	3				46		63			
14	781	149				177		69			
15	735	115	2			0	89	148			
16	837	411				39	60	25			
17	964	350				100	0	0			
18	1100	699	2			52		44			
19	536	371	59			103		0			
20	107	104				14		24			
21	66	213				0		13			
22	53	22				56		21			
23	240	0				0		93			
24	209	0				0		2			
25	76	0				15		105			
26	117	0						10			
27	0	0					1	0			
28	8	0						0			
29	87	1						13			
30	19	11						37			
31	0	0						0			
32	2	0						0			
33	0	0						3			
34	0	0						0			
34+	92	26				25		0			
jungle	0	0						61			
Total	15240	2899	63	0	0	2067	487	4619	98	0	0

Table A2. 4: Mpumalanga South age class distribution (DAFF, 2011)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	3924	2757	61			951	3366	3563	757	2	130
1	5478	1737	118			626	3884	4959	791	175	74
2	4065	1227	400			595	3691	7330	709	85	329
3	2545	1867	418			493	2975	7556	750	149	41
4	4163	978	388			350	3367	7665	863	47	244
5	3859	1520	42			365	2959	9420	771	30	27
6	3926	1211				180	4054	5873	926	53	66
7	4865	1440				136	3905	6397	1252	88	14
8	2799	610	5			121	3448	5759	1383	46	240
9	3100	642	13			215	1778	5762	1815	171	180
10	3518	321				618	1215	3453	1196		186
11	4219	702	65			356	1030	2450	1109		111
12	4337	710	14			282	528	2313	852	8	52
13	3859	1162	10			143	142	2606	557	30	27
14	3065	1222	10			86	78	1607	425		129
15	2707	777	72			8	48	727	228	8	5
16	3439	1279	10			143	25	268	44	23	
17	4343	1384	10			10	53	331	112	20	2
18	3520	1556	28			140	11	421	46	32	
19	3880	1667	139			64	1	159	15	3	4
20	2265	1151	36			81		134	20		
21	1220	506				12	21	168	35	34	
22	1136	426	13				4	17	5	42	
23	1089	390	10				9	396	20	13	
24	1790	175	58				4	218	3	18	
25	784	147	17			10	1	34			
26	1373	272	53			1		409		9	
27	657	61	83					17			
28	678	223	15			26		4			
29	409	222	26			2		25			
30	392	69	34					27		6	
31	126	31	23			2		33			
32	58	16						2			
33	119	28						1		8	
34	144	11	12								
34+	77	50	26			26		225		22	2
jungle							4	20	369		
Total	87928	28547	2209	0	0	6042	36601	80349	15053	1122	1863

Table A2. 5: Maputaland age class distribution (DAFF, 2011)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted		3270					2559				
1		488					672	488			
2		26					486	9			
3		689					288	472			
4		431					1109				
5		503					97				
6		54					42				
7		775									
8		192					140				
9		823					66				
10		550					53				
11						39	135	257			
12							187				
13						46	162	50			
14							32				
15		47				26	74	41			
16						170		3			
17						19					
18											
19											
20		27				216					
21		29									
22		113				283					
23		55				18					
24		88									
25		52									
26		238				45					
27											
28											
29											
30											
31											
32											
33											
34		59									
34+		232									
jungle											
Total	0	8741	0	0	0	862	6102	1320	0	0	0

Table A2. 6: Zululand age class distribution (DAFF, 2011)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	551	952					1864	270	255		94
1	61	9	4			2	4839	312	287		
2	67	19					6811	209	249		154
3	35	68					8512	246	306		
4	23	36					7782	251	325		
5	6	79					8907	221	211		
6	0	154					9257	190	354		
7	0	76					7877	336	295		8
8	0	8					4611	75	195		
9	51	33					2582	201	163		5
10	18	73					1542	14	259		
11	34	18					275	0	146		
12	0	169					418	5	28		
13	12	104				11	66	27	61		
14	24	11					35	2			1
15	31	118					14	17			
16	22	98				7	20	0			
17	51	76				0	20	2			
18	35	110				12	30	13			
19	12	245				5	0	4			
20	21	204				5	2	0			
21	0	468	26				5	17			1
22	0	372	35				6				
23	39	299				3	27				
24	0	117	24			4	5				
25	29	259				12	3				
26		19				9	0				
27		6				9	12				
28		0	16			26	1				
29		10	5				0				
30		3	2				0				
31		29					2				
32		3									
33		5									
34		4									5
34+	26	14	1			2		17			
jungle		0							5		50
Total	1148	4268	113	0	0	107	65525	2429	3139	0	318

Table A2. 7: KwaZulu-Natal Midlands age class distribution (DAFF, 2011)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	1886	831	108			71	3230	1771	2291	11	0
1	529	1390	114			14	3975	3458	3361	0	4
2	427	507	198			29	4582	5522	3429	0	0
3	1252	368	0			12	5616	7225	3239	0	0
4	2259	614	137			19	5380	5537	3496	13	5
5	1426	442	148			6	5042	5924	4478	21	1
6	1013	621	60			37	4744	4589	4085	35	3
7	947	616	51			67	3778	2355	5016	18	4
8	1421	491	82			33	4138	3423	6371	6	
9	1131	582	49			54	2959	1771	4917	11	
10	750	785	92			108	1964	1341	3173	21	
11	712	667	150			109	1305	668	2313	16	
12	906	1151	224			161	958	669	1422	17	7
13	901	967	287			206	1085	513	787	7	
14	461	1075	88			209	1002	447	492	4	
15	766	682	253			61	365	391	224	53	2
16	506	996	156			85	169	381	187	26	
17	453	633	93			105	117	173	131	56	3
18	560	1112	160			51	45	275	181	22	4
19	612	1263	77			27	67	52	40	55	
20	462	808	103			7	78	16	61	24	2
21	672	896	35			20	22	18	25	43	
22	505	684	94			15	2	38	2	10	
23	341	272	0			1	20	32	0	18	
24	234	367	9			1	48	17	0	0	
25	710	210	67			5	2	0	1	0	
26	264	312	12			60	0	3	0	4	
27	103	257	27			0	0	18	9	1	
28	299	115	35			3	1		0	1	
29	105	55	8						2	14	
30	51	25	0						0	0	
31	102	21	27						0	4	
32	76	78	19						5	0	
33	9	19	1						10	0	
34	31	0	2						10	0	
34+	79	68	8				9	8	0	2	
jungle	5	0	0				22		81	0	
Total	22966	19980	2974	0	0	1576	50725	46635	49839	513	35

Table A2. 8: KwaZulu-Natal North age class distribution (DAFF, 2011)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	602	214	22			90	1317	1251	2182		12
1	347	831	34				1992	2898	1446		3
2	155	280	8			130	2986	3658	1662		
3	134	249	11			16	3176	2908	1580		1
4	327	470	23			12	3052	2478	1898	4	8
5	151	371				120	2764	2710	1595		
6	250	185				6	2940	2385	1658		14
7	273	267					2493	1946	1558	5	
8	158	88				111	2560	1937	1539		54
9	1007	422				115	1634	1289	1586		
10	84	607	3			94	983	648	1146		
11	90	250					479	170	1290		
12	277	490				12	161	113	722		
13	120	450				2	98	43	842		
14	276	532	6				132	15	219	2	
15	166	695				41	145	43	126		
16	44	403					72	18	47		
17	248	464				2	51	67	80	15	
18	291	598				38	2	84	36		
19	231	504	3			55	3	42	38	7	
20	309	247					26				
21	156	239								12	
22	140	95									
23	33	202					2				
24	109	18				8					
25	104	35	25			3	1				7
26	232	16	19								
27	136	74	41							5	
28	64	39	39			6					
29	99	0	32								
30	23	29	28								
31	25	26									
32	346	12	8								
33	7	0									
34	0	0									
34+	3	44	29			15	4				
jungle	0	0				88	18		119		
Total	7017	9446	331	0	0	964	27091	24703	21369	50	99

Table A2. 9: KwaZulu-Natal South age class distribution (DAFF, 2011)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	2143	322	39			39	2433	359	543		
1	2252	805	32			12	1093	384	286		
2	1493	974	35			4	1525	3719	377	34	
3	2253	1019	12			14	1656	4598	256		
4	2556	493	133			94	2022	3409	368		
5	1967	327	51			194	3248	2373	447		
6	2737	663	40			45	2087	2541	378		
7	1455	854	6			39	2457	2185	844		
8	1769	1593	65			165	2440	1952	996		
9	1194	579	51			175	2018	1729	719		
10	941	444	82			290	1583	1380	680	1	
11	1424	127	13			314	1069	1170	186	29	
12	1695	201				393	775	848	165	2	
13	2046	136	7			488	641	695	376	9	
14	1527	128	10			387	494	273	210	1	
15	2005	309				320	146	275	425	5	5
16	1878	253				349	62	158	267	11	2
17	2205	616				23	166	216	294		
18	1632	89				0	173	79	276	2	1
19	1036	135					91	72	289		0
20	1087	101					34	39	58		4
21	943	119	18			3	88	46	9		
22	900		2			24	1	3	15		
23	577	134	9			7	33	42	17		
24	662	41				4	90	7		6	
25	505	86					9	33			
26	310	209						9			
27	289	171	19					3			
28	195	52				20	68	4			
29	64	54	23			27					
30	204	162	19						3		
31	79	43	2				60				
32	37	61	99								
33	12	30									
34	19										4
34+	25	67	64	607		80	412	72		6	7
jungle	0					10	7	15	80		13
Total	42116	11397	831	607	0	3520	26981	28688	8564	106	36

Table A2. 10: Eastern Cape age class distribution (DAFF, 2011)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	7499	3905	54	170	19		2582	872	230		6
1	1174	1523	377			204	792	1272	22		
2	1347	1346	216	35		211	792	913	33		
3	1319	1446	348			201	676	1029	32		
4	2094	1565	209	23		292	1152	111	34		
5	1286	1459	100	23		135	1541	431	85		
6	2257	1914		16		284	854	141	143		
7	1328	1662		53		385	751	419	84		20
8	971	1145	257	18		455	632	156	179		
9	1936	991	615	129		537	442	321	179		
10	2450	1060	30	200		1973	391	234	206		
11	1432	531	20	314		1379	135	71	10	4	
12	1685	500	17	458	28	1021	182	58	282		5
13	1237	172	120	410		1261	269	137	85		
14	2957	325	48	235		1610	192	84	15		
15	1946	509	67	309		744	323	67	19		
16	1934	296	53	7		687	128	145	61		
17	2259	633	161	206	30	246	112	160	3		134
18	2355	678	132	96	98	82	230	64	6		10
19	2468	909	0	67	134	91	148	144	30		1
20	1130	412	34	107	96		116	95	18		25
21	1695	509		40	98	44	34	90	12		
22	1011	456	2	89	128		27	69	6		
23	709	286		85	142	2	24	114			18
24	553	142		85	45		14	17			
25	422	163	16	53	3			62	6		2
26	649	217	6	66	148		26	39			
27	435	118	1	54	54		8	111			
28	272	101	25	82			33	31	5		
29	451	71	76	14	57	2		12			7
30	159	60	15	33	676		7	13			
31	129	149	18	123	386			18		3	
32	237	543	43	165	477	136	12	13		10	
33	26	168	48	4	381		40	93		3	83
34	36	82	57	35	164	2	12	22			
34+	261	271	148	44	191	50	13	57	221	2	24
jungle	0	0		25	85	14	2	97	160	33	12
Total	50109	26317	3313	3873	3440	12048	12692	7782	2166	55	347

