



research REPORT

**Assessment of the potential to produce biochar
and its application to South African soils as a
mitigation measure**

.....



environmental affairs

Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA



Assessment of the potential to produce biochar and its application to South African soils as a mitigation measure

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Foreword

Biochar is gradually gaining interest globally as a climate change mitigation measure in the agriculture forestry and other land use (AFOLU) sector. It is produced in the absence of oxygen through a process called pyrolysis, mainly from biomass material. However, a host of other materials (feedstock) can be used. Several studies in different areas across the world have demonstrated that deploying biochar in soils results in benefits that include enhanced agricultural yield, a reduction in leaching of nutrients, a reduction in soil acidity, increased soil water retention and a reduction in fertilizer use and irrigation requirements.

In South Africa, the recently published Mitigation Potential Analysis (MPA) and the National Terrestrial Carbon Sinks Assessment (NTCSA) identified biochar as one of the land-based mitigation opportunities that can contribute to a transition to a lower carbon economy. However, not much is known about biochar in South Africa despite the existence of a few very small-scale projects. Consequently, the current project was commissioned to assess the potential and sustainability to produce biochar at scale, mainly as a mitigation measure in

soils, in addition to other benefits (socioeconomic and environmental benefits). However, further ongoing and long-term monitoring and research into the production and application of biochar is required to address a number of uncertainties identified through this specific project.

Although the independent research and findings contained in this report do not necessarily represent the views, opinions and/or position of government, the Department believes that this research is critical to enhance our understanding of the potential and sustainability of the production of biochar, together with the socioeconomic and environmental benefits, especially in the AFOLU sector. Hence, the Department is happy to make this work publicly available and accessible.

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Table of contents

Executive summary.....	5
1 Introduction	8
2 Study context.....	10
2.1 Uses of biochar.....	10
2.1.1 Carbon sequestration	10
2.1.2 Soil amendment	12
2.1.3 Energy recovery	14
2.2 Feedstocks for biochar production	14
2.3 Technologies for biochar production	15
2.4 Biochar application to soils	19
2.4.1 Application methods	19
2.4.2 Application rates and frequency of application	20
3 Biochar production and application in South Africa	21
3.1 Feedstocks suitable for biochar production	21
3.1.1 Alien vegetation.....	22
3.1.2 Sawmill waste	24
3.2 Technologies for biomass production and energy recovery from biomass in South Africa	26
3.3 Potential areas for biochar application.....	26
3.3.1 Cultivated land	26
3.3.2 South African soil types suitable for biochar application	27
4 Techno-economics of biochar production.....	30
4.1 Description of the value chains.....	30
4.2 Model description and key assumptions	31
4.2.1 Feedstock properties.....	31
4.2.2 Harvesting considerations and costs.....	31
4.2.3 Transportation	32
4.2.4 Pre-processing and biomass conversion technologies.....	32
4.2.5 Product value and potential markets	32
4.2.6 Financial input parameters and calculated output indicators	34
4.3 Model outputs.....	34
4.3.1 Value Chain 1.....	36
4.3.2 Value Chain 2.....	37
4.3.3 Value Chain 4.....	38
4.4 Summary of the model outcomes and implications for biochar production and application in South Africa.....	39
4.4.1 Economic feasibility.....	39
4.4.2 Carbon sequestration potential.....	41
4.5 Final comments: factors potentially limiting the application of biochar in South Africa	42
5 Socioeconomic impacts of biochar production and supply	44
5.1 Employment.....	44
5.1.1 Employment in harvesting alien vegetation	44
5.1.2 Manufacturing in decentralised pyrolysis units	44
5.1.3 Manufacturing in a centralised pyrolysis unit.....	44
5.1.4 Increased productivity of agricultural land and food security	45
5.1.5 Provision of alternative fuels	45
5.1.6 Health and safety considerations	46

6	Business model for biochar production	46
6.1	Business model considerations for Value Chain 1	47
6.2	Business model considerations for value chain 2, 4 and 5	49
7	Conclusions and Identification of further research opportunities	50
7.1	Potential for biochar production in South Africa	50
7.2	The potential for biochar application in South African soils as a mitigation measure	51
7.3	Socioeconomic benefits of biochar production and application in South Africa	52
7.4	Recommendations for future work	52
8	References	54
	Appendix A: Techno-economic modeling: additional information	61
A1	Harvesting	61
A2	Transportation cost and distance	62
A3	Biomass conversion technologies	64
A4	Carbon balance	65
A5	Financial input parameters	67
	Appendix B: Sustainability considerations	68
	Appendix C: Scoping of a pilot project	69
C1	Description of the pilot site	69
C2	Activities to date	69
C3	Description of the pilot project	69
C4	Funding requirements	70
C5	Project time lines	71
C6	Expected benefits and success criteria	71
C7	Licensing and regulatory considerations	72
C8	Risks	72
	Appendix D: Details of stakeholder engagement	73
	Appendix E: Policy and regulatory framework considerations	75
E1	National Environmental Management Act (Act No. 107 of 1998)	75
E2	National Environmental Management: Air Quality Act (Act No. 39 of 2004)	75
E3	National Environmental Management: Waste Act (Act No. 59 of 2008)	76
E4	Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act No. 36 of 1947)	79
E5	Carbon offsets	79

List of figures

Figure 1:	Structure of the report	9
Figure 2:	Biochar in the carbon cycle	12
Figure 3:	Examples of pyrolysis configurations	16
Figure 4:	Products derived from biochar production	18
Figure 5:	Distribution of woody IAV in South Africa	23
Figure 6:	Location of sawmills in South Africa	25
Figure 7:	Distribution of cultivated land in South Africa (2014)	27
Figure 8:	Acidic soils in South Africa	28
Figure 9:	Distribution of sandy soils and soils with low WHC in South Africa	28



Figure 10: Soils with very low to low potential for erosion.....	29
Figure 11: Fertilizer price history	33
Figure 12: Value Chain 1 economic viability for different scenarios	36
Figure 13: Value Chain 2 biochar selling price for different harvesting radii and densities.....	37
Figure 14: Value Chain 2 biochar selling price for different IRRs and harvesting densities	38
Figure 15: Value Chain 4 projected IRR for different biochar selling prices	39
Figure 16: Map showing available IAV for sale into different markets to achieve a 15% IRR when 50% of available biomass is harvested at a 50 km harvesting radius. Product is from a centralised pyrolysis plant (Value Chain 2).....	40
Figure 17: Map showing available IAV for sale into different markets to achieve a 15% IRR when 100% of biomass is harvested at a 50 km harvesting radius. Product is from a centralised pyrolysis plant (Value Chain 2)	40
Figure 18: Distribution of cultivated land with acidic soils	42
Figure 19: Distribution of areas likely to have the greatest benefit from biochar application.....	43
Figure 20: The relationships of harvesting and extraction cost to harvesting density of IAV species.....	61
Figure 21: Harvesting radius illustration	62
Figure 22: Harvesting radius and density	63

List of tables

Table 1: Factors impacting on product yield and distribution.....	17
Table 2: Summary of different biochar application techniques	19
Table 3: Feedstocks considered and shortlisted in the study	21
Table 4: IAV species invasion in South Africa.....	23
Table 5: Costs of clearing, chipping and transport of various IAV species.....	24
Table 6: Sawmill waste produced per annum.....	25
Table 7: Value chains chosen for analysis.....	30
Table 8: Minimum product selling prices in 2015 for exceeding a 15% project IRR.....	35
Table 9: Tonnes carbon emission reductions over the baseline per tonne dry biomass consumed in the value chains.....	35
Table 10: Indicative GHG emission reductions for biochar produced from IAV when sold into different markets at 50% harvesting efficiency	41
Table 11: Indicative GHG emission reductions for biochar produced from IAV when sold into different markets at 100% harvesting efficiency	41
Table 12: Indicative annual carbon emission reductions for biochar produced from sawmill waste when sold into different markets	42
Table 13: Potential job creation at centralised production plants (data provided by technology suppliers).....	45
Table 14: Business model considerations for Value Chain 1	47
Table 15: Business model considerations for value chains 2, 4 and 5	49
Table 16: Harvesting process assumptions and data	62
Table 17: Transport process assumptions and data	63
Table 18: Mobile pyrolysis unit data and assumptions based on data supplied by Vuthisa Technologies.....	64
Table 19: Centralised pyrolysis technology data and assumptions based on data supplied by Thermex Carbontech	64
Table 20: Gasification technology data and assumptions based on data supplied by Prestige Thermal	65
Table 21: Carbon balance input parameters	66
Table 22: Financial input parameters	67
Table 23: Funding requirements for centralised pyrolysis unit.....	70
Table 24: Funding requirements for workshop and mobile units	70
Table 25: Regulatory requirement costs.....	71
Table 26: Project implementation	71
Table 27: Stakeholder engagement	73
Table 28: Description, applicability and minimum emission standards for char, charcoal and carbon black production as given in section 21 of the National Environmental Management: Air Quality Act.....	76
Table 29: Waste management activities that may be applicable to the production of biochar that require a waste management licence under the National Environmental Management: Waste Act.....	77
Table 30: Waste types defined under the National Environmental Management: Waste Act, which may be applicable in the context of biochar production.....	78

List of abbreviations

AEL	Atmospheric Emission Licence
AFOLU	Agriculture, Forestry and Other Land Use
AgriLASA	Agri-Laboratory Association of Southern Africa
ARC	Agricultural Research Council
CCA	Copper-chromium-arsenate
CDM	Clean Development Mechanism
CO ₂	Carbon dioxide
CO ₂ e	Carbon dioxide equivalent
CPI	Consumer Price Index
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DEROs	Desired Emission Reduction Outcomes
DFID	Department for International Development
DST	Department of Science and Technology
EIA	Environmental impact assessment
GHG	Greenhouse gas
GIS	Geographic Information System
IAV	Invasive alien vegetation
IPP	Independent Power Producer
IRR	Internal rate of return
IBI	International Biochar Initiative
LAN	Limestone ammonium nitrate
LCA	Life cycle assessment
MACC	Marginal abatement cost curve
MAP	Mono-ammonium phosphate
MPA	Mitigation Potential Analysis
MYPD	Multi-year Price Determination
N ₂ O	Nitrous oxide
NBI	National Business Initiative
NCCRP	National Climate Change Response Policy
NEMA	National Environmental Management Act
NEM: AQUA	National Environmental Management Act: Air Quality Act
NEM: WA	National Environmental Management: Waste Act
NERSA	National Energy Regulator of South Africa
NTCSA	National Terrestrial Carbon Sinks Assessment
ORC	Organic Rankine Cycle
PAH	Polycyclic aromatic hydrocarbons
REIPPP	Renewable Energy Independent Power Producer Procurement
RFA	Road Freight Association
S&EIR	Scoping and Environmental Impact Report
SABS	South African Bureau of Standards
SAEON	South African Environmental Observation Network
SARS	South African Revenue Service
SME	Small and medium enterprise
SPP	Sustainable People's Project
VCS	Verified Carbon Standard
WfW	Working for Water
WHC	Water holding capacity



Executive summary

Introduction

A number of activities have been undertaken in South Africa over the past eight years towards setting the policy and direction for reducing greenhouse gas (GHG) emissions from the economy. Through this work, GHG mitigation interventions have been identified for all sectors, including for the agriculture, forestry and other land use (AFOLU) sector. Both the National Terrestrial Carbon Sinks Assessment (NTCSA) and the Mitigation Potential Analysis (MPA) have identified the manufacture and burying of biochar as one of the mitigation measures available to this sector. In addition to having the potential to reduce GHG emissions, biochar is argued to have a number of benefits when applied to agricultural lands, including the ability to improve soil fertility and crop yields.

The potential of biochar to capture and store carbon in soils is attracting attention globally with various analyses having been done into its global sequestration potential. One analysis has suggested that the annual potential for the sequestration of atmospheric carbon dioxide (CO₂) globally could be at the billion-tonne scale within 30 years. Estimates of global biochar mitigation potential have, however, arisen primarily from small-scale studies that do not necessarily support generalisation to all locations and all types of biochar, given that the physical and chemical properties of biochar and the interaction with different types of soils can vary greatly. A need for further research and more robust data has thus been identified as being critical in determining both the global and local applicability and potential of biochar as a GHG sequestration option, and to guide the development of sound, locally applicable policies.

Based on these observations, the Department of Environmental Affairs (DEA), with financing from the UK's Department for International Development (DFID) under the Strategic Climate Policy Fund, commissioned this nationwide baseline study to assess the potential for biochar to be used as a GHG mitigation option in South Africa. The overall objective of the study was to explore the potential for and sustainability of the production of biochar at various scales, as well as considerations related to its application in agricultural soils at various scales as a land-based GHG mitigation option. Further aims were to identify strategic areas for piloting the production and deployment of biochar and to provide information that can be used to facilitate activities that will begin to address the data gaps around biochar production and application within the South African context.

The study outcomes were to be achieved through exploring potentially suitable feedstocks for biochar production, identifying potential geographical areas and soils for biochar application and assessing the economics of biochar production and application under a number of scenarios. Furthermore, consideration was given to the factors to be taken into account when establishing a business model for biochar production and the potential socioeconomic benefits of biochar production and supply, including employment and job creation.

While the study intended to provide as much detail as possible with respect to the above tasks, it was recognised that full information might not be available, and hence the study may not be conclusive in its findings. As such, the final task was the identification of further research focus areas and opportunities that need to be pursued to provide more information on biochar as a mitigation measure.

The study was to be achieved through a combination of the review of relevant literature, new analyses and an extensive stakeholder engagement process.

Uses of biochar

Prior to exploring the South African situation specifically, an overview of biochar and its potential uses are identified. In this study, biochar is defined as the char product that is created through the heating of organic biomass in a low or no-oxygen environment through a process called pyrolysis, and is then applied to agricultural or forest soils. The intention of producing and using biochar for this purpose is to limit the production of GHG emissions that would have occurred if the biomass had degraded naturally, while having the additional benefit of improving soil functions. It is recognised that the char product produced in this way can have a variety of other applications that may be preferred to burying it in the soil, including energy recovery, water treatment, the treatment of waste spills onto soils and into water bodies, aquaculture, additives to animal feed and additives to manure or compost. The preferred usage for the char will be locally specific and will depend on local markets. The focus of this report, however, is only on sequestration in soils, with an analysis of energy recovery being provided for comparison purposes in the economic model developed as part of this study.

Feedstocks for biochar production

Of the various feedstocks that are available for the production of biochar in South Africa, the study has identified invasive alien vegetation (IAV) and sawmill waste as those with the greatest potential and warranting further exploration. The motivation behind these choices is as follows:

- IAV is causing billions of rands of damage annually to South Africa's economy through its negative impacts on water resources and biodiversity, among others things, and efforts are underway to clear this vegetation at great cost through the Working for Water (WfW) Programme. Biochar production could add value to this resource and recover some of the cost of clearing.
- Residues from sawmills typically present a waste management challenge, and some of the practices currently employed (dumping and open burning) result in a deterioration of air quality and an increase in water pollution, with the associated secondary impacts. Recovery of energy and the production of biochar are potential solutions to managing these wastes that not only address the environmental issues, but recover value from an otherwise wasted resource. This waste stream has a further advantage that it is already concentrated at central locations. This reduces both harvesting and transport costs.

Other potential feedstocks were excluded from the study due to considerations such as competing markets or preferred options for value recovery, the potential for the introduction of contaminants and the potential to impact on food security.

Technical and financial feasibility

Biochar production through pyrolysis is proven to be technically viable at various scales, ranging from small-scale batch facilities to large continuous production units. Both small-scale and large-scale facilities have been proven with a wide range of feedstocks, including sawmill waste and IAV. The work presented in this report suggests, however, that while the technical feasibility is demonstrated, the economic viability of biochar production is less certain. The economic analysis suggests that it is not economically feasible to produce biochar for carbon sequestration purposes only as the returns are too low to justify the investment. If the simultaneous benefit of improving crop yields can be demonstrated and a consequent reduction in fertilizer use could be achieved, then various biochar production routes could potentially become financially justified.

Biochar for sale into the export markets is also a potentially viable option, depending on the prices that may be achieved. Finally, although not directly relevant to this study, the sale of the char product for use as charcoal is viable under certain circumstances.

The key factor that determines the extent of economic viability is the cost of accessing the feedstock. As the harvesting density decreases (and resulting feedstock extraction and transport costs increase), so the viability of the project decreases. Sawmill waste avoids the need to harvest and transport feedstocks, so shows far greater economic viability. What this suggests is that viability needs to be assessed on a case-by-case basis, making it difficult to draw generic conclusions for the country as a whole.

Suitability for application to soils

In terms of biochar use, the focus of this study was to explore the potential for biochar application in South African soils as a GHG mitigation measure. While biochar can theoretically be applied to any soil for the sole purpose of carbon sequestration, it was identified that soils that have low potential for erosion would be more likely to retain higher proportions of the carbon. Furthermore, given that biochar is likely to provide additional benefits to the soil in cultivated lands (known as soil amendment), it was proposed that the areas for application be restricted to cultivated areas. The choice of applying biochar to cultivated land is further motivated by the observation above, that biochar needs to offer more value than purely carbon sequestration to be financially viable.

Some soils may be better suited to biochar application for the purpose of soil amendment than others. Biochar used as an amendment in acidic and sandy soils has been widely demonstrated to have positive effects on crop yields. While adding this filter to cultivated lands reduces the potentially favourable areas in terms of soil types significantly, it is noted that the distribution of these areas is well correlated with the areas of the country that show the greatest feasibility for biochar production. The data on these target soil types was combined with the results from the economic model to provide an indication of the areas with the greatest viability for biochar production.

Having said this, while biochar application seems to generally enhance crop growth and soil nutrient status, little has been published on how these interactions occur and why the effects are so variable according to crop, soil and biochar type. There is still a need to conduct further research into the mechanisms by which biochar could provide beneficial functions to soil and the wider agricultural system, which are currently poorly understood.



Socioeconomic impacts

The results of the study suggest that the production and application of biochar to South African soils has the potential to have positive socioeconomic impacts. The harvesting, production, storage and transportation of feedstock and the application of biochar to soils is labour-intensive. It thus represents an opportunity for creating employment for unskilled, semi-skilled and skilled workers. Furthermore, the production and application of biochar could diversify and increase income, and consequently the spending power of employees, thus contributing to economic development in local communities. The production of biochar can, therefore, present opportunities for developing rural economies, especially since it has been shown that feedstocks are often located in areas where jobs are much needed. Further benefits relate to increased food security and the productivity of agricultural land due to the soil amendment benefits of biochar, and the provision of alternative fuels where the char product is used for applications other than burying it in the soil. Certain negative health and safety considerations were also identified, including those related to air pollution and safety when using the equipment required to produce biochar.

The study discusses a range of considerations relating to the establishment of a business model for biochar production under different scenarios. These considerations include those related to financial viability, capital investment, employment creation, skills, risks, linkages to the economy, balance of payments, technology commercialisation, the public-sector resources required to develop the industry, biomass ownership, and the use of trade-offs and alternative revenue streams.

Further research and pilot project

A proposal of additional research areas related primarily to interactions with soils and crops is presented in the final section. The key areas of further research relate to soil-biochar interactions and the stability of the biochar in the soil. The primary challenge is the local specificity of these interactions.

The proposal on different research areas is complemented by the design of a pilot study proposed for George's Valley near Tzaneen, which intends to advance the knowledge related to this product area. The study involves three key components: the construction of a large-scale biochar production facility to produce biochar from sawmill waste, the construction of a workshop to skill artisans in the production of mobile pyrolysis units and rocket stoves (which produce biochar while cooking), and the in-field testing of the impact of biochar on crops.

The latter component of the pilot study is to be developed with input from the University of Limpopo, which is already doing research in this area.

Legislative considerations

Finally, an overview of the policy and legislation relevant to biochar is presented. The key finding is that a full scoping and environmental impact report (S&EIR) is required for biochar production installations of any scale, product or type, and an atmospheric emission licence (AEL) is required for production installations that produce more than 20 tonnes of biochar a month. It must be noted that, in April 2015, the DEA released a draft declaration that seeks to make the same emission limits applicable to char plants and charcoal plants with a design production capacity of less than 20 tonnes of product a month. If this declaration comes into effect unchanged, the result will be that all biochar installations, regardless of production capacity, will require an AEL in order to operate legally.

Conclusion

In conclusion, it is noted that the absence of clear scientific evidence demonstrating biochar's carbon sequestration potential or its benefits as a soil amendment, as well as the product and site-specific interactions, makes it difficult to make definitive comments as to the extent to which biochar production and application for soil amendment and as a GHG mitigation measure at the national level is either viable or desirable. While ongoing research is required to explore these considerations, it may ultimately be necessary to evaluate opportunities on a far more localised level.

Finally, it is noted that, although the focus of this project was on biochar production and application to South African soils as a mitigation measure, the economic analysis shows that it might be more desirable to use a feedstock like IAV to create a char product for use in other applications.

1. Introduction

South Africa has signalled a clear intention to reduce greenhouse gas (GHG) emissions through the publication of the National Climate Change Response Policy (NCCRP). The NCCRP highlights that a combination of approaches to the mitigation of GHG emissions is required, which needs to have the co-benefits of contribution to job creation, economic development and other social, environmental and sustainable development dimensions. A number of studies have served to explore the technical and non-technical opportunities that are available to reduce GHG emissions in South Africa. These include the Long-term Mitigation Scenarios, the Mitigation Potential Analysis (MPA), the ongoing work on the development of Desired Emission Reduction Outcomes (DEROs), the National Terrestrial Carbon Sinks Assessment (NTCSA) and the work to meet international reporting requirements (e.g. National Communications and Technology Needs Assessments).

The NCCRP identifies the agriculture, forestry and other land use (AFOLU) sector as having an important role to play in reducing South Africa's GHG emissions. Both the NTCSA and the MPA have identified the manufacture and burying of biochar as one of the mitigation measures available in this sector. In addition to having potential to reduce GHG emissions, biochar is argued to have a number of benefits when applied to agricultural land, including the ability to improve soil fertility and crop yields (National Resources Defense Council, 2010). The importance of biochar in the generation of carbon-neutral energy and as a biomass waste management solution has also been demonstrated (Institute for Environmental Sustainability, 2010; Roberts, Gloy, Joseph, Scott & Lehmann, 2010; Sohi, Lopez-Capel, Krull & Bol, 2009).

The potential for biochar to capture and store carbon in soils, and therefore its potential role as a GHG mitigation option, is currently also attracting attention globally, in both academic and government spheres. Analyses have suggested that the annual potential for sequestration of atmospheric carbon dioxide (CO₂) globally could be at the billion-tonne scale within 30 years (Woolf, Amonette, Street-Perrott, Lehmann & Joseph 2010). Matovic (2011) estimated that charring and burying 10% of global net primary productivity each year would offset the current annual increase in atmospheric CO₂. As a result of such analyses, the discussion around biochar has moved from scientific studies to specific policy proposals for carbon offsets (De Gryze et al, 2010). Brick and Lyutse (2010), for example, published a report that assessed the major risks and potential around biochar production to help inform the development of specific policies in the USA. Similarly, Amezaga, Von Maltitz & Boyes (2010) have looked at the role biochar could play in the framework they developed

for the policy evaluation of bioenergy projects in the developing world.

To date, however, estimates of global biochar mitigation potential have arisen primarily from small-scale studies that do not necessarily support generalisation to all locations and all types of biochar, given that the physical and chemical properties of biochar and the interaction with different types of soils can vary greatly (Spokas & Reicosky, 2009; Kwapinski, Byrne, Kryachko, Wolfram, Adley, Leahy, Novotny & Hayes, 2010; Marx, Chiyanzu & Piyo, 2014; Kloss, Zehetner, Dellantonio, Hamid, Ottner, Liedtke, Schwanninger, Gerzabek & Soja, 2012; Sun, Geo, Yao, Fang, Zhang, Zhou, Chen & Yang, 2014). Furthermore, a great deal of uncertainty exists with respect to the other environmental, social and economic benefits and risks associated with different biochar production and use pathways, particularly at a local scale (Zhao, Cao, Mašek & Zimmerman, 2013; Kloss et al., 2012). A need for further research and more robust data has thus been identified as being critical in determining both global and local applicability, and the potential of biochar as a GHG sequestration option, and hence to guide the development of sound, locally applicable policies.

Based on these observations, the need exists to assess the potential for biochar production and application within the South African context. The Department of Environmental Affairs (DEA), with financing from the UK's Department for International Development (DFID) under the Strategic Climate Policy Fund, commissioned The Green House to conduct a nationwide baseline study to assess the potential for biochar to be used as a GHG mitigation option in South Africa. The stated overall objective of the study was to explore the potential for and sustainability of the production of biochar at various scales, as well as considerations related to its application in agricultural soils at various scales as a land-based GHG mitigation option. Further aims were to identify strategic areas for piloting the production and deployment of biochar and to provide information that can be used to facilitate activities that will begin to address the data gaps around biochar production and application within the South African context.

In meeting the overall aims, the following tasks were to be undertaken:

- Collation of data on suitable feedstocks for biochar production in South Africa
- Identification of the potential areas and soils where biochar could be applied in South Africa
- Exploration of the economics of biochar application for both application to soils and for recovery of energy (with the latter being explored as a reference case)
- Detailing the considerations to be taken into account when establishing a business model for biochar



production, including those relating to investments, technology choices, costs and performance

- Exploration of the potential socioeconomic benefits of biochar production and supply, including employment and job creation
- The definition of a potential pilot project on biochar production and its application

While the study intended to provide as much detail as possible with respect to the above tasks, it was recognised that full information might not be available, and hence the study may not be conclusive in its findings. As such, the final task was the identification of further research focus areas and opportunities to be pursued to provide more information on biochar adoption as a mitigation measure.