Table A2. 11: Southern Cape age class distribution (DAFF, 2011)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted		177	7	13701	975	24		18			8
1	631	274	66	187		18					
2		272	4	754							
3		656		340							
4		98		598	19			4	4		
5	4492	104	160	1044		146					2
6		126		718							
7		52		918				3			
8		9		445				11			
9		1		240							
10	2819	31	57	1178	8						
11		96		595							
12		972		871							3
13		35		1493				300			9
14		291		932	12	3		4			
15	1670	85	6	3180	8	5			4		20
16			4	1169				10			
17				1386				70			1
18		7	9	1054	14	23		32			10
19				1189	9			7			12
20	897		18	1646	103			25			97
21				855	76			5			7
22		47		715	94		35	11			
23		22		702	102	1		5			
24		15		693	80			38			2
25	573	79		1235	271			68	24		15
26		105		279	15			2			24
27		86		238	98			17			23
28		8		155	157	2		34			15
29		37		124	196			29			
30	147			522	214			9	50		18
31		39	7	157	148	2		8			4
32				121	126						4
33				41	198			17			
34				70	156						
34+ jungle	187	494	26	1050	2513	2		419	189	4	164
Total	11416	4218	364	40595	5592	226	35	1146	271	4	438

Table A2. 11: Western Cape age class distribution (DAFF, 2011)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted				4818							
1				208					1		
2		4	15	32	15						
3		7	20	271	19	13					
4		28	21	191							
5		66	32	242					1		
6		1	28	199	37						
7		5		192							
8				139	24						
9				118	7	2					
10				155	21						
11				173	20						
12	56			316	29			4			
13	50			382	10						
14				476	13	10		2			4
15	100			365	25						
16	1		24	462	10	20	1				
17				509	5						
18				419	14	37			1	2	
19				480			1	14			
20		6		541	36			5			
21				305	36			1			
22				132	113			16			
23				213	51			5			
24				263	73			29			
25				204	63						
26				99	33			1			
27				222	105						
28				64	44		2	5			
29				96	42						
30				146	106						
31		2		94	87			10			
32				159	39						
33				85	10						
34				67							1
34+			1	781	439	11	61	332		26	7
jungle				154	31						
Total	207	119	141	13772	1557	93	65	424	3	28	12

Table A3: Timber harvested from plantations in 2011 by species and forest zones (DAFF, 2011)

Limpopo							Mpumalanga North					
Species	Sawlog m3	Poles m3	Mining Timber Tons	Pulpwood Tons	Charcoal /firewood Tons	Other Tons	Sawlog m3	Poles m3	Mining Timber Tons	Pulpwood Tons	Charcoal /firewood Tons	Other Tons
Softwood	182621			13202	10670	5115	1409473	1457		566418	1671	12571
E. grandis	169621	64644	48077		11227	15856	42369	58793	465627	303182	3698	4905
Other Gum	1200	13438	1338		4395		2429		1840	55235		73
Wattle												
Other Hardwoods												
Total	353442	78082	49415	13202	26292	20971	1454271	60250	467467	924835	5369	17549

Central Districts							Mpumalanga South					
Species	Sawlog m3	Poles m3	Mining Timber Tons	Pulpwood Tons	Charcoal /firewood Tons	Other Tons	Sawlog m3	Poles m3	Mining Timber Tons	Pulpwood Tons	Charcoal /firewood Tons	Other Tons
Softwood	8548			307664	56		583834			778964	1935	9715
E. grandis							3006	9771	24949	179176	24	23
Other Gum				45502	2281		5467	725	17472	542765	4401	6120
Wattle				412						56752	7940	4164
Other Hardwoods								6125		18375		4045
Total	8548	0	0	353578	2337	0	592307	16621	42421	1576032	14300	24067

Maputaland							Zululand					
Species	Sawlog m3	Poles m3	Mining Timber Tons	Pulpwood Tons	Charcoal /firewood Tons	Other Tons	Sawlog m3	Poles m3	Mining Timber Tons	Pulpwood Tons	Charcoal /firewood Tons	Other Tons
Softwood							24165			4019		
E. grandis										1034092	12	
Other Gum										497543		
Wattle										19851	399	
Other Hardwoods												
Total	0	0	0	0	0	0	24165	0	0	1555505	411	0

Table A3 (Continued): Timber harvested from plantations in 2011 by species and forest zones (DAFF 2011)

KwaZulu-Natal Midlands							KwaZulu-Natal North					
Species	Sawlog m3	Poles m3	Mining Timber Tons	Pulpwood Tons	Charcoal /firewood Tons	Other Tons	Sawlog m3	Poles m3	Mining Timber Tons	Pulpwood Tons	Charcoal /firewood Tons	Other Tons
Softwood	245597	416		677171	83		42232			83246		
E. grandis	6667	24991	70	912646	62	400		2892	13769	215883	384	2112
Other Gum	282	13163		951262	1498			2696		124021	879	
Wattle		36		603234	9435	30154				114966	73790	1913
Other Hardwoods										5320		
Total	252546	38606	70	3144313	11078	30554	42232	5588	13769	543436	75053	4025

KwaZulu-Natal South							Eastern Cape					
Species	Sawlog m3	Poles m3	Mining Timber Tons	Pulpwood Tons	Charcoal /firewood Tons	Other Tons	Sawlog m3	Poles m3	Mining Timber Tons	Pulpwood Tons	Charcoal /firewood Tons	Other Tons
Softwood	275086			847258	3409	1232	621434	5438		257003	7624	3351
E. grandis	3213	21077		340448	365	118	2104	105558		4788	79222	444
Other Gum	13728	12505		704219	10		828	19729			952	36
Wattle				66581	365			1920			6256	
Other Hardwoods		600		1944			10			4658		
Total	292027	34182	0	1960450	4149	1350	624376	132645	0	266449	94054	3831

Southern Cape							Western Cape					
Species	Sawlog m3	Poles m3	Mining Timber Tons	Pulpwood Tons	Charcoal /firewood Tons	Other Tons	Sawlog m3	Poles m3	Mining Timber Tons	Pulpwood Tons	Charcoal /firewood Tons	Other Tons
Softwood	410276	49423					113567	17227				
E. grandis											18	
Other Gum	8693											
Wattle											10	
Other Hardwoods	2652											
Total	421621	49423	0	0	0	0	113567	17227	0	0	28	0

Table A4: Damages to plantations in 2011 (DAFF 2011)

	Limpopo					Mpumalanga North				
Area	Fires	Weather	Diseases	Insects	Animals	Fires	Weather	Diseases	Insects	Animals
Softwood	25	8			5	267	106		12	107
Hardwoods	114	4			1	516	25		0	0
Total Area	139	12	0	0	6	783	131	0	12	107
	Central Districts					Mpumalanga South				
Area	Fires	Weather	Diseases	Insects	Animals	Fires	Weather	Diseases	Insects	Animals
Softwood	1					923	155	94		346
Hardwoods						1538	2148	50	62	235
Total Area	1	0	0	0	0	2461	2303	144	62	581
	Maputaland					Zululand				
Area	Fires	Weather	Diseases	Insects	Animals	Fires	Weather	Diseases	Insects	Animals
Softwood						146				
Hardwoods						807	15	18		21
Total Area	0	0	0	0	0	953	15	18	0	21
	KwaZulu-Natal Midlands					KwaZulu-Natal North				
Area	Fires	Weather	Diseases	Insects	Animals	Fires	Weather	Diseases	Insects	Animals
Softwood	286	401	3	1	63	197	8			62
Hardwoods	2668	4258	508	96	278	1160	361	125	62	115
Total Area	2954	4659	511	97	341	1357	369	125	62	177
	KwaZulu-Natal South					Eastern Cape				
Area	Fires	Weather	Diseases	Insects	Animals	Fires	Weather	Diseases	Insects	Animals
Softwood	1173	294	259	32	43	1685				110
Hardwoods	253	13956	5	287	10	436				
Total Area	1426	14250	264	319	53	2121	0	0	0	110
	Southern Cape					Western Cape				
Area	Fires	Weather	Diseases	Insects	Animals	Fires	Weather	Diseases	Insects	Animals
Softwood	602	10		15	22	2550		35		
Hardwoods										
Total Area	602	10	0	15	22	2550	0	35	0	0

2010 Data

Table A5: Age class distribution per species and forest zone for 2010 (inventory of growing stock)
Table A5. 1: Limpopo age class distribution (DAFF, 2010)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	392	130				10	1978	498	0		
1	192	27				158	715	213	14		
2	442	262				181	1131	507	4		
3	302	130		1		117	1026	333	12		
4	408	119				404	1573	493	0		
5	239	135				299	852	348	9		
6	347	126				418	944	208	13		
7	454	168				418	759	187	5		
8	326	38				533	703	180	8		
9	509	40				249	764	154	5		
10	454	249				200	566	266	0		
11	546	193		3		171	641	344	0		
12	709	289		20		148	459	328	0		
13	884	251		20		78	519	162	3		
14	1134	150				14	715	40	0		
15	1043	280	11			50	788	0			
16	1979	432				32	608	7			
17	564	122	7			6	536	20			
18	565	231		4		69	562	1			
19	389	168		1		70	336	0			
20	581	96	10			80	182	1			
21	490	264	30			76	107	9			9
22	455	104		6		6	21	1			
23	453	152	16			60	5	0			3
24	375	88				18	1	4			
25	366	439	43			61		0			
26	444	148	43			4	2	8		3	
27	178	176	77			25		6			7
28	167	88	70			24					
29	152	253	48			34					9
30	146	87	60			38	10			7	12
31	37	240	61			34					16
32	62	125	62			13					
33	89	82	132								
34	10	2	141								
34+	114	182	143			59	5				36
jungle	50	10	4								
Total	16047	6076	958	55	0	4157	16508	4318	73	10	92