The study was to be achieved through a combination of reviewing the relevant literature, performing new analyses and an extensive stakeholder engagement process.

This report presents the final outcomes of the study.

Figure 1 illustrates the structure of the report. It begins by presenting the background context in Section 2, which details the potential uses for biochar, feedstocks and technologies for its production, as well as considerations related to its application to soils and other sustainability considerations. Section 3 identifies the potential feedstocks and areas that could be suitable for biochar application in South Africa. In Section 4, the comparative economics of biochar for carbon capture and energy production are considered for the two feedstocks that show potential in South Africa: sawmill waste and invasive alien vegetation (IAV). The socioeconomic impacts of biochar production are examined in Section 5, and considerations relating to the business model for production are explored in Section 6. Section 7 draws together a set of conclusions and identifies potential areas for future research within the South African context. A set of appendices contains additional information to that presented in the main text, as well as the design of a private project and a review of the relevant policy and regulatory frameworks.

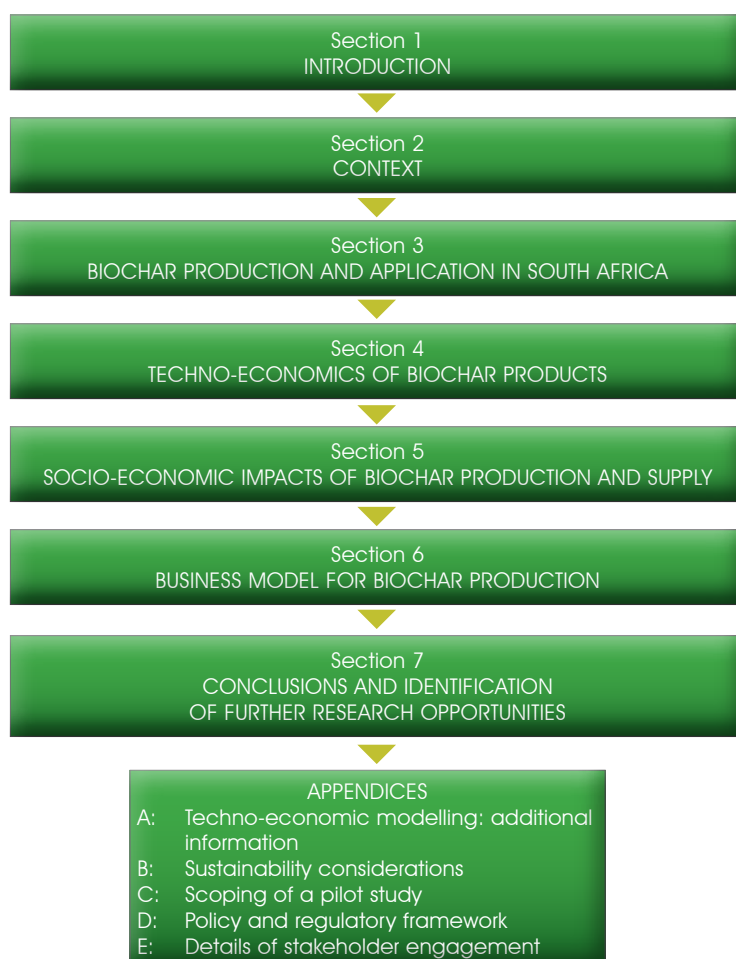


Figure 1: Structure of the report

2. Study context

To provide a context for the study and ensure that the most up-to-date information would be used to inform the study, an extensive review was conducted of the academic and public literature. This review was supplemented with initial observations gathered from engagement with local stakeholders. The study context includes a definition of biochar and its potential uses, an overview of the different feedstocks that can be used in its production, a review of the available production technologies, and considerations relating to the application of biochar to soils.

2.1 Uses of biochar

In this study, biochar (sometimes known as biological charcoal) is defined as the char product that is created through the heating of organic biomass in a low or no-oxygen environment through a process known as pyrolysis. It is then applied to agricultural or forest soils. The intention of producing and using biochar for this purpose is to limit GHG emissions that would have occurred if the biomass had degraded naturally, while having the additional benefit of improving soil functions (Spokas, Baker & Raicosky, 2010).

Some of the soil function benefits of applying biochar include increasing agricultural yield, reducing the leaching of nutrients from the soil, reducing soil acidity, increasing water retention in soil, and reducing irrigation and fertilizer requirements (Woolf et al., 2010; Laird, Brown, Amonette & Lehmann, 2009; Driver & Gaunt, 2010; Sohi et al., 2010; Larson, 2007).

It needs to be recognised, however, that there is no agreed definition of the physical and chemical properties of biochar (Lehmann, Gaunt & Rondon, 2006), and the term is also used to describe a char product employed in applications other than soil amendment and carbon sequestration. Such applications include, but are not limited to the following:

- Energy recovery
- Water treatment
- Treatment of waste spills onto soils and into water bodies
- Aquaculture
- Additives to animal feed
- Additives to manure or compost

This study focuses on three of the uses of biochar or char: carbon sequestration, soil amendment and energy recovery. These uses are discussed in greater detail in the following sections.

2.1.1 Carbon sequestration

Biochar for carbon sequestration in soils is the main focus of this study. During the production of biochar (as discussed in Section 2.3 below), a portion of the carbon from the biomass is incorporated in a stable form in the solid biochar product. When applied to soils, a large proportion of the carbon in the solid is retained in the soil, resulting in a negative carbon balance and thus offering an effective GHG mitigation benefit. The carbon in the remaining gas and bio-oil may, however, be re-released into the atmosphere when these products are burned to recover their energy value (Lehmann, Czimczik, Laird & Sohi, 2009).

Some analyses have suggested that deployment of biochar into soils represents a very substantial carbon sink. Lehmann et al. (2006) suggest that application of biochar to the 1 600 million hectares of cropland and 1 250 million hectares of temperate grasslands globally at a rate of 140 tonnes of carbon per hectare would result in a total of 400 gigatonnes of carbon sequestration. This is approximately 50 times the current anthropogenic carbon emissions of 7.8 gigatonnes of carbon per year (Raupach, Marland, Ciais, Le Quéré, Canadell, Klepper & Field, 2007). Other suggestions have been made that within 30 years, the annual sequestration of atmospheric CO₂ in the soil could reach the billion-tonne mark globally (Sohi, Lopez-Capel, Krull & Bol, 2009). However, these projections are typically based on the outcomes of a range of small-scale studies (see, for example Sohi et al. (2009) for details of such studies).

The analyses that project the carbon sequestration potential differ widely regarding assumptions about the stability of the biochar and the period over which carbon is stable (Hammes & Schmidt, 2009). The large-scale global analyses typically assume that biochar is stable in soils for over 100 years, with views on biochar storage horizons in the literature ranging from centennial to millennial time scales. A study conducted by Roberts, Gloy, Joseph, Scott and Lehmann (Roberts et al., 2009) assumed a mean residence time of 1 000 years or longer. Gaunt and Lehmann (2008) assume 100% stability of carbon in biochar only over a 10-year period. Similarly, Spokas et al. (2010) review a range of studies looking at biochar degradation in soils, and conclude that different biochars have residence times in soil ranging from 100 years to over 1 000 years. On the other hand, some laboratory-based studies using biochar have shown some mass loss in a period of days to years (Sohi et al., 2009). Hamer, Marschner, Brodowski & Amelung. (2004) found a 16 to 51% loss of biochar over a two-year period. Loss of biochar over time is not only a result of mineralisation, but could also be due to leaching, illuviation and erosion (Lehmann et al., 2009). Differences in findings such as these materially affect conclusions about the carbon storage benefits of biochar, and as such, generalisations



cannot be made about the storage potential of biochar for all locations and biochar types.

It is noted that the assumption of long retention periods is, however, not unfounded. Some biochar residues from forest fires, for example, have been found to be more than 10 000 years old (Preston & Schmidt, 2006). Biochar found in the Terra Preta and Terra Mulata soils of the Amazon region have been radio-carbon dated and found to originate from up to 7 000 years ago (Glaser, Haumaier, Guggenberger & Zech, 2001; Liang, Lehmann, Sohi, Thies, O'Neill, Trujillo, Gaunt, Solomon, Grossman & Neves, 2010; Neves, Petersen, Bartone & Da Silva, 2003).

When considering the GHG implications of using biochar, indirect GHG emission benefits also need to be taken into account. The first of these is the indirect emission savings that can be achieved through the reduction of requirements for synthetic fertilizer, which carries with it a (sometimes very high) carbon footprint. Secondly, it has been argued that biochar can retain nitrogen in the soil, thereby reducing the emission of nitrous oxide (N_2O), which has a global warming potential much greater than that of CO_2 (Cayuela, Sánchez-Monedero, Roig, Hanley, Enders & Lehmann, 2013). Rondon, Ramirez and Lehmann (2005), for example, reported reductions in N_2O emissions of 50 and 80% following biochar addition to soils. This benefit may be particularly significant for biochar applied to agricultural soils because, while N_2O is produced naturally in soils through nitrification and denitrification (Davidson, Swank & Perry, 1986), these processes are significantly enhanced by nitrogen fertilization. This is reflected in the fact that agricultural land accounted for about 60% of the global atmospheric N_2O emissions in 2005 (Crutzen, Mosier, Smith & Winiwarter, 2007), and in South Africa, agricultural soils represent the main source of anthropogenic N_2O emissions in comparison with other sectors, such as energy and livestock (which only contribute to around 9 and 4% of N_2O emissions respectively) (Department of Environmental Affairs, 2014).

The mechanisms of how biochar might reduce N_2O emissions still remain unclear and not much quantitative data is currently available. For these reasons, the potential reduction of N_2O emissions as a result of biochar addition to soils is not considered further in this study, but it is important to note that biochar application may be able to provide a significantly higher GHG mitigation potential than is suggested by this study.

In addition to the GHG mitigation benefits, there are some sources of GHG emissions associated with biochar production and use. These emissions are primarily

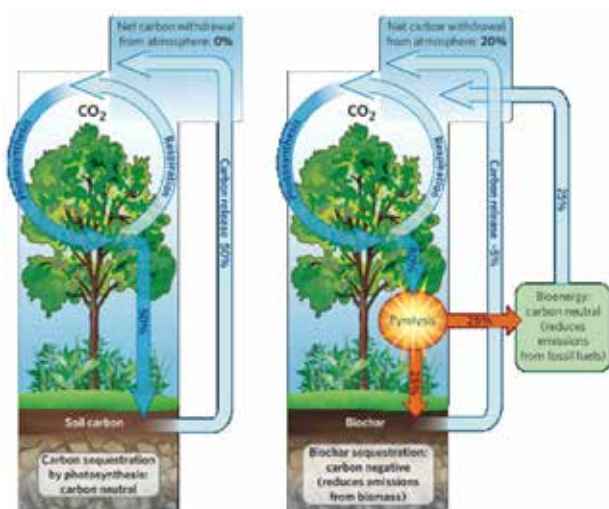
attributed to the use of fossil fuels associated with the transportation and production of biochar, as well as, in some cases, the use of fossil energy to initiate the pyrolysis production process. Together, these factors may reduce the net biochar GHG mitigation benefits.

Life cycle assessment (LCA) is an environmental analysis tool that can assist in understanding the net mitigation benefits of biochar production and application. In an LCA, the environmental implications of all the stages of a product or service's life cycle are modelled, from the mining, extraction or growing of its raw materials, to the manufacture, distribution and use of products, right to the end of life (e.g. recycling, landfill or, in this case, combustion). Inputs and outputs are not only considered for the product under study, but also for all the other materials used in the life cycle of the product. Inputs include the use of resources, such as land and water, as well as material inputs, such as fuels, chemicals, etc. Outputs are released into air, water and land associated with the system, as well as all its products and by-products. Together, these processes make up the life cycle of the system to be analysed, as defined by the system boundary.

A key consideration in any life cycle study involving biomass is the decision that is taken on how biogenic carbon is accounted for. Either one of two methodological approaches can be taken:

1. Uptake of CO_2 by plants is accounted for, and is balanced by accounting for CO_2 emissions from burning or consuming the biomass
2. Uptake of carbon by nature is not accounted for, and the CO_2 emissions of the biomass are given a zero global warming potential (i.e. are not included in the total GHG emissions for the system)

In both cases, the net effect is the same, being that burning or consuming the biomass is carbon neutral. The important thing, however, is to be consistent, as mixing the two approaches will provide misleading results. For example, including carbon uptake, but not including combustion emissions, will result in the system obtaining a double credit. Misleading results can also occur when the first approach is taken in a system model that is not truly cradle to grave. For example, if carbon uptake is included in the production of bioenergy, but the use phase is not included within the system boundary, the system will show a negative overall carbon footprint. An illustration of the carbon life cycle for biomass and biochar, showing the benefit of biochar, is given in Figure 2.