Table A5. 2: Mpumalanga North age class distribution (DAFF, 2010)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	5094	3274	877	92	84	437	994				
1	1935	2099	546			867	1317	19			
2	3500	4087	1466			1027	1288				
3	2970	2394	674			534	582				
4	3284	2842	515			747	494				
5	2609	1778	612			507	512				
6	3086	1974	331			672	369				
7	2019	1201	295			970	280				
8	1824	1078	291			771	289				
9	2420	1299	177			1121	137	8			
10	2100	2475	196			898	184				
11	1829	1592	371			1333	51				
12	2398	2493	432			1088	53				
13	5252	1546	251			536	22				
14	3407	1893	306			592	40				
15	3725	2815	226			235	9				
16	2250	1395	30			209	81				
17	2184	1562	83			121	14				
18	2333	1276	96			119	19			6	
19	2266	1754	122			69	33				
20	2160	1206	71			6	91			1	
21	2051	1330	36			28	40			14	
22	1949	1962	186			105	17			15	
23	1963	1326	399			25	13				
24	1587	1321	220			24	2			19	
25	1444	1865	329			81	9			1	
26	1471	1020	225			156	26		1	2	
27	1052	887	198			102	5			3	
28	784	778	238			79	12				
29	454	380	255			4	20			30	
30	330	429	182			0	4			2	
31	258	216	174			11	28				
32	242	326	46			41	1				
33	158	71	106				0				
34	306	126	64				14				
34+	471	93	91			15	145			9	
jungle	110	10	20				32				
Total	73275	54173	10737	92	84	13530	7227	27	1	102	0

Table A5. 3: Central Districts age class distribution (DAFF, 2010)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	936					129	203	258			
1	1106					134		42	59		
2	487					97		356			
3	797					56	51	290			
4	914					239		513			
5	591					216		691			
6	603	27				46	53	476			
7	547					57	32	472	39		
8	554					102		382			
9	255					110		207			
10	421	22				133		51			
11	248	3				153		137			
12	786	2				60		51			
13	812	134				155	89	63			
14	747	103	2			63	73	89			
15	809	445				35		148			
16	1015	350				105					
17	1200	699	2			30					
18	539	388	59			103		67			
19	356	124				14		2			
20	362	564				4		14			
21	43	94				56		104			
22	69							7			
23	225							4			
24	209							12			
25	76					15	1	101			
26	117										
27								12			
28	8	1									
29	87							1			
30	19	11						37			
31	2							3			
32											
33											
34											
34+	92	26				25					
jungle								61			
Total	15032	2993	63	0	0	2137	502	4651	98	0	0

Table A5. 4: Mpumalanga South age class distribution (DAFF, 2010)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	6110	3456	73			936	3294	4028	804	2	62
1	5086	1418	118			335	3748	6878	765	175	41
2	4031	2307	400			764	3804	8729	834	85	523
3	3961	1132	418			256	3129	6973	859	149	12
4	4000	1382	430			389	3220	6819	716	47	83
5	5267	1460				114	3098	8632	953	30	29
6	5347	1683				272	3774	6429	1020	53	241
7	3699	1148				155	4137	6715	1102	88	179
8	2984	631	5			91	3293	5388	1503	85	182
9	3813	712	13			384	1840	5192	1753	132	88
10	4024	594				639	1086	2653	1015	0	58
11	3849	926	65			316	1074	2946	1299	8	39
12	4482	931	24			287	505	2673	634	30	138
13	3839	1150	7			100	201	1964	630		101
14	3951	1480	10			174	86	903	307	8	74
15	2994	1226	72			135	36	726	284	20	5
16	4579	1528	10			10	60	502	25	19	2
17	3822	1627	28			118	28	262	47	25	
18	4611	2038	107			64	2	240	46	14	
19	2948	1500	55			157	22	128	40		4
20	1619	904	36			27	4	109	6	34	
21	1169	438				2		610	25	45	
22	999	700	63				3	284	5	10	
23	844	247	10				9	56	20	18	
24	1859	174	58			10	1	10	3		
25	865	72	17			1	22	12		9	
26	1149	256	53					395			
27	821	65	137					17			
28	431	269	15			26		21			
29	425	184	38			2		34			
30	396	109	42			2		19		9	
31	70	16	15					23			
32	130	33						1			
33	142	11								8	
34	37	22	12								
34+	112	40	26			26		225	6	22	2
jungle							4	20	369		
Total	94465	31869	2357	0	0	5792	36480	80616	15070	1125	1863

Table A5. 5: Maputaland age class distribution (DAFF, 2010)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted		3006					2371				
1		488					672	488			
2		26					486	9			
3		689					288	472			
4		431					1109				
5		503					97				
6		54					42				
7		775									
8		192					140				
9		823					66				
10		550					53				
11						39	135	257			
12							187				
13						46	162	50			
14							32				
15		47				26	84	41			
16						170	59	3			
17						19	49				
18											
19							43				
20		27				216					
21		29									
22		113				283					
23		55				18					
24		88									
25		317									
26		238				45					
27											
28											
29											
30											
31											
32											
33											
34		59									
34+		260									
jungle											
Total	0	8770	0	0	0	862	6075	1320	0	0	0

Table A5. 6: Zululand age class distribution (DAFF, 2010)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	552	955					1926	83	262		94
1	61	9					7504	417	283		
2	67	19					7394	209	251		154
3	35	68					8802	255	304		
4	23	36					9013	242	325		
5	6	79					8960	223	229		
6	0	154					8963	293	331		
7	0	76					6627	525	299		8
8	0	8					3826	39	203		
9	51	48					1194	10	165		5
10	18	57					511	31	254		
11	34	18					112	24	143		
12	0	169				13	69	0	25		
13	12	107					237	19	61		
14	24	10				1	21	0			1
15	31	122				6	13	4			
16	22	97				0	10	0			
17	51	78				12	43	0			
18	35	105				5	30	4			
19	12	245				5	7	0			
20	21	204					0	4			
21	0	467	26				3	17			1
22	0	380	35			3	6				
23	39	293				4	27				
24	0	117	24			12	12				
25	29	263				9	3				
26		25				19	13				
27		0				15	0				
28		0	16				0				
29		10	5				0				
30		3	2				2				
31		29					2				
32		7									
33		3									
34		0						5			5
34+	26	20	4			13		12			
jungle		0							5		50
Total	1149	4281	112	0	0	117	65330	2416	3140	0	318

Table A5. 7: KwaZulu-Natal Midlands age class distribution (DAFF, 2010)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	720	301	145			85	3751	2861	2532		
1	509	622	197			3	4980	5815	3321		4
2	938	396				24	4774	6081	3121		
3	2349	396	141			9	5316	4748	3163		
4	1525	500	148			10	4885	4540	3925	13	5
5	1143	416	60			12	5525	4923	4915	21	1
6	947	668	51			76	4586	4322	5094	35	1
7	1196	443	42			41	4315	2415	6012	18	4
8	1202	454	89			74	3178	2371	5347	6	
9	1085	670	87			76	2256	1489	4262	17	
10	771	898	153			137	1785	1325	3658	18	
11	1034	976	224			150	1516	1354	1995	25	
12	798	908	283			195	1336	644	1223	8	7
13	555	1139	105			183	1137	780	752	7	
14	771	881	240			178	1086	771	371	13	
15	477	677	151			33	341	462	264	44	2
16	430	935	104			63	189	427	292	26	
17	767	859	172			114	59	115	58	69	6
18	749	1357	77			69	50	34	96	29	1
19	818	1131	94			21	65	14	27	42	
20	687	900	45			51	60	35	16	24	2
21	451	1128	85			12	11	77		59	
22	286	568	28			4	1	18	2	7	
23	319	348				1	20	10	1	5	
24	622	301	13			5	49	4	1		
25	222	275	63				1	20	9	4	
26	259	286	20			123		3	9	1	
27	243	405	35			6		2	2		
28	143	86	30							1	
29	74	69	3				1			18	
30	29	10	9								
31	101	24	40						5	4	
32	70	75	4						10		
33	25	19	2						10		
34	23	29						1			
34+	68	61	8				9	7		2	
jungle	5						22		81		
Total	22411	19211	2948	0	0	1755	51304	45668	50574	516	33

Table A5. 8: KwaZulu-Natal North age class distribution (DAFF, 2010)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	366	562	36			110	1341	1331	2017		15
1	192	545	8			92	2025	3244	1453		
2	264	405	11			14	3337	3458	1693		1
3	188	381	23			10	3539	2651	1727	4	8
4	175	357				12	2870	2351	1718		
5	312	256				126	2909	2839	1756		14
6	304	268					2763	2290	1801	5	
7	140	174				111	2460	1931	1527		3
8	171	245				115	2326	1961	1512		51
9	945	444				94	1320	1245	1481		
10	98	528	3				990	635	1250		
11	82	543					536	159	1399		
12	221	424				12	146	161	1067		
13	172	446				2	239	21	396		
14	238	693	6			41	139	33	169	2	
15	137	580					143	99	97		
16	88	413				2	25	62	73		
17	215	444					29	35	64	15	
18	347	805				101	2	25	23		
19	331	338	3			1	3	42	38	7	
20	154	278					26				
21	154	86								12	
22	57	263									
23	114	103				8	2				
24	104	35	25			3					7
25	232	21	19								
26	136	76	41							5	
27	64	39	39			6					
28	99		32								
29	26	34	28								
30	31	26	10								
31	344	12	8								
32	9										
33	0										
34			29			15					
34+	3	44					4				
jungle						88	18		119		
Total	6513	9868	321	0	0	963	27192	24573	21380	50	99

Table A5. 9: KwaZulu-Natal South age class distribution (DAFF, 2010)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	1468	469	48			124	1403	1867	277		
1	1665	1146	21			6	1385	3944	400		
2	2581	1182	9			5	1401	3513	258	34	
3	2445	492	136			102	2885	2202	246		
4	1972	332	52			221	2446	2229	383		
5	2665	703	40			48	2689	2492	889		
6	1625	862	6			54	2601	2012	1056		
7	1693	1624	65			124	2024	1939	712		
8	1084	618	51			177	2022	1370	761		
9	964	467	82			248	1723	1314	321	1	
10	1504	116	13			298	1390	1205	393	2	
11	1717	202				400	1360	1262	502	28	
12	1941	137	4			514	1001	596	275	2	
13	1768	128	10			411	613	629	433	9	
14	2202	234				340	392	771	343	1	2
15	2045	230	34			279	265	289	371	5	3
16	2031	634				96	160	166	539	11	2
17	1435	152				1	332	80	475		1
18	1776	151					63	67	68	2	
19	1758	101					89	50	24		
20	1187	96				3	14	3	15		4
21	1085		18			22	70	10	17		
22	686	134	11	1		7	3	42		6	
23	717	42				4	20	40			
24	511	128					90		2		
25	335	209					2	10			
26	330	180	19					8			1
27	189	107				20	3				
28	69	57	23			27	65				
29	295	186	51						6		
30	122	73	2								
31	47	82	127				60				
32	34	31									
33	4										4
34	36	22	8			54					
34+	19	80	125	607		28	413	72		6	6
jungle						10	7	15	80		13
Total	42005	11407	955	608	0	3623	26991	28197	8846	107	36

Table A5. 10: Eastern Cape age class distribution (DAFF, 2010)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	7787	4063	254	176	19		2585	875	234		6
1	1216	964	294			107	757	1272	22		
2	1544	1807	297	34		325	719	918	33		
3	1854	1705	227			54	693	1023	32		
4	1117	1623	63	23		331	1251	109	34		
5	2361	1569		23		98	1525	431	85		
6	1385	1857		16		305	797	143	143		20
7	987	1237	229	61		322	828	420	84		
8	1779	1376	595	10		530	619	156	206		
9	1928	1098	91	122		536	383	321	179		
10	1934	582	9	200		1777	402	234	220		
11	1225	399	20	331		1363	207	71	53	4	
12	1709	430	17	441	28	1021	137	58	236		5
13	2479	270	120	425		1261	317	137	85		
14	2629	322	48	239		1578	233	65	15		
15	1359	393	67	289		771	297	67	33		36
16	1724	305	53	25		687	96	145	17		5
17	2309	715	161	199	30	246	213	175	3		154
18	2760	611	132	85	98	80	163	65	6		7
19	2575	941	36	67	134	91	125	144	25		43
20	1672	494		129	96	46	137	117	4		10
21	910	500	5	30	98		27	59			
22	1014	366		90	128		36	69	6		
23	390	290		90	142	2	25	118			18
24	459	150		111	46		3	18			
25	769	267	21	39	7		8	62	6		2
26	449	112		81	148		24	39			
27	400	85	1	39	54		27	111			
28	616	109	76	82			11	31	5		
29	187	64	14	37	57	2		12			7
30	126	60	72	35	676		7	13			
31	229	318	21	170	386		10	18		3	
32	68	356	91	70	477			13		10	2
33	145	259	58	104	383	148	42	99		3	81
34	31	121	78	35	164	2	12	22			2
34+	412	311	153	44	191	54	16	57	199	8	21
jungle				25	85	14	2	97	160	33	12
Total	50538	26129	3303	3977	3447	11751	12734	7784	2125	61	431

Table A5. 11: Southern Cape age class distribution (DAFF, 2010)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted		177	7	13800	922	24		18			8
1	631	184	66	403		18					
2		272	4	497							
3		656		335							
4		106		749	19			4	4		
5	4492	181	160	944		146					2
6		73		501							
7		19		986				3			
8		9		277				11			
9		1		365							
10	2819	31	57	1327	1						
11		54		673							
12		488		580							3
13		40		1799	10			269			9
14		170	2	1103	2	5		4			
15	1670	73	8	3153	8	3			4		20
16				1285				10			
17			1	914		23		47			1
18		7	9	1242	23			31			10
19				1224	15			6			12
20	897		18	1559	136			25			97
21				652	114		35	5			7
22		47		832	86	1		15			
23		21		736	86						
24		15		494	143			38			2
25	573	97		1092	148			62	24		15
26		103		300	69			2			24
27		71		184	188	2		30			24
28		16		208	189			20			14
29		28		350	134			30			
30	147	2		457	252	2		9	50		22
31		37	7	144	141			1			
32				53	223			10			4
33				143	142			8			
34				99	119			24			
34+ jungle	187	343	26	1056	2503	2		376	189	4	164
Total	11416	3321	365	40516	5673	226	35	1058	271	4	438

Table A5. 12: Western Cape age class distribution (DAFF, 2010)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted				4885							
1				148					1		
2		4	35	92	34	13					4
3		33	21	293							
4		66	32	211							
5		2	28	220					1		
6		6		220	37						
7				183							
8				110	24	2					
9				103	7						
10				157	34						
11				142	19						
12	56			365	17			4			
13	50			399	10						
14				490	28	10		2			
15	100		24	314	10		1				
16	1			513	10	20					
17				485	5						
18				490	14	37			1	2	
19				457			1	14			
20		6		500	36			5			
21				275	36			1			
22				150	113			16			
23				238	56			5			
24				278	71			29			
25				141	60						
26				152	58			1			
27				130	96						
28				90	28		2	5			
29		2		128	67						
30				109	90			10			
31				125	96						
32				130	22						
33				82	10						
34				40	2						1
34+				814	437	11	61	332		26	7
jungle				155	31						
Total	207	119	140	13814	1558	93	65	424	3	28	12

2007 Data

Table A6: Age class distribution per species and forest zone for 2007 (inventory of growing stock)

Table A6. 1: Limpopo age class distribution (DAFF, 2007)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	375	277	15			93	1428	478			6
1	257	42	14	1		311	946	418	24		
2	609	126				249	1035	370	4		
3	318	147		4		335	874	248	13		
4	423	187				358	1041	412	5		
5	521	11				437	832	181	13		
6	319	63				439	841	193	5		
7	483	208				442	723	337	2		
8	380	175				197	801	459	7		
9	595	343	21			169	612	353	3		
10	839	253				52	667	148			
11	1072	153		29		24	915	143			
12	958	195	11	22		18	1095	64	2		
13	2121	432		7		10	918	19	1		
14	631	264	8	18		39	861	36			
15	594	256		2		81	602	6			
16	462	192		6		25	584	16			
17	646	113	10			55	421	6			
18	723	221	31			114	253	14			10
19	370	87		1		45	304	3			
20	570	136				66	133	11			3
21	364	190				12	129	16			
22	463	421				32	79	1		3	
23	569	145	26			30	45	10			
24	289	208	14			41	39	12			7
25	211	57	127			39	25	6			
26	230	294	44			2	21				10
27	208	73	97			42				7	13
28	100	250	62			22					17
29	95	177	60			12					
30	110	198	182			43					
31	48	9	153			13					
32	42	1	83								
33	14		89								
34	24	14	140								
34+	103	179	134			74					28
jungle	50	10	4								
Total	16186	6107	1325	90	0	3921	16224	3960	79	10	94

Table A6. 2: Mpumalanga North age class distribution (DAFF, 2007)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	5264	2778	563	92	84	153	3046	730			
1	2183	993	743			319	4469	1188			
2	3656	2377	500			266	5865	2070			
3	3884	2935	508			950	4061	1555			
4	3588	1669	696			824	5330	2104			
5	2645	1421	268			830	2954	1729			
6	2120	1130	211			699	3185	652			
7	2958	2102	194			1000	2857	873			
8	2171	1158	344			1363	2335	395			
9	2700	1230	405			951	1834	480			
10	3503	1801	255			772	1586	857			
11	3221	1632	334			547	1669	1647			
12	5693	4101	372			354	1156	1369			
13	4691	2427	89			343	1173	531			
14	3123	2011	70			62	1100	184			
15	4080	2769	218			208	433	308			
16	2382	1362	180			75	460	22			7
17	2595	2817	66			34	451	394			
18	3125	1819				45	366	274			2
19	3964	2424	5			99	530	72			19
20	2839	1680	47			42	548	57			14
21	7285	6443	713			87	230	33			
22	1759	1473	402			54	310	30			
23	3128	1769	225			210	387	7			10
24	1381	1472	454			182	182	28			2
25	1241	1174	664			86	87	9			1
26	693	765	463				32	1			2
27	494	588	414				7	31			
28	556	669	198				13	20			
29	603	288	227			7	74				
30	516	148	405				47	13			
31	393	17	139			43	14	1			
32	124	54	150				35	6			19
33	115	7	33			9	29	10			
34	162	19	40			1	12				
34+	323	71	52			21	180	160			4
jungle	110	23	46			3	64	34			
Total	89268	57616	10693	92	84	10639	47111	17874	0	0	80

Table A6. 3: Central Districts age class distribution (DAFF, 2007)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	345	2		33		188		54			
1	448	31				270					
2	597	56		313		175	7	440			
3	784	346		45		44	10	152			
4	307	33		76		231		31			
5	188			124			44	165			
6	346			99		122	21	395			
7	352	48		89		107	23	221	39		
8	519					177	25	205			
9	392	56		55		208	144	196			
10	662	117		47		25	7	63			
11	193	164		76		29	68	137			
12	328	487					31	243			
13	555	125				1	77	45			
14	122	200				34	60	1			
15	471	90					66	61			
16	148	116				64	18				
17	291	178					43	7			
18	357	196					333	35			
19	246						244	7			
20	264	190					143				
21	211					47	93	1			
22	77	3		15			31				
23	112						25	16			
24	27						16				
25	16						17	101			
26	75							17			
27		11				1		42			
28	2					4					
29	5		11								
30	37	1	18								
31	13	13	9								
32	127										
33	27			24							
34											
34+	48										
jungle	7			1				61			15
Total	8699	2463	38	997	0	1727	1546	2696	39	0	15

Table A6. 4: Mpumalanga South age class distribution (DAFF, 2007)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	4948	1627	76			256	936	5329	717	10	25
1	4205	2670	173			543	1503	10470	751	214	80
2	5322	1346	400	1		133	1718	9331	741	85	28
3	5499	1397	418			254	1878	9973	1239	137	271
4	4633	1042	388			337	2821	9708	1176	91	210
5	5467	745				343	2284	10051	1044	40	199
6	3567	865				532	2372	6693	1387	53	114
7	4074	877				228	2009	6984	1319	94	106
8	3618	1326	90			224	1522	6273	818	94	107
9	4066	1145	45			322	1184	4365	1699	132	179
10	4680	901	9			234	681	2981	963	4	168
11	4818	1290	38			120	512	2729	675	21	89
12	4252	1600	22			214	178	2137	382	4	105
13	4735	1721				43	284	1021	302	42	251
14	3263	1835	38			109	207	521	131		
15	5383	2132	72			64	84	1034	148	3	8
16	4015	1825	23			121	137	291	97	45	
17	3200	1262	42			55	8	215	45	55	
18	3174	1354	11			42		704	31	14	4
19	1343	1695	93			199	3	417	10		
20	1114	425	49			193	24	255	18	3	
21	873	439				30		42	8	25	
22	881	309				1	25	25	20	9	
23	735	413	55						23		1
24	1516	173	167					14			
25	2381	139	51			8		415			
26	403	18	27					11			
27	322	95	76			2		7			
28	125	479	98					2		6	
29	237	34	21					464			
30	1273	11	5					12			
31	80	13	9					21		8	
32	35	17	17					10			
33	226	43				7			7	1	
34	104	11				2					
34+	67	24	3			19	8	8	24	22	11
jungle								20	368		
Total	94634	31298	2516	1	0	4635	20378	92533	14143	1212	1956

Table A6. 5: Maputaland age class distribution (DAFF, 2007)