Source: <http://www.biochar-international.org/biochar/carbon>
 Note: Different studies report different values for the percentages of carbon reporting to the air and soil to those shown in the diagram.

Figure 2: Biochar in the carbon cycle

Various studies on the life cycle implications of biochar production and use are available in the literature (Dutta & Raghavan, 2014; Roberts et al., 2009; Gaunt and Lehmann, 2008; Sparrevik, Adam, Martinsen & Cornelissen, 2014; Hammond, Shackley, Sohi & Brownsort, 2011; Afrane & Ntiamoa, 2011). A comparison between the findings of these studies is, however, difficult due to different study scopes, assumptions, inputs, technologies considered and the way in which the storage and stability of carbon in the biochar in soil is modelled.

Despite the lack of comparability between different LCA studies, some broad observations can be made. These include the following:

- All the studies demonstrate a net GHG mitigation benefit associated with biochar (although it needs to be reiterated that this depends on the assumptions about the period of stability of the biochar in the soil).
- One study (Roberts et al., 2010), however, suggests that biochar may at present only deliver climate change mitigation benefits and be financially viable as a *distributed* system using waste biomass. Transportation distances of feedstocks should be minimised for the realisation of both the environmental benefits and the economic profitability of system.
- Despite the positive GHG mitigation benefits, there are potentially negative air quality impacts (i.e. particulate emissions) associated with charcoal and biochar production processes.

On the basis of the overwhelming body of literature on the subject, the study proceeds on the understanding

that biochar does indeed offer a GHG mitigation benefit, although its quantification needs to be further explored.

As indicated previously, in South Africa, both the MPA and, more recently, the NTCSA identified biochar as a potential mitigation measure when applied to cropland. The MPA considers biochar produced only from IAV being added to agricultural soils as a mitigation measure. It is assumed in the MPA that 30% of the available IAV is used to produce biochar. Using this assumption, the study estimates that by 2020, a reduction of GHG emissions of 619 kt carbon dioxide equivalent (CO_2e) could be achieved, with a reduction of 939 kt CO_2e by 2050. The MPA acknowledges, however, that using IAV as a feedstock may be difficult and expensive to implement. The NTCSA estimates that the production of biochar could potentially reduce emissions by 642 kt CO_2e per annum, if applied to 700 000 hectares of agricultural land. In both cases, however, the lack of scientific evidence and need for further research were identified as key limiting factors when making assumptions about their overall GHG emission reduction potential. The NTCSA, for example, gives biochar one of the least favourable rankings of the project activities assessed due to the number of unknowns around the application and potential mitigation benefits of biochar. The current lack of methodologies available for its application through either the Clean Development Mechanism (CDM) or the Verified Carbon Standard (VCS) is noted as an additional challenge (see Appendix E5 for further information).

Finally, it should be noted that having standards to quantify the mitigation benefits of biochar would help to facilitate the increased participation of biochar projects in offset programmes and carbon markets, such as the emerging carbon tax mechanism in South Africa. The International Biochar Initiative (IBI) attempted to develop a biochar carbon offset methodology to quantify the stable carbon component of biochar, as well as the avoided emissions from feedstock that would otherwise be combusted or decompose. Unfortunately, the methodology has been suspended after being peer-reviewed, and the conclusion was reached that there is insufficient evidence to support this method. No other methodologies for assessing the mitigation benefits of biochar were found in the literature.

2.1.2 Soil amendment

The second proposed benefit of biochar arises from its use as a soil amendment (Bayabil, Stoof, Lehmann, Yitaferu & Steenhuis, 2015). A soil amendment, alternatively referred to as a soil conditioner, is defined as any material that is added to the soil to improve its physical qualities, especially its ability to provide nutrition for plants. Soil amendments can thus improve poor soils or rebuild soils that have been damaged due to poor



management to make them more usable and maintain healthy soils. A soil amendment can be used to replace or reduce the use of synthetic fertilizers (Laird et al., 2009; Driver & Gaunt, 2010; Mukherjee, 2013).

Although biochar has been shown to have positive effects on soil and crop yields, the underlying mechanisms are still poorly understood. The ability for biochar to act as a soil amendment has been associated with a number of physical and chemical changes in soil properties after application, such as increased water and nutrient availability, increased organic carbon content, increased pH in acidic soils and modified soil biota (Beesley, Moreno-Jiménez, Gomez-Eyles, Harris, Robinson & Sizmur, 2011; Demisie, Liu & Zhang, 2014; Fang, Singh, Singh & Krull, 2014; Lu, Sun & Zong, 2014; Luo, Durenkamp, De Nobili, Lin & Brookes, 2011; Woolf, 2008). Further details of these benefits are as follows:

- **Increased water and nutrient availability:** Biochar has a porous structure and a large surface area that is argued to improve nutrient availability and water retention in soil, as well as reduce the leaching of nutrients and agricultural chemicals. Furthermore, the application of biochar to soil may reduce the soil bulk density, thus increasing water infiltration, root penetration and soil aeration (Laird et al., 2009). Increased nutrient availability also results in improved fertilizer use efficiency (Roberts et al., 2010) and improved water holding capacity (WHC). Improved WHC and nutrient availability due to the application of biochar has been recorded in numerous studies, such as Uras, Carrier, Hardie and Knoetze (2012), Yadav, Sharma and Kothari (2002), Peake, Reid and Tang (2014) and Bayabil et al. (2015). Peake et al. (2014) observed that the effects of biochar application on available water were more distinct in sandier soils than in silty soils.
- **Increased organic carbon content:** It has been argued that soil organic carbon is closely related to the formation and stability of soil aggregates, and that by increasing organic carbon content, soil losses can potentially be reduced. Both Demisie et al. (2014) and Nelissen, Ruyschaert, Mank'Abusi, D'Hose, Al-Barn, Cornelis and Boeckx (2015) found that the application of biochar to soil increases the organic carbon content. In addition, numerous studies have shown that biochar increases the total organic carbon and its labile fractions, which subsequently increases microbial activity, soil aggregation and carbon sequestration, improving overall soil quality (Nelissen et al., 2015; Fang et al., 2014).
- **Increased pH in acidic soils:** Biochar has the effect of increasing soil pH, thereby decreasing the need for liming. This effect has been documented in several

studies (Uras et al., 2012; Sika & Hardie, 2014). Soil acidity adversely affects plant growth, particularly the damaging effects of toxic levels of aluminium at low soil pH. Furthermore, nutrient availability is linked to soil pH, with macronutrients decreasing with increasing acidity (Schroeder, Robinson, Wallace & Turner, 1994). During the pyrolysis process, base cations, including calcium, magnesium and potassium, in the biomass are transformed into oxides, hydroxides and carbonates, and are mixed with the biochar. These bases, found in most biochars, function as liming agents when applied to the soil, and thus increase pH and decrease the concentration of aluminium in acidic soils (Laird et al., 2009). High concentrations of aluminium and high acidity are often limitations to growth in tropical soils. One exception is biochar produced from sugar cane bagasse, where the biochar is acidic.

- **Modified soil biota:** Soils contain microbial communities, made up of various microorganisms with numerous functions, which are partly responsible for increased soil productivity and nutrient turnover and utilisation (Nielsen, Minchin, Kimber, Van Zwieten, Gilbert, Munroe, Joseph & Thomas, 2014). Although less emphasis is placed on the influence of biochar on changes to microbial communities, biochar may indirectly affect plant growth by positively modifying soil microbial communities (Laird et al., 2009).

It is noted that, although there is evidence of biochar application resulting in significant agricultural benefits, a small number of studies has shown no significant positive effect of biochar application on crop productivity (Blackwell, Riethmuller & Collins, 2009; Hammond, Shackley, Prendergast-Miller, Cook, Buckingham & Pappa, 2013; Tammeorg, Parviainen, Nuutinen, Simojoki, Vaara & Helenius, 2014; Nelissen et al., 2015), and some studies have even identified adverse effects (Sohi et al., 2009). Furthermore, the beneficial effects of biochar may be determined by the presence of other components in the soil. These results suggest that, as a result of variable chemical and physical properties, the application of biochar to different soil types will result in different biophysical interactions and processes (Nelissen et al., 2015). Consequently, additional research is necessary to fully understand location-specific findings to account for effects of geographic variations in soil type, climate, cropping and pyrolysis feedstock (Sohi et al., 2009).

Finally, there are some safety concerns about biochar use within agricultural systems worth mentioning. Hale, Lehmann, Rutherford, Zimmerman, Bachmann, Shitumbanuma, O'Toole, Sundqvist, Arp and Cornelissen (2012) suggest that analysis of a limited number of biochar samples has indicated the presence of toxic combustion products, such as polycyclic aromatic

hydrocarbons and dioxins, but at concentrations below those that would give rise to environmental risk (Garcia-Perez & Metcalf, 2008; Brown, Kercher, Nguyen, Nagle & Ball, 2006). This seems to be feedstock-dependent, however, and a complete assessment of the impacts of toxic substances within feedstocks and biochar has not been made (Sohi et al., 2009). It has been identified that for dioxins to be formed, a specific set of conditions is required, including the presence of chlorine (or other halogens), partially combusted hydrocarbons, the presence of a catalyst (typically a metal or metal oxide) and specific temperatures. Garcia-Perez and Metcalf (2008), for example, suggest that no studies have identified dioxins in biochar produced from woody biomass. The concern about potential dioxin formation may therefore only be valid when biochar is produced from mixed municipal solid waste or if biochar-making operations are used to process other waste that may contain chlorine and potential catalysts, such as printed plastic containers and plastics containing halogens. The potential concern about the formation of toxins has not been investigated further in this study, but it is suggested that the introduction of materials other than pure feedstocks into pyrolysis units should be avoided.

2.1.3 Energy recovery

Two aspects of energy recovery from biochar production are considered in this study. The first was mentioned previously: that the steam, gas and oil by-products of biochar manufacture for carbon sequestration can be recovered for their energy value, giving rise to a secondary revenue stream and GHG mitigation benefit (Gaunt & Lehmann, 2008; Bridgwater & Peacocke, 2000). The combustion of volatiles in the wood during pyrolysis releases around two-thirds of the energy in the wood as heat, which can be used to produce steam or for combustion in electricity-generation technologies (Baker, Bartle, Dickson, Polgase & Schuck, 1999). Bio-oils can be burned to provide energy for heating, or can be refined to transportation fuels if sufficient volumes are available (Laird, 2008). Like bio-oils, syngas can also be used to heat the pyrolyser or provide energy for household and industrial uses. In addition, syngas and bio-oils can be used to produce steam to drive turbines in centralised power-generation systems (Laird, 2008). The potential for using bio-oil does, however, depend on the scale of the operation, and hence the volumes of oils that are produced.

The second energy-recovery option that is compared to the use of biochar for carbon sequestration in soils is burning the char product directly as a carbon-neutral or low-carbon energy source (Laird, 2008). It is estimated that, globally, 41 million tonnes of char is produced annually for cooking and industrial purposes (Lehmann et al., 2006). The production and use of char is more energy

efficient than the direct burning of wood as a cooking or heating fuel (Demirbas, 2004). Char can also have other environmental benefits relative to the use of wood, particularly in cases when the feedstock used replaces the collection of indigenous vegetation for firewood, as it widens the options for the types of biomass that can be used for energy to include, for example, crop residues, animal dung and other by-products of agriculture and livestock-related activities. These feedstocks are already used globally to provide a significant proportion of household energy needs (Food and Agriculture Organisation, 1983). The use of char for energy also has several social benefits when considered relative to a cooking fuel such as paraffin that has high indoor fire risks and health impacts that are associated with poor indoor air quality due to its combustion (Bhattacharya, Albina & Salam, 2002).

In the context of GHG mitigation, there is also increasing interest internationally in replacing coal with char for energy applications in industry and for use in industrial processes, such as the production of iron and steel (Da Costa & Morais, 2006; Mullen, Boateng, Goldberg, Lima, Laird & Hicks, 2010; Sohi et al., 2009). It must be recognised that industrial production processes potentially require high volumes at centralised locations that may not be compatible with char produced from feedstocks that are widely dispersed, and hence this application is not considered further in this study.

2.2 Feedstocks for biochar production

A variety of feedstocks can be utilised for biochar production. Feedstocks currently used at a commercial scale internationally or in research studies include wood chips and wood pellets, tree bark, crop residues (including straw, corn stover, nut shells and rice hulls), switch grass, organic wastes (including grain, bagasse from the sugarcane industry and olive waste), chicken litter, dairy manure, sewage sludge and paper sludge (Yaman, 2004; Das, Garcia-Perez, Bibens & Melear, 2008; Sohi et al., 2009; Shinogi, Yoshida, Koizumi, Yamaoka & Saito, 2002; Bates, Edberg & Nuttall, 2009; Elsayed, Matthews & Mortimer, 2003; Galbraith, 2006; McKay, Hudson & Hudson, 2003; Thornley, Upham & Tomei, 2009; Aylott, Taylor, Casella & Smith, 2009; Barrow, 2012).