	Softwoods Species	Hardwoods
	elliottii	grandis
Age	ha	ha
unplanted	2044	3889
1		500
2		1500
3		1000
4	1333	841
5	1460	500
6	1300	1200
7	1700	1200
8		
9	934	
Total	8771	10630

Table A6. 6: Zululand age class distribution (DAFF, 2007)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	557	588					1458		344		11
1		6					2714	176	365		
2	67	83					8041	242	280		
3	18	156	3686				8322	299	257		
4	23	43	1				8211	490	288		
5	9	109					8235	260	230		69
6		219					5618	212	336		157
7		90					4832	204	228		75
8		84					4300	212	262		309
9	64	583					2710	127	196		14
10	31	623					1489	33	206		13
11	35	217					1135	101	127		176
12	5	395					393	6	11		86
13	15	375		21			237	12	10		15
14	31	338				4	190	1			139
15	71	446		8		5	54	5			115
16	39	432		17		3	96		5		52
17	55	273		10			29	14			84
18	77	184	2	12			1				144
19	29	131		116			55	26			
20	118	178		62		2	87				
21	245	125	13	10			41				
22	161	279	10	10			56				1
23	112	148		24		25	64				
24	25	253					3				
25	88	18	16								
26	31	15	5					6			
27	44	5	9								
28	1		2	2			2				
29		4					2				
30	18	59	5								
31	22							5			
32	26	28									
33	41										
34	19					2					5
34+	115	43	45								31
jungle		48	29			1			5		50
Total	2192	6578	3823	292	0	42	58375	2431	3150	0	1546

Table A6. 7: KwaZulu-Natal Midlands age class distribution (DAFF, 2007)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	2059	385	272			75	2362	2386	3680		
1	1021	492	118			28	5881	5046	3321		4
2	1341	454	64			101	4791	5011	4747	9	3
3	1898	370	52			212	5209	5554	5151	21	
4	1120	729	42			160	3962	3888	4742	35	2
5	926	314	57			85	3438	3375	5451	18	1
6	884	583	125			183	2931	3279	5156	7	
7	1047	625	174	2		159	3271	2721	4410	17	
8	1272	955	292			266	2757	2515	3470	5	
9	881	915	379			257	3455	2642	4031	40	
10	739	1293	111			333	3182	2501	2499	21	
11	1211	526	217			184	2161	1997	1946	10	7
12	565	862	185	32		6	1888	1623	1297	39	
13	614	782	88			82	1235	1957	907	40	
14	1357	826	173			8	963	635	308	41	
15	1628	1187	104			59	290	188	184	53	3
16	1084	961	182			27	126	125	50	24	
17	1229	1013	47			24	120	74	23	29	
18	1014	1708	141			39	87	102	25	23	6
19	643	1151	28			5	2	45	2	47	
20	461	892	3			45	11	16	4	1	
21	551	694	35			17	38	6	1	5	
22	245	369	49			19	15	21		3	
23	205	241	54			122	134	6	4	1	
24	431	515	98			1	1		12		10
25	166	63	43			2	2				
26	129	86	18				2			1	
27	121	53	29								4
28	78	35	29			1					
29	123	59	44				132				
30	69	10	13							4	
31	20	65						1			
32	28	14	8							1	
33	101	26						3			
34	6		1							2	
34+	71	114				4	3	8		6	2
jungle	21	4					22	16	78		
Total	25359	19371	3275	34	0	2504	48471	45741	51499	503	42

Table A6. 8: KwaZulu-Natal North age class distribution (DAFF, 2007)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	147	217				123	1648	1242	1883		21
1	84	133				100	2531	2461	1444	3	14
2	154	188	6			6	3242	2058	1728		24
3	145	199				10	2905	2569	1933		
4	382	177				123	2763	2179	1922	5	9
5	315	483				116	2343	2700	1804		3
6	288	670				102	2529	2478	1309		20
7	100	277				20	2587	1534	1444	1	47
8	323	737				1	3269	1173	1616		8
9	1095	950				29	1528	726	2258		
10	149	725				2	673	435	1147		
11	240	714				42	419	353	988	2	
12	240	719	3			20	790	313	304	14	3
13	218	530				30	268	255	193		
14	233	451	3			12	215	145	87		
15	264	701				63	25	52	140		
16	287	285					75		36		
17	133	266				16	5		8	8	
18	118	146							22		
19	65	257	3							12	
20	161	271				8					
21	112	111				3					
22	273	41	25			14					
23	150	54	19				2				7
24	70	51	41			6				5	
25	126	8	57								
26	22	36	43								
27	53	51	20								
28	395		18								
29	32	16	19								
30	47	41					6				
31	15	23	15								
32	54	1	34			17					
33	1	5				26					
34		9									
34+	2						4				
jungle						150	18		193		
Total	6493	9543	306	0	0	1039	27845	20673	20459	50	156

Table A6. 9: KwaZulu-Natal South age class distribution (DAFF, 2007)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	1825	300	22			321	1485	488	777		
1	1689	1506	104			16	2152	1209	551	34	
2	2485	546	93			339	2320	1378	668		
3	2496	358	86			209	2063	891	970		
4	1993	168	12			113	1848	1005	794		
5	2101	199				370	1855	766	817		
6	1438	164				191	1819	690	470		
7	1267	218				327	1739	821	728		
8	2343	59				248	1995	1039	965		
9	1894	127				211	1669	981	514	2	2
10	2697	675	4			507	1715	1186	566	28	
11	1638	159	10			394	1578	1289	500	2	
12	2150	308				306	1051	908	791	9	
13	2003	35	34			330	642	197	726	1	2
14	1715	143				54	288	60	527	4	1
15	1026	32				8	131	39	95	13	
16	1501	262	13			3	218	58	54		
17	3083	90					56	9	15		
18	1911	281				25	63	10	13	2	
19	1086	277		1			23	46		6	
20	490	222	18			22	31	40			
21	307	165	42			18	17	3	23		
22	221	91	28					6		5	
23	423	348	180				90			29	
24	247	64	8			2					
25	97	219	242			27	2				
26	90	126	13				3		6	11	
27	55	43	56			8	65				
28	83	172	108								
29	60	195	13								
30	43	153	182				63			6	
31	21	84	159			69	5	2		2	2
32	6	42	89			1					
33	31	59	39			3					
34	1	5	51				2				
34+	53	3	17	607		30	414	61		2	
jungle	606	678	35			107	35	40	135		5
Total	41175	8576	1658	608	0	4259	25437	13222	10705	156	12

Table A6. 10: Eastern Cape age class distribution (DAFF, 2007)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	6887	3959	75	129	19	113	2704	1496	382		
1	1982	2443	241	16		113	627	367	17		
2	3254	1631	748	17		284	797	1739	43		
3	2744	1493	40	39		428	1066	126	457		
4	1922	515		223		165	1132	353	217		
5	1547	339		112		256	1668	285	437		
6	1255	568		48		396	839	259	72		
7	2103	691	48	36		399	971	441	458		5
8	1980	663	75	25		348	744	385	54		
9	1804	615	24	137		1705	458	349	61		
10	1374	361	20	357		1560	402	140	75	4	
11	2048	492	17	435	28	1013	211	129	13		
12	2354	245	124	534		921	253	187	27		123
13	2632	252	79	236		1593	340	168	78		
14	2087	469	72	344		594	83	65	59		1
15	1809	440	77	145		704	178	107	35		
16	2665	752	204	103	30	253	161	58	25		
17	3150	875	132	157	98	70	45	122			
18	2073	1127		52	148	94	73	161			18
19	1168	582	5	105	118		37	105	4		
20	765	528	9	63	105		25	74			1
21	559	271		128	140	10	57	45	14		
22	823	263	81	143	142		29	176			
23	513	236	38	189	73		14	34			
24	458	142	93	41			10	16			11
25	588	226	69	49	148		4	33		3	
26	280	193	144	72	54		16	13			
27	197	62	36	20	31		84	7	5		2
28	308	176	249	5	57	2		5			
29	275	122	17	5	676					17	
30	132	330	85	100	644		6		47	6	
31	130	394	31	92	446	37	9	1			5
32	267	327	65	171	383	164	20	94		13	76
33	17	95	40	32	164						
34	127	56	112	3	41	2	9	30	10		
34+	1473	382	78	46	234	39	19	97	190	10	38
jungle	2151	371	82	23		70	4	115	169	35	5
Total	55901	22686	3210	4432	3779	11333	13095	7782	2949	88	285

Table A6. 11: Southern Cape age class distribution (DAFF, 2007)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted		2689		9426	4	13					1
1		1622		599							
2		555	82	858							
3		547		764	2						
4		606		786				4	4		1
5		816	36	653							
6		1521	62	797							
7		1280	10	1152				3			
8		1428	30	1592							1
9		507		1507				9			2
10		587	1	1629	1	3					
11		565		2295	41	7		4			1
12		855	6	1902	21						10
13		382		1488	38			32			31
14		443	37	1682	41	2					17
15		342		1182	114			14			12
16		278		1320	74			62			16
17		251		1030	283			58			28
18		432		899	333						10
19		328		792	160	1		35			
20		271		966	216			3			35
21		320		790	354			30			43
22		441		613	331			21			39
23		70		548	317			26			8
24		77		371	363	2		40			27
25		105		238	418			31			2
26	2	141		559	296			51			39
27		79		431	444	2	12				8
28		122		215	234			3			1
29		41		664	1014	1		32			14
30		119	6	382	842						7
31		347		280	680	1		3			4
32		171	20	699	894	1		148		4	1716
33		133	40	128	343			7			3
34		48		72	229			15			11
34+	9	488	32	539	3473	27		498			26
jungle								64			
Total	11	19007	362	39848	11560	60	12	1193	4	4	2113

Table A6. 12: Western Cape age class distribution (DAFF, 2007)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted				2902							
1		66	60	296							
2		9		220							
3		5		237							
4		1		77		2					
5		6		130							
6		4		145	37	2					
7				106	19						
8				232	21						
9				281	7						
10				421	24						
11	165			580	18			4			
12	200		22	372	13		1				1
13	200			448	10	10					
14	168			510	10						
15	106			541	5	20					
16	2			594	14		1				
17	2	6		372	19	36		19			
18				398	51						
19				459	70			1			
20				350	112			21			
21				278	67			1			
22				188	48			24			
23				163	52		12	2			
24				98	68						
25	5			142	107			1			
26				193	76						
27		2		188	111			5			
28	5			158	41						
29				105	47						
30				92	17						
31				81	43						
32				121	21						1
33				75	34						
34				96	36			3			1
34+			1	857	742	22	61	331		5	75
jungle				298	44						
Total	853	99	83	12804	1984	92	75	412	0	5	78

2003 Data

Table A7: Age class distribution per species and forest zone for 2003 (inventory of growing stock)