Various studies on feedstock supplies for biochar production that are potentially available globally have been conducted (see Woolf, 2008). In India, work is in progress to expand a National Biomass Resource Atlas to check what potential feedstocks are currently being used for biochar production and assess how much there is available. In Brazil, large amounts of biochar may be able to be produced using land that has been cleared, degraded and abandoned (Strezov, Evans & Hayman, 2008). In the Maldives, there are plans to produce biochar



from crop waste and mix it with fish-processing effluent using community-size pyrolysis units. In India, *Jatropha* spp. plantations are being explored for biodiesel, alcohol and biochar (Hooda and Rawat, 2006).

Barrow (2012) proposes that algae could be produced as a biochar feedstock in lagoons using poor-quality water and effluent or exhaust gases from industry or power generation for nutrients. Aquatic plants could also be considered as a raw material for biochar production. Similarly, saline or polluted water that is unsuitable for food crops may support the production of algae or salt-tolerant plants, such as palms, reeds and mangroves for biochar feedstock (Barrow, 2012).

The suitability of a particular biomass resource as a potential feedstock for biochar production depends on various characteristics, such as moisture content, calorific value, fixed carbon, oxygen, hydrogen, nitrogen, volatiles, ash content and cellulose:lignin ratio. Certain feedstock properties, such as size or silica content, can limit the practicality of using it for biochar production (Jirka & Tomlinson, 2013).

The significant abundance of lignocellulosic biomass globally and its suitability for biochar production makes it a widely considered feedstock for this application. Lignocellulosic biomass includes biomass such as agricultural residues (corn stover, crop straws and bagasse), herbaceous crops, woody plants, forestry residue, waste paper and other municipal green wastes that are composed mainly of cellulose, hemicellulose and lignin. The composition and proportions of these constituents vary with the type of biomass (McHenry, 2009; Sánchez, 2009; Mohan, Pittman & Steele, 2006). Feedstocks with a high lignin content produce the highest biochar yields when pyrolysed at moderate temperatures (to the order of 500 °C) (Fushimi, Araki, Yamaguchi & Tsutsumi, 2003; Demirbas & Balat, 2006).

There are noted to be concerns that biochar feedstock production could compete with food production, and hence the decision to use biomass for this purpose needs to take into account the potential for leading to negative food security impacts (Demirbas & Balat, 2006; Hooda & Rawat, 2006; McHenry, 2009; Stamatov & Rocha, 2007). This is particularly important in a developing country like South Africa. Rather than negatively impacting on food production, biochar feedstock options should be chosen in such a way as to help prevent erosion, rehabilitate degraded land and/or improve the habitat for the conservation of wildlife (Barrow, 2012).

The feedstocks offering the best chance of financial viability are often derived from biomass residues such as by-products from agriculture and forestry. In many cases, these residues already present waste management

challenges, and biochar production can therefore be viewed as a potential solution, although it is possible that there may be competition for these feedstocks, for example, for composting or in biorefineries. The largest limitation to the suitability of a feedstock, however, is often the ability to procure it in large and continuous quantities and at low cost. This includes the costs of harvesting and transportation (Day, Evans, Lee & Reicosky, 2005; Das et al., 2008).

2.3 Technologies for biochar production

Biochar is produced via a reaction known as pyrolysis, which is the thermal degradation of biomass in the absence of oxygen. In addition to the primary biochar product, by-products of pyrolysis can include syngas and bio-oil. Different pyrolysis process configurations have been developed, ranging from very basic systems to highly sophisticated equipment that operates on a continuous basis, is optimised to a specific feedstock and for producing a particular product suite, and produces gaseous streams that are clean enough for electricity generation in gas engines. Some examples of equipment configurations are shown in Figure 3.

In the most basic systems, variations of which have been used in rural areas for hundreds of years, biochar production is carried out using batch processes in box kilns, pits and earth mounds, and traditional brick kilns (Garcia-Perez, Lewis & Kruger, 2010). The kiln is loaded with biomass, and heat is produced by combusting part of the feedstock (Ronsse, 2013). Once pyrolysis has been initiated, the process continues autonomously. Traditional kilns are labour-intensive, inexpensive and portable. However, they are inefficient and produce low yields of biochar, have significant feedstock burn-off, and are a source of air pollution, as some of the pyrolysis gases produced are released into the atmosphere (Sparrevik, Adam, Martinsen & Jubaedah, 2015).

Modern processes utilising retort kilns can recirculate pyrolysis gases and combust them internally, reducing local air pollution impacts and sustaining the pyrolysis process. The processes may require the use of start-up fuel to raise the temperature of the pyrolysis chamber and remove water from the biomass before pyrolysis (Sparrevik et al., 2015). For industrial-scale production, automated and continuously operated kilns are used (Ronsse, 2013). Continuous processes result in higher yields of biochar in comparison to batch processes, although these are significantly more expensive and complex than batch processes (Hensley, Gu & Hagan, 2011).

Although batch operations are relatively simple to build and operate, there are a number of disadvantages in comparison to the more sophisticated continuous systems (Ronsse, 2013).



(i) A basic burner at the Sustainable People's Project in Tzaneen. This device can be used as a stove, while at the same time producing biochar.



(ii) A vertical burner at the Sustainable People's Project. Gas from the top of the burner is recycled to the combustion zone as an additional fuel. This unit is configured to recover the bio-oil shown in Figure 4(i).



(iii) A commercial biochar plant in Australia. (Source: <http://www.biorenewal.org/home/biochar-production-technology>)



(iv) A mobile biochar unit in Australia. (Source: <http://energyfarmers.com.au>)

Figure 3: Examples of pyrolysis configurations



The most important differences are the following:

- Product heterogeneity can exist between different batches.
- Heat is not used optimally due to the sequential nature of the heating and cooling stages.
- The composition of the mixture of gases and vapour change throughout the process, which results in the processing or recovery of these vapours being more difficult.

In most pyrolysis units, heat, gas and/or electricity are produced as final products together with the biochar. In larger continuous pyrolysis units, the syngas produced is normally of a quality that is high enough to be combusted in a gas engine to generate electricity. In smaller pyrolysis installations, the syngas is typically burned in the pyrolysis unit to generate process heat, and the waste heat is then captured and sent to an Organic Rankine Cycle (ORC) unit to generate electricity.

The product mix is determined by factors that include temperature, residence time and feedstock type, with the yield and carbon content of the biochar mainly being influenced by the pyrolysis temperature (Roberts, 2010). Table 1 presents a summary of the considerations that determine product yield and distribution from the pyrolysis of biomass. In general, increasing the temperature results in an increase in the carbon content of the biochar product (Lehmann et al., 2006), although biochar yield tends to decrease with increasing temperature, as higher temperatures promote biomass decomposition and favour the yield of liquid and gas components (Mašek, Brownsort, Cross & Sohi, 2013). In terms of residence time, pyrolysis is categorised as slow and fast pyrolysis. Fast pyrolysis takes place in less than two seconds, while slow pyrolysis takes place over a number of hours. Fast pyrolysis is used to produce high liquid and gas yields, while slow pyrolysis produces char as the primary product. Examples of some of the product outputs are shown in Figure 4.

Table 1: Factors impacting on product yield and distribution

Factor	Description
Process configuration	Options include the following: Batch processes where individual batches are heated and cooled sequentially. Batch processes are energy-intensive, as they require reheating every time the reactor is charged. Gases are often released into the atmosphere, which results in the loss of hydrocarbons and causes impacts associated with air emissions. Traditional batch processes used to produce charcoal include pits, earth mounds, and brick and metal kilns. These are easy to construct, but are inefficient, leading to low yields, significant feedstock burn-off and no heat recovery. Modern processes incorporate energy generation and the recovery of gases and liquids. Figure 3(ii) is an example of a batch process configuration. Semi-batch processes, in which removable retorts are inserted inside a stationary firewood box. The pyrolytic vapours are able to escape the retort and enter the combustion chamber, allowing the vapours to generate part of the heat required to drive the process. The heat-containing vapours are recycled between batch reactors. Once the process is complete, the retort can be removed and replaced by another, while it is left to cool. This process configuration has better time efficiencies than batch systems, but is more expensive to install and operate. Continuous processes that result in higher yields of biochar compared to the batch processes. Technologies include drum pyrolysers, screw-type pyrolysers and rotary kilns. Continuous processes are generally more expensive than the other configurations, but produce higher yields over the same time period. Figure 3(iii) shows an example of a continuous process configuration.
Feedstock composition	Biomass is composed of three main polymer groups: cellulose (40 to 50%), hemicellulose (15 to 25%) and lignin (20 to 30%), with the proportion varying, depending on the type of biomass. The remaining 5 to 10% consists of mineral matter and other organic compounds. Lignin is the component that is converted to biochar, while the other components contribute to liquid and gas formation (Van de Weerdhof, 2009)
Temperature	The controlling variable of pyrolysis reaction kinetics is temperature, and the peak temperature has a significant effect on the balance of the liquid and biochar produced. Higher temperatures lead to lower char yields, as more volatile material is forced out of the biomass, reducing the yield, but increasing the carbon in the biochar. Increased temperatures lead to higher liquid yields, up to a maximum temperature value (typically in the range of 400 to 550 °C). Above this maximum temperature value, vapour decomposition becomes dominant and the liquid yields are reduced. Gas yields increase with higher temperatures as vapour decomposition leads to gas production.

Factor	Description
Residence time, gas flows and pressures	Long vapour residence times and low gas flow rates are required to maximise biochar production. High gas flow rates and short vapour residence allow minimal contact time between vapours and biochar, thereby inhibiting secondary char formation and promoting bio-oil formation. The effect of pressure on product distribution follows a similar trend. High pressures result in an increased activity of vapours at the surface of the biochar, leading to increased secondary char formation.



(i) Bio-oils.



(ii) Fine-grained biochar (following a process of grinding to different-sized grains for different uses).



(iii) Larger-sized biochar product.

Figure 4: Products derived from biochar production



It is noted that vacuum and microwave pyrolysis systems for biochar production are in the early stages of development and are not commercially available in South Africa at present. In vacuum pyrolysis, organic material is heated in a vacuum to decrease its boiling point and avoid unwanted chemical reactions. Microwave pyrolysis is best suited for producing higher gas yields with a high syngas content.

2.4 Biochar application to soils

Biochar application to soils is considered in terms of application methods and application rates.

2.4.1 Application methods

Biochar can be applied to soils mechanically, by hand, by means of mechanical equipment or with the assistance of animals (Blackwell et al., 2009). Table 2 summarises the various methods that may be used for biochar application to agricultural soils.

Table 2: Summary of different biochar application techniques

Application method	Description	Potential impacts/benefits
Trench and fill	Cutting trenches and then using a lime spreader or similar device to fill the trenches with biochar (The Biochar Application Network, 2010).	This method may lend itself to high biochar application rates in soil for carbon sequestration. It is labour- and carbon-intensive, but the combination of high saturation rates and improved agronomic productivity may make the practice viable. It is unknown how well biochar migrates vertically through the soil profile, and performance may deteriorate at small distances from the point of application.
Broadcasting/top dressing	Adding biochar to the soil surface can be done by hand on a small scale or on a larger scale by using lime/solid manure spreaders or broadcast seeders.	Hand application is well established, although it is not viable at scale due to the labour intensity. There are human health concerns about hand application due to prolonged contact with airborne biochar particulates. Top-dressed biochar is susceptible to wind and water erosion. Tonnages of biochar application may be relatively low per hectare. Additional equipment would be needed to incorporate applied compost into top soil, increasing costs and the carbon footprint.
Spreading and disking	Conventional agricultural application equipment is used to apply biochar to the soil surface along with a disking pass to enable shallow incorporation of the biochar into the soil.	Several large-scale biochar trials have been conducted using this application method (Blackwell et al., 2009; Lehmann et al., 2009; The Biochar Application Network, 2010). Technology lends itself to careful calibration of output. Concerns surrounding environmental air quality and product loss due to wind and water erosion remain.
Deep banding	This involves applying an amendment in a narrow band without disturbing the entire soil surface. Banding allows biochar to be placed inside the soil, while minimising soil disturbance, making it possible to apply biochar after crop establishment (Blackwell et al., 2009).	The deep banding of biochar has been successfully implemented in several wheat fields in Western Australia. It is a low-impact application method. The biochar is deposited directly into the rhizosphere. Relatively low rates of application are technically possible with one pass. The process is relatively labour-intensive.

When biochar is applied as a soil amendment, it should ideally be incorporated near the surface of the soil, as this is where the bulk of nutrient cycling and uptake by plants takes place. If biochar is to be applied to soil solely for carbon sequestration purposes, however, placement deeper in the soil may be desired (Major, Rondon, Molina, Riha & Lehmann, 2010).