Table A7. 1: Limpopo age class distribution (DAFF, 2003)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
Unplanted	467	60		34			948	32			
1	599	176		1		435	1933	562	33		
2	323	159				336	1882	616	34		
3	591	234	13	17		314	2238	577	9		
4	517	144				363	1835	535	4		
5	536	162		8		126	1718	455	14		
6	838	406		6		8	2014	772	8		
7	2438	448		4			1474	652	64		
8	657	208	35	11		14	2110	282	15		
9	695	232		17		67	2106	479	83		
10	607	203	1	4		22	1973	115	45		
11	558	248	14	26		74	1673	326	3		
12	704	332	30	27		76	1259	372			7
13	464	88		2		10	1143	90			
14	567	131		9		65	829	21			11
15	669	96		2		65	471	19			1
16	427	368		1		65	525	38			
17	446	137				25	690	54			
18	350	236	16	4		22	218	56			6
19	364	124	17			49	190	6		4	9
20	402	344	26			24	263	5			11
21	421	97	43			72	158	15			14
22	241	305	36			19	85	6			17
23	179	133	15			9	60	6		3	6
24	103	246	174			42	53	5			
25	103	66	219			12	58			3	
26	91	99	131			14	31	21		1	
27	114	112	151			22	26				
28	122	35	119			12	49				2
29	71	9	76			40	3				
30	16		103			13	2				
31	64	462	234			42	37				
32	7		82								
33	65		97								3
34	8	28	77								
34+	34	69	68			30		28			49
jungle	4	140	7				144	10			2
Total	14862	6337	1784	173	0	2487	28198	6155	312	11	138

Table A7. 2: Mpumalanga North age class distribution (DAFF, 2003)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	7212	2794	471	82	84	950	2951	1262	2	1	
1	3185	1107	579			992	5631	1017			
2	3272	1421	326			1060	3721	1202			
3	2289	1232	137			1108	3501	496			
4	2845	1195	243			1682	3617	1196			
5	2914	1179	363			2166	3040	958			
6	4025	1540	378			1147	3341	531			
7	3435	1420	273			984	3048	1183	39		34
8	4151	2524	273			598	2995	2313			46
9	5065	4136	384			497	3016	1936			70
10	6320	2897	112			243	3333	1040			9
11	3881	2193	118			236	2728	368			113
12	2847	2304	295			391	3391	210			
13	2435	2925	191			190	2322	64			6
14	3120	1968	74			70	1160	378			3
15	4178	5703				89	1489	202			
16	3495	2135				68	1132	27		18	16
17	3118	1853	2			182	988	40		14	
18	3024	2272	56			125	694	25			
19	2972	1843	399			126	627	17			8
20	2477	1821	241			177	699	22			6
21	2223	2043	405			292	519	26			3
22	1499	1402	687			179	301	21			1
23	1313	1152	835	10		78	98	5			5
24	948	1438	912			91	200	13			
25	766	1197	906	19		20	80	15			1
26	982	767	523			36	718				
27	1079	396	627			23	19	1			13
28	756	369	509			8	18				24
29	788	316	496			54	41				
30	536	181	447			116	45	13			
31	491	79	151			1	18	4			
32	185	98	53			9	40	2			6
33	257	11	38			4	7	17			
34	92	12	46				21				
34+	448	171	190			127	120	91		1	45
jungle	142	47	19			2	77	41	50	7	5
Total	88765	56141	11759	111	84	14121	55746	14736	91	41	414

Table A7. 3: Central Districts age class distribution (DAFF, 2003)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	725							50			
1	241					141	6	380			
2	408					134		557			
3	323					123		213			
4	351					80		66			
5	169	9				20		245			
6	356	13				66		365			
7	320	30				194		279	39		
8	370	165		8		47		214			
9	532	243				48		461			
10	708	63				49		98			
11	484	277						12			
12	571	281				4		113			
13	686	160				2		20			
14	669	546				4		58			
15	253	488				1		136			
16	845	383				89		6			
17	713	120						4			
18	851	68						8			
19	258	47				17					
20	313	30				5					
21	252	144						12			
22	116	168	226								
23	125	154									
24	24	22						39			
25	5					4		1			
26		28									
27											
28	86	41									
29	137										
30	48					29					
31											
32	2										
33											
34	44										
34+	175		18			72					3
jungle						4		61			
Total	11160	3480	244	8	0	1133	6	3398	39	0	3

Table A7. 4: Mpumalanga South age class distribution (DAFF, 2003)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	9062	1360	199			167	1064	4393	956	62	
1	3619	906	132			275	3769	13035	2747	17	256
2	5069	629	290			184	1913	7988	1335	67	190
3	5056	769				434	2612	6691	2155	32	199
4	4563	1060	5			415	3599	7915	1646	60	131
5	4254	1227	9			534	3044	7620	1574	40	104
6	4366	1131	70			535	3771	6725	1492	64	108
7	4211	908	31			310	2277	6234	1754	65	178
8	5424	999	16			273	2347	4584	1067	55	164
9	4161	1628	26			244	1404	4920	1340	52	75
10	5360	1596	2	1		84	964	4686	817	16	102
11	4514	1945	48			38	1212	2825	767	30	263
12	4516	1996	28			27	226	2198	260	34	36
13	4116	1547	56			64	186	1646	196	69	86
14	3952	1031	73			34	149	1082	153	63	
15	3661	1467	16			28	11	1777	108	48	5
16	1657	1599	121			178	17	834	7	42	
17	1125	843	105			145	12	406	2	18	
18	1228	642	10			20	28	127	12	23	
19	1869	612	44				65	30	20	93	
20	1434	184	127				4	32			
21	2645	389	170			37		37		1	1
22	1473	840	238			84		25			
23	1346	430	275			25		9		2	
24	991	415	160			2		2		2	
25	989	136	131			1	2	1	60		
26	860	56	65					21		3	
27	563	23	112					10			
28	418	30	74					22			
29	820	59	23			15		22		47	
30	436	65	59			41			6	7	
31	397	23	35							12	
32	116	11	12			5					
33	74	11	5			10					
34	38	11					2				
34+	38	25				22	171	7	27	25	8
jungle	3							20	582	15	
Total	94424	26603	2767	1	0	4231	28849	85924	19083	1064	1906

Table A7. 5: Maputaland age class distribution (DAFF, 2003)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted		2663					32				
1		44					39				
2		724					246				
3		748					106				
4		522					57	4			
5							1166				
6							777	136			
7						222	884	126			
8						282	2805	250			
9						241	911	103			
10						143	928				
11		15					261				
12		9					95				
13						125	122				6
14						288	1				
15		51				367					
16		177				82		7			4
17		184				276					
18		584				121					
19		244				25					
20		272				153					
21		242									
22		7									
23											
24											
25		28									
26											
27											
28		84									4
29											
30		447									
31		210									
32		68									
33		253									
34											
34+		223				148					2
jungle											
Total	0	7799	0	0	0	2473	8430	626	0	0	16

Table A7. 6: Zululand age class distribution (DAFF, 2003)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	552	676				145	3311		243		11
1		320					7155	1243	1204		
2	67	485	1			117	5876	1767	853		
3	177	247	1			101	5849	2727	753		
4	73	295	3			12	6438	2315	703		
5	6	667				226	6821	2782	674		69
6	52	920	23			326	6470	2930	723		157
7	42	510				430	5824	3248	291		75
8		581	12			219	5556	3798	242		309
9	58	543				132	5468	972	276		15
10	29	439				67	3846	133	79		13
11	152	886				118	2202	555	118		176
12	298	939	16			117	1350	288	75		86
13	83	785				6	965	279	122		13
14	245	1057	12			16	632	86	71		139
15	46	1467	53				507	14	37		115
16	68	596	89			155	735		1		52
17	68	825	44			83	486				84
18	39	855	104			22	190				144
19	12	378	49				368				
20	9	202	16			19	175				
21		138	14			24	68				
22		95	58			16	12				1
23	39	82	90				1				
24		73	5			44	5				
25	29	70				1	2				
26		19	2					6			
27		18				39		5			
28		23	30			1					
29		128									
30			27			58					
31			26			7					1
32		54	3			6					
33		1	8			15					14
34		7	31			4	11				5
34+	26	52	3			12	29	2			32
jungle									20		50
Total	2170	14433	720	0	0	2538	70352	23150	6485	0	1561

Table A7. 7: KwaZulu-Natal Midlands age class distribution (DAFF, 2003)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	1087	87	129			206	2374	1456	2852	12	
1	1272	264	46			47	4425	3741	6027	21	
2	2311	1280	69			246	4731	2645	4742	19	8
3	1818	411	101			176	4483	2549	4430	18	
4	1388	887	180			130	3686	3207	4590	43	3
5	1764	719	281			221	5182	3641	4181	44	1
6	1523	605	339			419	4007	4005	4109	34	9
7	1129	613	67			381	4373	2869	4214	23	2
8	1698	602	224			363	3771	2507	4647	69	6
9	1472	607	175	32		246	3996	2128	3275	24	
10	1586	941	118			330	2718	2215	2783	58	
11	1821	986	134			59	2110	1402	1788	71	13
12	1147	1084	121			26	1415	855	887	76	
13	2327	1024	152			30	795	267	536	54	
14	3386	1222	56			24	515	317	179	78	3
15	2605	1814	167			34	265	292	203	27	
16	1314	1193	48			8	205	161	64	11	2
17	1074	785	6			33	241	118	33	4	2
18	864	1285	40			14	29	28	8	321	
19	609	910	15			4	152	13	47	19	3
20	612	476	64				118	20	14	27	
21	427	348	64			9	37	5	22	16	
22	500	381	118			12	207	14		20	
23	482	237	65			1	9		17	5	
24	187	115	88				4				
25	225	42	20			2	2	2	3	9	
26	174	71	79				40		3		
27	270	53	68							4	
28	115	22	38				138				
29	102	31	27			1					
30	79	21	9					3		19	
31	20	41	2				162		12		
32	21	7	21					12			1
33	67	10									
34	16	3								2	
34+	109	121				125	6	4	4	6	2
jungle	25	1					44	32	261		
Total	35626	19299	3131	32	0	3147	50240	34508	49931	1134	55

Table A7. 8: KwaZulu-Natal North age class distribution (DAFF, 2003)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	338	288	2			2	1412	673	2064		2
1	517	184				14	2578	2703	2482		13
2	449	213					2937	2415	1973		15
3	195	199				19	2972	2463	1802		9
4	404	258				35	2249	2510	2126		17
5	202	257	19			16	2710	2641	2273		34
6	46	297	3			21	2652	2124	2050		14
7	86	411				2	3121	1598	1897		43
8	354	579				67	3168	1116	1886		8
9	1197	841	12			8	1301	1237	2191	2	
10	141	1045	3			20	670	818	1608	14	
11	320	250					307	293	1031		
12	392	261					117	72	740		
13	819	976				19	251	452	185		
14	494	505	3				152	76	69		
15	262	481					350	85	97		
16	169	348					49		18		
17	211	276					62		5	1	
18	268	48	6				30		22		
19	368	25	3			16	1				
20	380	83									
21	205	63	25			6					
22	187	21	47				2				
23	121	27	73				2				
24	79	52	43								
25	67		32								
26	400	2	23				1				
27	71	15	32						9		
28	57	40	33				2		10		
29	68	60	49								
30	61	24				17					
31		9				77					
32	1		2								
33		5				15					
34			10								
34+	19	21					4	38			25
jungle						150	10	15	365		
Total	8948	8164	420	0	0	504	27110	21329	24903	17	180