In conventional field cropping systems, biochar should be incorporated into routine operations wherever possible, ensuring that the costs of using biochar are kept as low as possible. For example, biochar can be applied together with lime (Major et al., 2010). The majority of biochar field trials reported to date used this method for incorporating biochar into soil (Yamato, Okimori, Wibowo, Anshori & Ogawa, 2006; Steiner, Teixeira, Lehmann, Nehls, De Macêdo, Blum & Zech, 2007; Asai, Samson, Stephan, Songyikhangsuthor, Homma, Kiyono, Inoue, Shiraiwa & Horie, 2009; Major et al., 2010).

Mixing biochar with other soil amendments, such as manure, compost or lime before soil application, can improve efficiency by reducing the number of field operations required. Since biochar has been shown to absorb nutrients and protect them against leaching (Major et al., 2009; Novak, Busscher, Laird, Ahmedna, Watts & Niandou, 2009), mixing with biochar may also increase the benefits of manure or other soil amendments.

Biochar can also be mixed with liquid manures and applied as a slurry. Fine biochars will likely be best suited to this type of application using existing application equipment, and dust problems associated with these would be reduced. Biochar could also be mixed with manure in holding ponds and could potentially reduce gaseous nitrogen losses as it does when applied to soil (Rondon et al., 2005; Yanai, Toyota & Okazaki, 2007; Spokas & Reicosky, 2009).

Of these methods, some lead to lower soil carbon emissions from soil disturbance than others. This CO₂ emission potential is important to take into consideration when considering the overall mitigation potential of biochar. Banding and broadcasting are argued to be the application methods with the lowest carbon emissions, while methods such as spreading and disking, which result in topsoil mixing, have higher emission rates (Blackwell et al., 2009).

2.4.2 Application rates and frequency of application

The key factor that limits the amount of biochar that can be applied to soils is not related to sequestration, but rather to the impact of biochar on plants growing in the soil. Several studies in the published literature on biochar for use as a soil amendment have reported positive effects of biochar application on crop yields at rates of 5 to 50 tonnes of biochar per hectare, with appropriate nutrient management. This is a large range, but often when several rates are used, areas with higher biochar application rates show better results (Chan, Van Zwieten, Meszaros, Downie & Joseph, 2008; Major et al., 2010). De Gryze et al. (2010) showed that an application rate of 5 tonnes of biochar per hectare can decrease fertilizer needs by 7% as a result of increased nutrient availability. The maximum amount of biochar that can be applied to soil has been assessed by Lehmann et al. (2006), who state that even with very high application rates of biochar (up to 14 tonnes of carbon per hectare), crop yield improvements can be achieved with no registered negative impacts.

Instances of decreasing yield due to a high biochar application rate have, however, been reported. Rondon, Lehmann, Ramírez and Hurtado (2007), for example, showed a decrease in crop yield when the equivalent of 165 tonnes of biochar per hectare was added to poor soils in a pot experiment. This, however, is a very large amount that is unlikely to be practically feasible in the field, at least not for a one-time amendment. Similarly, Asai et al. (2009) reported greater rice yields with 4 tonnes per hectare of biochar, but when 8 or 16 tonnes per hectare of biochar were applied, yields were no different from the unamended control. A more recent field study on a poor, acidic soil in the USA showed that peanut hull and pine chip biochar applied at 11 and 22 tonnes per hectare could reduce corn yields below those obtained in the control plots, under standard fertilizer management (Gaskin, Speir, Harris, Das, Lee, Morris & Fisher, 2010). The reasons for such a decrease remain to be fully explored.

It is noted that, unlike manure, compost and fertilizers, a single application of biochar can be beneficial over several growing seasons due to its resistance to decomposition in soils (Major, 2010). However there is no conclusive statement that can be made as to whether larger applications of biochar in a once-off application or smaller application amounts over a number of years are more effective.



3. Biochar production and application in South Africa

3.1 Feedstocks suitable for biochar production

As described in Section 2.2, a wide range of feedstocks can theoretically be converted into biochar. The initial list of potential feedstocks for consideration in this study, along with the motivations for inclusion in or exclusion from the study, is shown in Table 3. The shortlisting was based on the outcomes of stakeholder consultation, literature and feedback from the Project Steering Committee. It is noted that, when considering whether production of biochar at scale from any of these feedstocks is potentially feasible in South Africa, one of the key factors that needs to be taken into account is the likelihood of feedstock procurement.

Table 3: Feedstocks considered and shortlisted in the study

Feedstock	Included in the study?	Motivation for inclusion/exclusion
Invasive alien vegetation	Yes	IAV is causing billions of rands of damage to South Africa's economy annually through the negative impact it has on water resources and biodiversity, among others (Department of Water Affairs, 2013). Large-scale efforts are underway to clear this vegetation at great cost through the Working for Water (WfW) Programme. Biochar production has been identified as an opportunity to add value to this resource and recover some of the cost of clearing.
Manure	No	Manure can be very costly to collect. It is often very wet and requires high levels of energy input to dry. There are also many competing uses for manure, such as energy production through biodigestion.
Organic waste (municipal solid waste, urban wood residue)	No	There is a risk of contamination by toxic substances and heavy metals when using municipal solid waste and urban wood residue. These feedstocks may be suitable for use as carbon sink only (for example, in landfill sites), but may not be suited to soil application. There are also competing uses for organic waste, such as composting.
Crop residue (wood chips, corn stover, paper mill sludge and most urban, agricultural and forestry biomass residues)	Yes – residue from sawmills only	Residue from the forestry sector (particularly residue from sawmills) typically present a huge waste management challenge, and the practices currently used (dumping and open burning) result in a deterioration of air quality and water pollution, with the associated secondary impacts. The recovery of energy and the production of biochar offer a potential solution to managing these sources of waste, which not only address the environmental issues, but recover value from an otherwise wasted resource. This waste stream has a further advantage in that it is already concentrated at central locations. Harvesting and transport costs are thus avoided. The other crop residues listed usually have higher-value uses and are already accounted for. Agricultural residue is typically left on the field to reduce moisture loss from the soil and provide nutrients for the following season.
Bioenergy crops, with a focus on those that do not compete with food production	No	The planting of bio-energy crops could displace native ecosystems and people, and also potentially affect water use. There are also problems associated with monocultures and concerns around genetically modified species.

On the basis of the information shown in Table 2, alien invasive plants and sawmill waste were identified as the preferred feedstocks to explore in this study. Further information on these two biomass resources are presented in the subsequent sections.

3.1.1 Alien vegetation

Of the estimated 9 000 plants introduced into South Africa, 198 are currently classified as being invasive. It is estimated that these plants cover about 10% of the country's surface area, with coverage growing at an exponential rate (Department of Water Affairs, 2013). It is suggested that IAV is the single-biggest direct threat to South Africa's biodiversity and threatens water security, the ecological functioning of natural systems and the productive use of land. IAV species increase soil erosion and intensify the impacts of fires and floods. IAVs can also divert enormous amounts of water from more productive uses (Kotzé, Beukes, Van den Berg & Newby, 2010). A range of alien species is typically present in any one area, with one or more species potentially dominating.

3.1.1.1 Suitability of alien vegetation for biochar production

IAV species include both hardwoods and softwoods, of which the former are better suited to biochar production as they give rise to biochar products with greater structural integrity. It has been suggested that most of the biomass that would be available for biochar production will come from invasions by *Acacia* and *Eucalyptus* species, with relatively low contributions from other groups¹. Furthermore, a 2001 report conducted for the Department of Water Affairs and Forestry (2001) suggests that straight and bent wood stems and heavy branches of the *Acacia* species are particularly well suited to pyrolysis. Having said this, softwoods can also be used for biochar production, particularly for biochar applications where product integrity is less of an issue.

Some research into the production of biochar from different IAV species has already been conducted in South Africa. *Pinus*, *Eucalyptus* and *Acacia* species have all been demonstrated to be suited to biochar production (Sika & Hardie, 2014; Carrier, Joubert, Danje, Hugo, Gorgens & Knoetze, 2013; Uras-Postma, Carrier & Knoetze, 2014).

3.1.1.2 Feedstock availability

Kotzé et al. (2010) conducted a national survey to assess the extent of coverage of alien vegetation and help provide insight into the amount and types of IAV available in South Africa. The study sampled land coverage using field surveys conducted from an aircraft. The results were then extrapolated based on knowledge of the association between individual species and the environment, including soil type, terrain and climate.

In 2012, the Council for Scientific and Industrial Research (CSIR) developed a national resource map for woody biomass distribution in South Africa using data from the Kotzé et al. (2010) study. The aim of this initiative was to assess, manage and monitor the sustainability of bio-energy in the country (Von Maltitz & Stafford, 2012). The study concluded that there is approximately 165 million tonnes of woody IAV available in South Africa, spread over about 44 million hectares, giving a mean IAV biomass standing stock of about 3.7 tonnes per hectare with a range from 0 to 228 tonnes per hectare.

Table 4 highlights the important groups of IAV in South Africa, and indicates the estimated area of invasion, as well as the projected number of years that will be required to treat the invasion. As indicated later in this report, the wide coverage in terms of area translates to a substantial tonnage of feedstock availability, with the tonnes of feedstock that can be recovered per hectare varying depending on the biomass density, as well as factors such as accessibility. Furthermore, the long time periods required for clearing indicates that a biochar or energy recovery industry built on IAV in certain parts of the country could be sustainable for a period of decades.

¹ Personal communication: William Stafford (CSIR), April 2015.

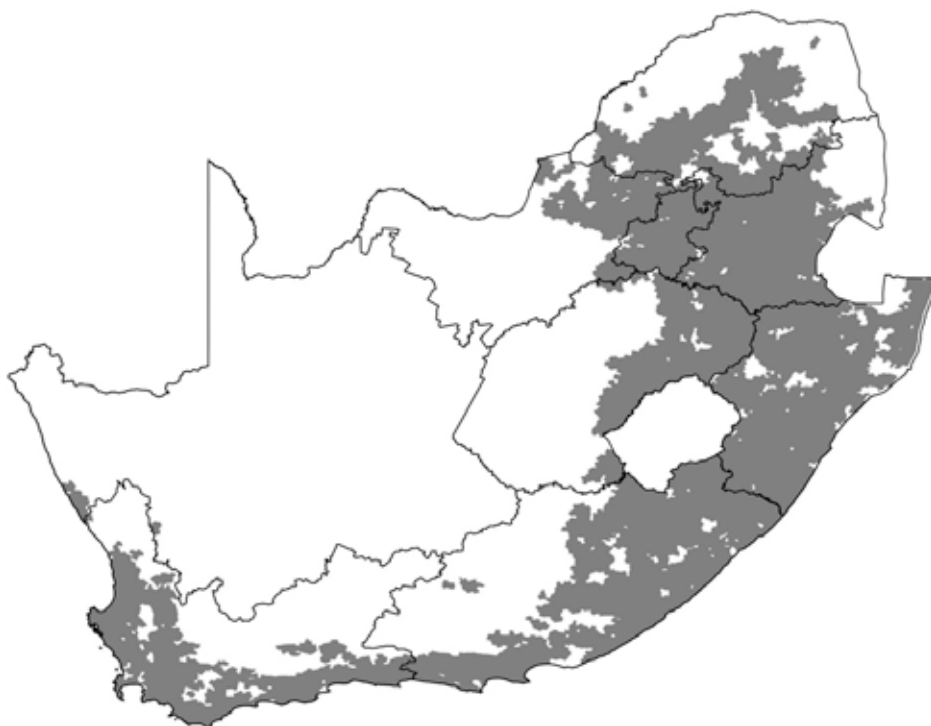


Table 4: IAV species invasion in South Africa

IAV species/genus	Estimated area in South Africa (hectares or equivalent 100% cover)	Predicted time needed to treat the national infestation (years)
Acacia species (Australian wattles)	719,979	31
<i>Cereus jamacaru</i> (queen of the night cactus)	21,950	1.3
<i>Lantana camara</i>	69,268	7
Eucalyptus species	62,949	13
Pinus species	77,093	22
<i>Chromolaena odorata</i>	43,227	15
<i>Solanum mauritianum</i> (bugweed)	89,491	23
Prosopis species (mesquite)	173,149	38
Populus species (poplar trees)	15,235	18
Hakea species	64,089	63
<i>Melia azedarach</i> (syringa)	72,625	83
<i>Rubus</i> species (bramble)	26,461	23

Source: Marais, Van Wilgen and Stevens, 2004

Figure 5, which was developed for this report, shows the geographic distribution of woody IAV as a feedstock in South Africa as the shaded areas. Unfortunately, the data is not available to disaggregate by species type. It is recognised, however, that the densities of woody IAV vary greatly, as do the physical properties of the environment in which it grows. As indicated above, factors including slope, access and land ownership will all affect the cost of recovering this biomass, and hence the financial viability of producing biochar from these areas. Note that not all the species listed in the table above are woody, and would hence be excluded from the mapping in Figure 5.



Source: Map developed for this study using data provided by the CSIR for the compilation of the South African Environmental Observation Network (SAEON)/Department of Science and Technology (DST) Bioenergy Atlas².

Figure 5: Distribution of woody IAV in South Africa

² Provided by William Stafford (CSIR) (personal communication).