Table A7. 9: KwaZulu-Natal South age class distribution (DAFF, 2003)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	420	20				1373	992	1505	1059		
1	609	463				17	2081	1781	846	34	
2	1194	392	53		16	7	2201	1892	820		20
3	726	187	83		62	46	1702	1483	680		7
4	1526	306	12		59	292	1866	1371	639		
5	1153	117			238	189	2707	1831	851		3
6	1305	245			44	62	2631	1860	1060		
7	591	252			47	225	2555	1939	858		8
8	892	740			24	283	2491	2298	871		11
9	1410	982			12	167	2074	2280	1154	7	20
10	2372	261			1	68	2485	1532	1338	35	8
11	1220	376				3	2192	738	833	6	35
12	1109	431					1579	432	683	9	9
13	1682	465					1510	131	88	1	
14	2625	236			17		535	26	90	12	
15	2783	459			8		767	89	19	21	
16	892	286	9	1			616	94	11		
17	1113	436	40				276	100		2	
18	450	463					96		3		1
19	372	276	19				60	7		2	
20	676	409	18		18	2	58	9	2		
21	311	366	30		18	27	148		5	5	
22	166	160	141				10	6			
23	84	727	55				7		1		
24	165	226	181								13
25	58	342	106				106			11	
26	122	156	70								
27	67	57	14			82					8
28	136	185	186				75				
29	103	303	160							6	3
30	58	200	165				5	2		2	
31	21	195	38		5						
32	67	79	96								
33		42	1			61	2				
34	14	5	12								
34+	62	4	4	607	9		414	61		2	
jungle					2		27	35	104		4
Total	26554	10849	1493	608	580	2904	32268	21502	12015	155	150

Table A7. 10: Eastern Cape age class distribution (DAFF, 2003)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	8165	2877	38	250	55	1592	1254	171	142		12
1	1848	959	9	222		364	892	317	89	5	
2	3148	1467	906	45	125	389	978	233	361		11
3	2947	992	122	122	52	515	1203	149	180	14	
4	1349	1179	82	67	25	681	1305	523	174		8
5	1666	693	51	94		1780	1742	415	61	31	
6	970	781	26	66		1267	1182	197	145	28	1
7	3235	1119	69	340		2083	1433	295	82	7	11
8	3174	809	157	489	28	1028	859	193	121	18	
9	2520	578	55	699		1917	613	186	172		
10	1295	637	196	459		1192	429	142	31		59
11	1417	1072	62	394		968	245	79	33	9	13
12	2307	1707		220		394	233	140	19		23
13	4076	1826	311	247	30	375	173	148	9		23
14	5347	1708	35	147	33	107	174	417			25
15	1445	1028	43	139	163	4	62	161	18		30
16	825	981	7	187	169	27	92	208	28		1
17	614	720		61	97		71	125			3
18	545	653		166	144		19	66	4		2
19	828	792		119	142		19	30		4	
20	754	492	27	152	86		12	33	161		6
21	555	353	14	142			21	27	82		8
22	775	515	29	187	130		13	8	11		5
23	354	246	17	79	103	2	7	6			3
24	280	252	48	16				7	2	3	
25	716	395	18	4	39				5		
26	428	341	30	14	407			1			
27	235	220	48	131	707	18	5				
28	661	512	19	169	734	37	18	2		17	2
29	355	705	32	69	449	19	2	8	6	6	
30	246	436	49	60	221	19	28				
31	179	79	24	39	28	19					
32	184	414	52	197	267	157	16	77		14	116
33	81	51	10	3		15			12		
34	123	74	7	12		2	4			5	
34+	1170	1144	8	35		46	13	142	43	49	29
jungle	3	83	31	22	1	53	124	202	230	33	137
Total	54820	28890	2632	5864	4235	15070	13241	4708	2221	243	528

Table A7. 11: Southern Cape age class distribution (DAFF, 2003)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted	5	143	3	7052	55						365
1		-85		482							
2		445		767							
3		924	100	334							
4		1948	-26	1147				4			
5		1465	26	1134							
6	7	807		590						20	
7		504	10	476	-27			3			
8		560		1172	48	2		9			3
9		465	6	3267	2	5					11
10		404	1	1429	12						30
11	10	478	38	1723	11	6					13
12		738		1254	-7			4			24
13		156		1717	78			42			13
14		274		2183	3			11			6
15		253		954	319			84			26
16		35		633	104	1					8
17		349		915	183			26			29
18		186		708	-53			-3			20
19		311		1773	-22			36			22
20		344		701	117			21			61
21		200		434	215	2		35			5
22		151		374	280			48			15
23		120		441	366			65			27
24		277		1140	765	2		7			29
25		26		382	561			6			9
26		11		437	361			3			14
27		-192	6	812	-42	1	12	37			7
28		-73		382	88						4
29		181	-50	1741	72			7			13
30		408	49	646	484	7				3	17
31		53		357	170			15			5
32		472	14	709	102	-2		371		1	1422
33		9	1	222	1036	1		7			
34				195	9						
34+		350	10	628	2262	22	2	106			
jungle				14		58					300
Total	22	12697	188	39325	7552	105	14	944	0	24	2498

Table A7. 12: Western Cape age class distribution (DAFF, 2003)

	Softwoods Species						Hardwoods				
	patula	elliottii	taeda	radiata	pinaster	other	grandis	other gum	wattle	poplars	other
Age	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
unplanted			125	2996							
1		6	50	146							
2			10	111		2	1				
3				94							
4			10	87							
5				342							
6	3		48	574		2					
7	34	4	29	566	7			2			
8			35	640	39		1	1			5
9			50	425				2			
10			20	374		10					2
11	22		60	596						2	14
12	15			527	1		4				
13	2		60	368		20					
14			56	268	33						
15			10	517	73	36		1			
16			10	294	55						63
17			10	416	57						
18			20	382	128			4			
19			10	128	17						
20			30	178	91			2			
21		3	30	159	200			2			
22			35	137	71			1			
23			10	276	145			6			
24		2	10	151	124						
25			10	254	108						
26			10	179	27						1
27			10	181	42						
28			10	114	20						
29			24	160	61			3			
30			17	150	46						3
31			22	365	88	18	6	14			6
32			4	224	65	21	55	216		21	37
33			10	111	71						
34			10	83	97	1					4
34+		6	32	1013	892			107		5	122
jungle	4			280							
Total	80	21	887	13866	2558	110	67	361	0	28	257

APPENDIX B – SAMPLE CALCULATIONS

The following sample calculation is for the Limpopo forest region.

Carbon Stock calculations of the Limpopo forest region

The following databases are used to calculate the carbon stock in the Limpopo forest:

- Growth curves per species
- Age class distribution per species in the Limpopo forest:
- The basic wood density is 0.497 for hardwood and 0.501 for softwood
- The carbon fraction of dry matter is 0.47.

The growth curves per specie is shown in Table A1. The growth curve for *Eucalyptus grandis* translates to Figure B1 shown below:

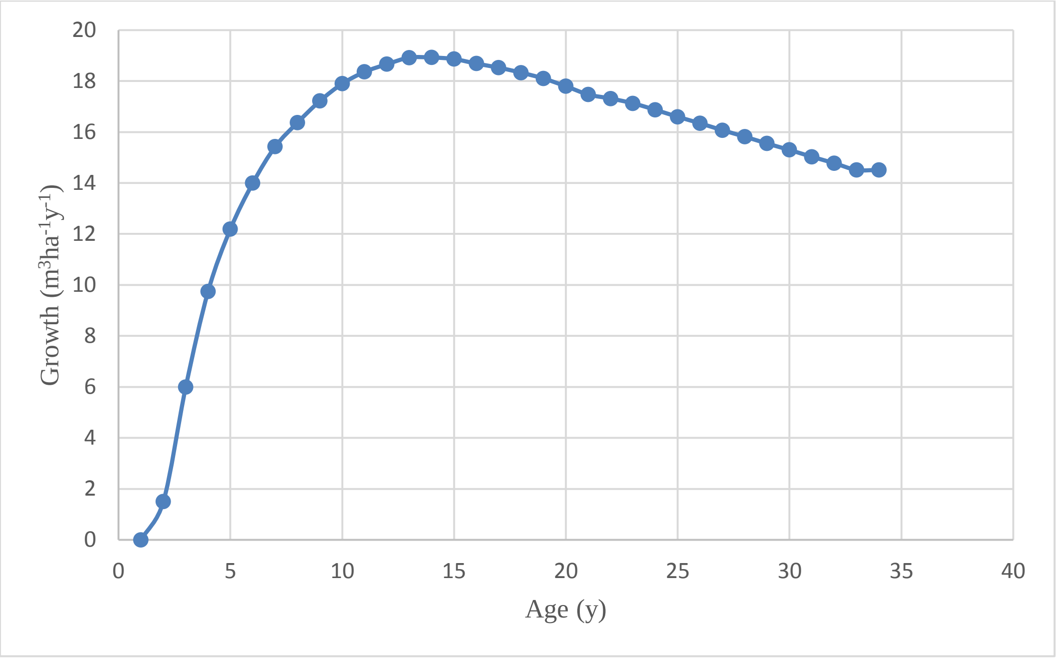

Figure B1: Growth curve for *Eucalyptus grandis*

The yield also known as the specific volume in m3/ha is simply integrating the growth curve. The trapezoid rule is used for the integration and the results is shown in Figure B2.