3.1.1.3 Harvesting costs

There are a number of costs associated with the harvesting, extraction, chipping and transportation of IAV. Mugido, Blignaut, Joubert, De Wet, Knipe, Joubert, Cobbing, Jansen, Le Maitre and Van der Vyfer (2014) present an indication of the range of costs for a specific alien-clearing project in the Nelson Mandela Metropolitan Municipality. The clearing of IAV took place within a 50 km radius of the Coega Industrial Development Zone. Table 5 gives a breakdown of the harvesting and extraction, chipping and transportation costs of various IAV species from this study. As can be seen from Table 5, the cost of harvesting and extraction, chipping and transportation varies widely depending on the species, as well as site density, tree sizes and slope (Mugido et al., 2014). On average, harvesting and extraction makes up 49% of the total costs, followed by chipping (33%) and transportation

(18%). In general, the cost of clearing increases substantially with the density of the invasion, and approximately 57% of the harvesting costs are a result of clearing large trees (Marais, Van Wilgen & Stevens, 2004). Chipping costs depend on operational issues such as road conditions, access and transport.

Mugido et al. (2014) based the transportation costs on the actual realised cost of transportation from the harvesting site, with distances varying between 30 and 50 km. The unit costs varied from R1,09/tonne.km to R4,63/tonne.km, with an average of R2,50/tonne.km. This is higher than the industry average of R1,10/tonne.km (Mugido et al., 2014). The higher cost of transportation is most likely a result of the method used, such as outsourcing to a contractor who uses non-customised bins (Mugido et al., 2014).

Table 5: Costs of clearing, chipping and transport of various IAV species

Class/ species	Harvesting and extraction (ZAR/ha)		Chipping (ZAR/ha)		Transport (ZAR/ha)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
<i>Acacia longifolia</i>	25 403	43 487	13 678	23 340	9 513	14 853
<i>Acacia mearnsii</i>	15 431	21 097	5 831	22 045	2 433	8 834
<i>Acacia saligna</i>	5 046	14 274	2 545	5 081	2 579	3 089
Acacia	7 726	20 093	8 696	20 009	4 176	11 773
Acacia	13 812	21 523	10 976	11 285	6 597	6 951
Eucalyptus						
Pinus						
Acacia	8 135	15 048	8 567	27 027	4 874	13 819
Pinus						
Eucalyptus	8 644	34 502	3 863	21 245	1 468	16 522
Acacia						
Eucalyptus	19 719	23 083	18 957	43 312	10 784	12 721
Acacia						
Pinus						

Source: Mugido et al., 2014

3.1.2 Sawmill waste

3.1.2.1 Feedstock availability

In the processing of felled trees in sawmills, approximately 50% of the logs become waste wood material, with waste streams including sawdust, woodchip, bark, planer shavings and pole shavings. As such, the industry gives rise to large volumes of waste material that could be used to produce biochar or for energy recovery (Biomass Producer, 2013). Table 6 provides an indication of the scale of sawmill waste or residue biomass produced per annum in South Africa (Sawmilling South Africa, 2011). A proportion of the residue biomass is often used for steam production in the sawmilling process. However, it is estimated that between 1 000 000 and 1 500 000 tonnes per annum still remains and is potentially available for the production of biochar (Sawmilling South Africa, 2011). This estimation correlates with the data used in the Bioenergy Atlas produced by SAEON³.

³ Provided by William Stafford (CSIR) (personal communication).



Table 6: Sawmill waste produced per annum

Industry intake	Percentage of intake wood on a mass basis	Tonnes of output
Chip produced for sale	17	720 000
Sawdust and shaving	19	780 000
Bark	12	500 000
Solid wood	4	175 000
Total residue biomass	52	2 175 000

Figure 6 below shows the location of sawmills in South Africa. The boundaries shown represent the municipal boundaries in South Africa. The sawmills are mainly concentrated in Limpopo, Mpumalanga, KwaZulu-Natal and the Western Cape, hence it is these provinces that offer the greatest potential to produce biochar from sawmill waste.



Source: Map generated for this report using data provided by DAFF⁴

Figure 6: Location of sawmills in South Africa

⁴ Provided by DEA (personal communication).

3.2 Technologies for biomass production and energy recovery from biomass in South Africa

As described in Section 2.3, a wide range of potential technologies is available to produce biochar. For the analysis in this study, two groups of technologies were considered for biochar production in South Africa that are considered to form the “outer bounds” of what is possible, with a range of options being found in between. These technology groupings are as follows:

- Small-scale, simple, decentralised pyrolysis units, which are typically home-made and are already widely deployed for the production of charcoal
- Large-scale sophisticated pyrolysis units

The latter has the advantage of being easier to control, and to offer the greater potential for the simultaneous recovery of energy products in the form of bio-oil and biogas.⁵

In addition to the pyrolysis technologies considered for biochar production, gasification for electricity production from the biomass stream was considered for the comparison of the economic profiles. Gasification is similar to pyrolysis, but operates at higher temperatures and is optimised for high-quality syngas production that can be used in a gas engine for electricity generation. Some gasification installations can be modified to produce biochar, but most of them are optimised to only yield the gas product.

3.3 Potential areas for biochar application

This study now considers which soil types and areas may be best suited for the application of biochar. The first recommendation that was made, based primarily on interaction with stakeholders, is that biochar should be used on cultivated land, for two reasons. The first of these is to take advantage of the soil amendment benefits as discussed previously (even though these are not readily quantified), and the second is that it is preferable not to disturb existing vegetation for the sole purpose of adding biochar. The first task, therefore, was to map out the cultivated land in South Africa (see Section 3.3.1).

As indicated previously, international studies have found that the impacts of biochar applied as a soil amendment for crops range from highly positive to neutral and sometimes even negative (Sohi et al., 2009). These observations seem to indicate that different biophysical

interactions and processes occur when biochar with different chemical and physical properties is applied on different soil types, which makes it difficult to generalise about when and where biochar may find the best application. Furthermore, in deciding which specific soil types used for cultivation in South Africa are best suited to biochar application, it is recognised that little data exists on the interactions between biochar and particular South African soil types. It is also difficult to correlate findings from studies done internationally with South African soil types.

Peake et al. (2014), however, suggest that it is the physical properties of the soil that are likely to determine its suitability for biochar application. Other literature indicates that the greatest improvements in crop yields from biochar application that have been demonstrated repeatedly are for acidic and sandy soils, and so it is soil types with these properties that of greatest interest in this study (Lehmann et al., 2006; Rondon et al., 2007; Steiner et al., 2007; Kimetu, Lehmann, Ngoze, Mugendi, Kinyangi, Rika, Verschot, Recha & Pell, 2008). Furthermore, as discussed previously, biochar has benefits for soils with a low WHC. Finally, the potential for soil erosion is considered significant in the potential for soils to retain biochar. The distribution of the different soil types is explored in Section 3.3.2.

Both the areas of cultivated land and the target soil properties are mapped out using Geographic Information System (GIS) plots to show their spatial distribution. In Chapter 4, the individual factors are considered concurrently, and their intersection is considered along with the results of a techno-economic analysis to provide further mappings of the potential areas and soils for biochar application in South Africa.

3.3.1 Cultivated land

The geographic distribution of cultivated land in South Africa is largely climate-driven and covers approximately 12 033 000 hectares of the total land area in South Africa. Distribution data of irrigated and dryland agriculture, as well as forestry in South Africa, was combined to give an indication of the total area where biochar can potentially be applied as a soil amendment. Figure 7 shows the geographic distribution of land currently under cultivation in South Africa. Note that the darkness of shading represents a higher concentration of cultivated land, while lighter shaded areas mean that cultivated land is more widely distributed.

⁵ It is noted that both of these products can also be recovered from the small-scale systems, however, with less product consistency. Hence, their recovery is excluded for the purposes of this analysis. Having said this, the authors are aware of at least one site where the bio-oil recovered from biochar production is potentially finding a market as a creosote replacement for wood preservation. See the pilot project described in Appendix C for details.



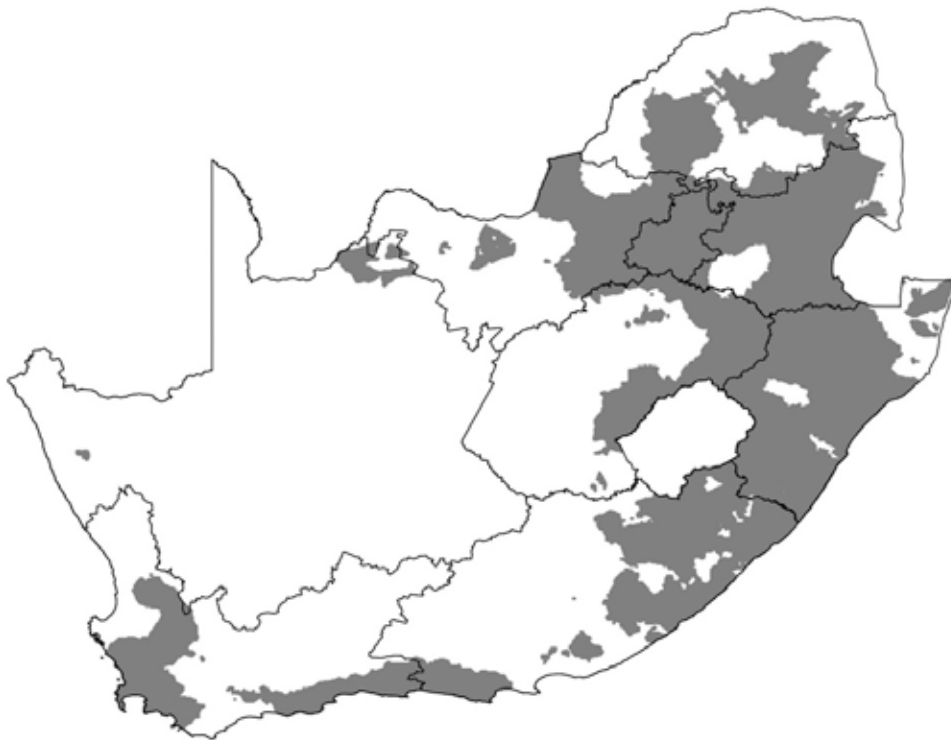
Source: Map generated for this study using data from the Agricultural Research Council (ARC) (Agricultural Research Council, 2014)

Figure 7: Distribution of cultivated land in South Africa (2014)

3.3.2 South African soil types suitable for biochar application

Data was collected and compiled on the distribution of soils with properties suitable for biochar application. As discussed above, although increased crop yields as a result of biochar addition have been reported in many different soil types, the greatest and most consistent improvements in yields are found in acidic soils, sandy soils and soils with low WHC (Roberts et al., 2010). Soil erosion potential was also considered to be important here.

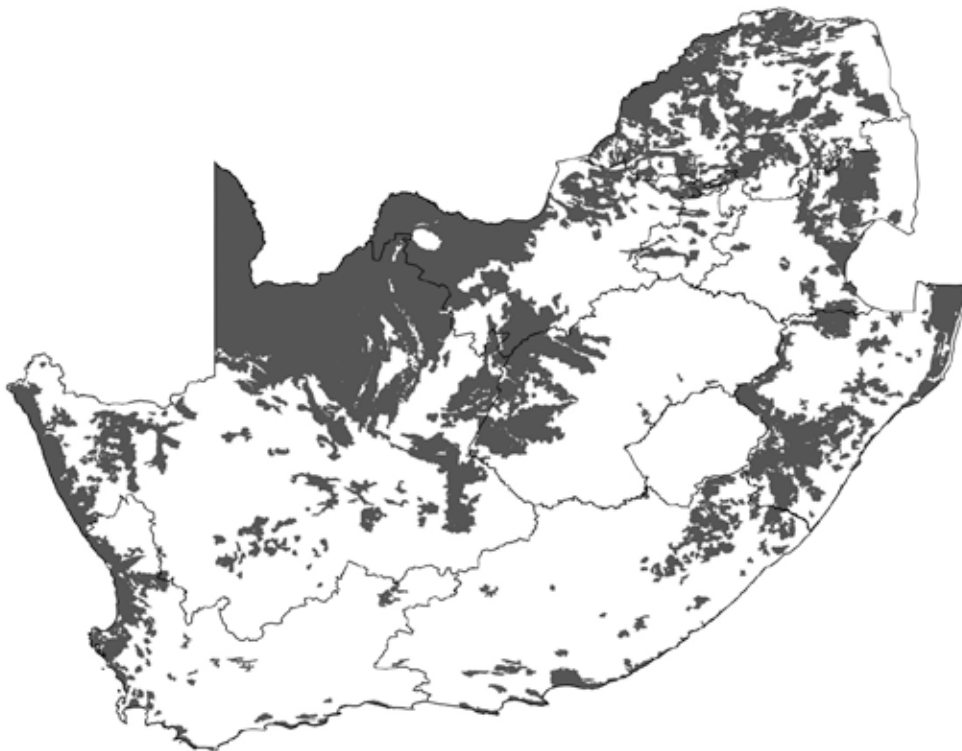
Soil acidity adversely affects plant growth, and nutrient availability is linked to soil pH (Schroeder et al., 1994). During the pyrolysis process, base cations in the biomass are transformed into oxides, hydroxides and carbonates, and mixed with the biochar (Laird et al., 2010). These bases function as liming agents when applied to the soil and increase pH, and so can provide benefits when applied to acidic soils (Laird et al., 2010). For these reasons, data was collected on soil acidity at a national scale, and an output was created showing acidic soils ($\text{pH} < 7$) in South Africa (Figure 8). As there is no conclusive evidence on the effects of biochar on particular ranges of acidity in soils, all acidic soils were included with the assumption that biochar application would be equally viable regardless of acidity level.