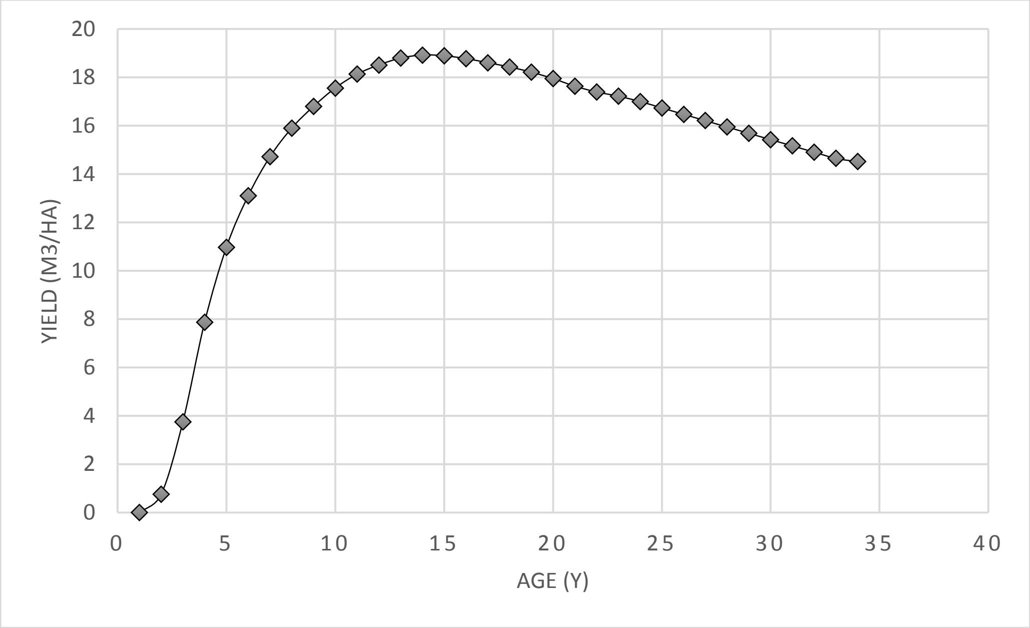

Figure B2: Yield or specific volume for *Eucalyptus grandis*

The yield for all the other species is calculated in the same way.

The carbon stock is the area per age category multiplied by the yield, tree age and the factor (1+R).

Example:

Tree age = 5 years

Area covered = 1272 ha

Yield = 12.2 m3/ha

R = 0.28

$$stock = 1272\,ha\ \times 12.2\frac{m^3}{ha.age} \times (1+0.28) \times 5\,y = 99318\,m^3$$

Table B1 shows the stock calculations for *Eucalyptus grandis*.

The same calculation is performed for all other tree species in the Limpopo forest region and the stock is the sum for all the species.

Table B1: *Eucalyptus grandis* stock calculation in the Limpopo province

Age y	Area ha	Yield m3/ha	stock m3
1	712	0	0
2	652	1.5	2504
3	1054	6.0	24284
4	1229	9.8	61352
5	1272	12.2	99318
6	827	14.0	88919
7	978	15.4	135199
8	705	16.4	118214
9	729	17.2	144634
10	596	17.9	136556
11	631	18.4	163151
12	614	18.7	176046
13	466	18.9	146734
14	494	18.9	167565
15	679	18.9	245961
16	806	18.7	308472
17	626	18.5	252403
18	540	18.3	228096
19	527	18.1	232049
20	347	17.8	158121
21	163	17.5	76571
22	107	17.3	52182
23	22	17.1	11095
24	4	16.9	2074
25	1	16.6	531
26	0	16.3	0
27	2	16.1	1111
28	0	15.8	0
29	0	15.6	0
30	10	15.3	5875
31	0	15.0	0
32	0	14.8	0
33	0	14.5	0
34	0	14.5	0
34+	5	14.5	3251
jungle	0	15.2	0
Total	14798		3042267

Output calculations of the Limpopo forest region

The following databases are used to calculate the output flow of carbon from the Limpopo forest:

- Timber harvested from Limpopo plantations by species
- Limpopo plantation areas damaged
- Industry conversion factors for roundwood
- The basic wood density is 0.497 for hardwood and 0.501 for softwood
- The carbon fraction of dry matter is 0.47.

The following industry conversion factors for conversions between metric tons and cubic metres of roundwood were used:

Table B2: Industry conversion factors

Softwood

- Sawlogs 1 ton = 0.94m³
- Pulpwood 1 ton = 1.0m³

Eucalyptus grandis

- Sawlogs 1 ton = 0.94m³
- Pulpwood 1 ton = 1.47m³

Other Gum Species

- Sawlogs 1 ton = 0.78m³
- Pulpwood 1 ton = 1.25m³

Wattle 1 ton = 1.138m³

Other hardwoods 1 ton = 1.03m³

Output from harvest

The timber harvested from Limpopo plantations by species is shown in Table A3 and it is in multiple units of cubic metres and tons. The table is converted using the industry conversion factors to one unit i.e. cubic metres. The results are shown in Table B3. The values are then converted to carbon dry mass using the basic wood density and the carbon fraction of dry matter.

Table B3: Output from the Limpopo forest from harvest

Species	Sawlog m3	Poles m3	Mining Timber m3	Pulpwood m3	Charcoal /firewood m3	Other m3	Total m3	Total ton C.dm
Softwood	182621	0	0	13202	10670	5115	211608	49811
E. grandis	169621	64644	70673	0	16504	23308	344750	80476
Other Gum	1200	13438	1673	0	5493.75	0	21804	5090
Wattle	0	0	0	0	0	0	0	0
Other Hardwoods	0	0	0	0	0	0	0	0
Total	353442	78082	72346	13202	32667	28423	578162	135377

Output from damages

The output due to disturbances are calculated using equation 2.9

$$L_{disturb} = [A_{disturb} \times B_W \times (1 + R) \times CF \times fd] \quad (2.9)$$

The average above-ground biomass in land affected by disturbance Bw in ton/ha is the growing stock in ton C divided by the plantation area. The outputs due to disturbances is shown in table B2

Table B4: Output from the Limpopo forest from disturbances

Disturbance	Area ha	Bw ton C /ha	fd	Output ton C d.m
Fires	139	5.18	1	921
Other	18	5.18	0.3	36
Total				957

Input calculations of the Limpopo forest region

The input into the forest corresponds to the amount of carbon sequestered and it is calculated once the output flows and the carbon stock change are determined.

$$Change\ in\ Stock = Input\ flows - Output\ flows \quad (B1)$$

The change in flows is simply the difference between the forest carbon stock at the end of 2011 and the forest carbon stock at the end of 2010.

The 2011 carbon stock of is 2 693 000 ton C d.m. and the 2010 carbon stock is 2 593 000 ton C d.m. The stock change is therefore 2 693 000 - 2 593 000 = **100 000 ton C d.m**

The total output from the Limpopo forest (harvesting plus disturbance) is 135 000 ton C d.m. Therefore using the mass balance principle (equation B1) the input flow is calculated to be 100 000 + 135 000 = **236 000 ton C d.m.**

The unit ton C.dm/ha is equivalent to the unit Mg C/ha which is reported in most journals and papers

Productivity in the forest regions

The productivity is simply the input growth divided by the area planted (plantation area) and it represents the carbon sequestered in the forest.

According to Figure 4.1, the forest growth rate for the entire South African forest region in the year 2011 is 5 328 000 t C.dm. Of this, the total harvest done in 2011 summed up to 4 337 000 t C.dm and the total carbon lost to the atmosphere via disturbance was 133 000 t C.dm. Applying the MFA mass balance principle, it can be shown that the forest sector is carbon positive with respect to forest management activities. That is the change between the forest growth (input) and the carbon losses from the forest due to harvesting and losses to the atmosphere via disturbances (outputs) is positive. This positive change increases the 2010 forest carbon stock by 857 000 t C.dm.

APPENDIX C – VERIFICATION OF MASS BALANCE

The mass balance principle was used to calculate the net carbon dioxide uptake from the atmosphere, stored in the trees as living biomass; that is, the tree growth or total carbon input flow to the forest. The input flow must equal the output plus the carbon stock difference in the year of study, 2011. The output flow and the carbon stock difference are first calculated, then the mass balance principle is applied to calculate the input flow. It was mentioned in Section 2.9.1.1 and Section 3.2.4.2 that the input flow could be calculated using the *Gain-Loss Method*, which was then used to verify the mass balance. The input flow using the *Gain-Loss Method* was calculated at 5 410 000 t C.dm which fall within the error interval of the 5 328 000 ± 442 000 t C.dm as shown in Figure 4.1.

The total annual input for the South African forest was calculated using the mean annual increment (MAI) shown in **Appendix C**, Table C3 and the plantation area shown in Table C1. The rotational age in Table C2 was used to select the particular MAI to use in the calculation. Equation 3.2 was then applied to calculate the input flow (in m^3/y) in the forest for the base year 2011.

$$G = \sum_{i,j}\left(A_{i,j} \times MAI_{i,j} \times [1 + R]\right) \qquad (3.2)$$

Finally the basic wood density (0.497 for hardwood and 0.501 for softwood) was then used to convert the input to ton C $d.m.y^{-1}$

Table C1: RSA Plantation area according to main purpose for which trees are grown (DAFF, 2011)

Species	Sawlog ha	Poles ha	Mining Timber ha	Pulpwood ha	Other ha	Total ha
Softwood	441513	11150		194349	3885	650897
E. grandis	14721	17512	48375	224633	1009	306250
Other Gum	1996	5208	5399	194987	2799	210389
Wattle	728	3725	2778	92797	579	100607
Other Hardwoods	530	156	353	3576	601	5216
Total	459488	37751	56905	710342	8873	1273359

Table C2: RSA rotational ages according to main purpose for which trees are grown (DAFF, 2011)

Species	Sawlog	Poles	Mining Timber	Pulpwood	Other
Softwood	28	28		18	26
E. grandis	11	9	9	9	9
Other Gum	21	9	11	9	9
Wattle	10	10	11	10	9
Other Hardwoods	32	12	10	12	18

Table C3: RSA rotational ages and mean annual increments (Godsmark, 2013)

R.S.A.		Rot Age	MAI
Patula	Sawlogs	28	11.1
Elliottii	Sawlogs	28	11.1
Taeda	Sawlogs	28	11.1
Radiata	Sawlogs	28	11.1
Pinaster	Sawlogs	28	11.1
Other	Sawlogs	28	11.1
Patula	Pulp ex Pulp	18	14.6
Elliottii	Pulp ex Pulp	18	14.6
Taeda	Pulp ex Pulp	18	14.6
Radiata	Pulp ex Pulp	18	14.6
Pinaster	Pulp ex Pulp	18	14.6
Other	Pulp ex Pulp	18	14.6
Patula	Poles	20	10.1
Elliottii	Poles	20	10.1
Taeda	Poles	20	10.1
Radiata	Poles	20	10.1
Pinaster	Poles	20	10.1
Other	Poles	20	10.1
Grandis	Sawlogs	23	26.6
Grandis	Pulp ex Sawlogs	23	4.3
Grandis	Pulp ex Pulp	9	23.1
Grandis	Poles	9	18.1
Grandis	Mining Timber	10	18.5
Other Gum	Sawlogs	31	15.9
Other Gum	Pulp ex Pulp	10	16.8
Other Gum	Poles	11	16.3
Other Gum	Mining Timber	10	15.4
Wattle	Pulp ex Pulp	10	8.8
Wattle	Poles	13	8.4
Wattle	Mining Timber	11	8.6