Source: Map generated for this study using data from the ARC (Agricultural Research Council, 2014)

Figure 8: Acidic soils in South Africa

Similarly, data was compiled and an output produced showing sandy soils and soils with low WHC in South Africa. This is shown in Figure 9.

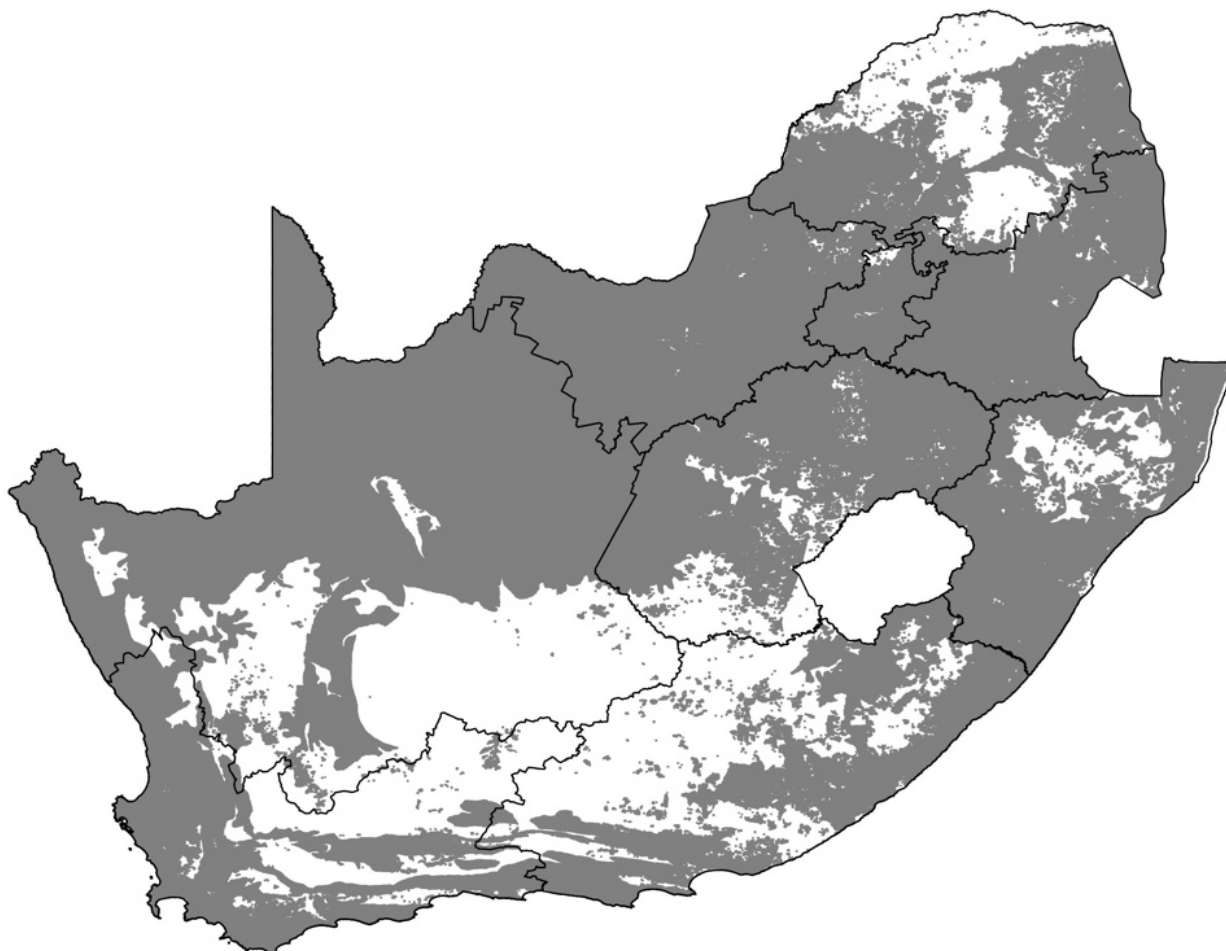


Source: Map generated for this study using data from the ARC (Agricultural Research Council, 2014)

Figure 9: Distribution of sandy soils and soils with low WHC in South Africa



Finally, given that the stability of biochar in soils is an important factor to consider when using biochar as a soil amendment, it has been assumed that it is preferable to add biochar to soils that are stable and not prone to erosion under current climatic conditions. A map output was produced showing the geographic location of soils that have a low to very low probability of erosion under current climatic conditions (Figure 10).



Source: Map generated for this study using data from the ARC (Agricultural Research Council, 2014).

Figure 10: Soils with very low to low potential for erosion

In Section 4.4 the information presented above is overlaid and discussed in terms of the economic analysis to provide an overall indication of the best-suited areas for biochar application.

Despite these observations, however, it is noted that the majority of soils in South Africa are low in soil organic content, and so biochar application may help boost productivity in most areas. Soil degradation is also severe in South Africa, and acidification is becoming an increasingly major problem (Schroeder et al., 1994). As a result, soil fertility, for both small-scale and commercial cropping, is a serious issue (Department of Environmental Affairs, 2010). Most agricultural lands in South Africa could therefore potentially benefit from biochar application.

4. Techno-economics of biochar production

This section of the report explores considerations related to the economic viability of the production of biochar from the two different target feedstocks at two different scales of production. These two scales of production technologies are consistent with those discussed in Section 3.2. For larger, centralised biochar production facilities, the co-production of electricity or heat is also included in the analysis. As indicated previously, the use of the biomass stream for electricity production via gasification is also presented for comparison.

The economic analysis was conducted using an Excel model that was built for this purpose. The model was designed and populated using a combination of information found in the open literature, data gathered during site visits and information obtained from technology providers. The remainder of this section describes the value chains that were modelled, presents an overview of the model and discusses the model outputs.

4.1 Description of the value chains

From the two different feedstocks identified in Section 3.1 (IAV and sawmill waste) and the three thermal biomass conversion technologies presented in Section 3.2, six value chains were constructed for the assessment of the comparative economics of energy recovery and biochar production. These value chains are described in Table 7. Data was gathered from a single technology provider to populate the model for each of the value chains, as indicated in the table.

Table 7: Value chains chosen for analysis

No.	Feedstock	Process	Products	Technology provider	Comments
1.	IAV	Pyrolysis (mobile)	Biochar	Vuthisa Technologies	The technology considered is a mobile unit that generates biochar at the harvesting site. The biochar may then be buried at the site where it is generated, or transported elsewhere for use.
2.	IAV	Pyrolysis	Biochar, electricity	Thermex Carbontech	IAV is harvested and transported to a centralised pyrolysis unit where biomass is chipped, dried and converted to biochar and a gas stream, which is used for the recovery of electricity. Electricity is generated via an ORC. This technology has less stringent feed requirements and comes at a lower capital investment than the gasification process of Prestige Thermal (value chains 3 and 6), but also has a lower overall efficiency. The process yields very high-quality biochar and, without changes to the equipment, can be optimised for either biochar or electricity production. This value chain was simulated for average values of all products produced and not optimised for specific product production.
3.	IAV	Gasification	Electricity	Prestige Thermal	The IAV is harvested and transported to a centralised gasification unit where the biomass is chipped, ground, dried and gasified. The gas is then converted to electricity. No biochar or bio-oil is produced. Electricity is generated via a gas engine. Heat recovered from the process is used to generate additional electricity via a steam turbine.
4.	Sawmill waste	Pyrolysis	Biochar, electricity	Thermex Carbontech	Similar to Value Chain 2, except that no costs are incurred in harvesting or transporting the feedstock. The pyrolysis unit will be situated at the sawmill where the waste is generated.



No.	Feedstock	Process	Products	Technology provider	Comments
5.	Sawmill waste	Pyrolysis	Biochar, process heat	Thermex Carbontech	Similar to Value Chain 4, with changes being the removal of the harvesting and transportation steps and the omission of the ORC unit. This results in a much lower capital cost, and process heat is produced instead of electricity. This route should only be considered at industrial sites where there is a use for the generated heat.
6.	Sawmill waste	Gasification	Electricity	Prestige Thermal	The same as Value Chain 3, except that no harvesting or transportation is required. The gasification unit will be situated at the sawmill where the waste is generated.

4.2 Model description and key assumptions

This section presents the key model input data and assumptions for each value chain. These are considered in terms of the following:

- Feedstock (Section 4.2.1)
- Harvesting (Section 4.2.2)
- Transportation of the feedstock to the site (Section 4.2.3)
- Pre-processing of biomass and conversion technologies (Section 4.2.4)
- Products and potential markets for these products (Section 4.2.5)

The model financial input parameters and output indicators calculated for evaluating the economic performance of the different value chains are discussed in Section 4.3.

The GHG emissions for each value chain were also calculated in the model for the purpose of comparing the carbon offset potentials of the different value chains and for the inclusion of a carbon price in the economic assessment. The methodology for the calculation of the emissions is explained in Appendix A4.

The economic performance of each value chain was assessed by calculating the price at which the various products need to be sold in order for the project to achieve a target internal rate of return (IRR). In the value chains with only one product (biochar or electricity), the required selling price of this product is determined to obtain the desired IRR. For value chains with more than one product (biochar and electricity or biochar and process heat), an assumption was made that the electricity or heat is sold at current market prices, and the selling price of biochar was then calculated to achieve the target IRR.

4.2.1 Feedstock properties

Value chains 1, 2 and 3 utilise IAV, and value chains 4, 5 and 6 utilise sawmill waste. Harvested IAV is assumed

to have an initial moisture content of 50% (weight percentage) (based on stakeholder inputs), while the sawmill waste is assumed to have a sun-dried moisture content of 20% w/w. Both feedstocks were assumed to have an average gross calorific value of 19 MJ/kg⁶.

4.2.2 Harvesting considerations and costs

Harvesting is only relevant for the value chains utilising IAV as feedstock (value chains 1, 2 and 3). The type of feedstock, the density of the feedstock on the land (tonne per hectare), the topography of the land, the cost of equipment and fuel required, and the cost of labour all determine the approach used for harvesting and its cost. All these factors vary significantly across the different vegetation landscapes across South Africa. Data from a recent local study by Mugido et al. (2014) was used to derive a harvesting cost from a specific harvesting density. For the purposes of modelling the harvesting cost of value chains 1, 2 and 3, the harvesting density was fixed at 50 tonne per hectare to avoid having to simulate a range of harvesting densities for each value chain. This value was chosen as it falls in the middle of the range of data from literature. Using the relationship between harvesting density and cost (as derived from literature), an indicative harvesting cost of R17 000 per hectare at 50 tonne per hectare harvesting density was determined for use in this study. See Appendix A1 for more details on the relationship between harvesting cost and harvesting density.

The IAV density data was based on the dataset developed for the SAEON/DST Bioenergy Atlas⁷, which, in turn, used data from the National Invasive Alien Plant Survey (Kotzé et al., 2010). Species of interest (woody biomass) were mapped on a national scale and information was extracted on the densities of the invasions. Finally, this data was summarised spatially (see Figure 5).

For the purpose of this study, the data was further aggregated and mapped onto the mesozone framework

⁶ http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,177178&_dad=portal&_schema=PORTAL
⁷ Provided by William Stafford (CSIR) (personal communication).

developed by the CSIR (Naudé, Badenhorst, Zietsman, Van Huyssteen & Maritz, 2007). It is important to note that the current data can only give an indication of relative densities in South Africa. The actual densities are likely to be slightly higher than those used in this study. For the purpose of this study, however, which aims to provide a baseline assessment, these relative densities are sufficient as they highlight potential areas where further, regional-scale assessments should be conducted.

For identifying the land areas in South Africa where specific IAV biomass densities could be harvested, a conservative assumption was made that only 50% of the available biomass, as estimated from the data underpinning the GIS mapping, can be harvested. This means that land with a total biomass density of 100 tonne per hectare will only allow for a total harvest of 50 tonne per hectare.

Information from stakeholders was used to inform the labour requirements associated with harvesting biomass. Based on this information, a value of 500 kg was used as the average quantity of biomass that can be harvested per person per day, although it is recognised that this will vary vastly depending on the terrain and type of biomass. It was further assumed that harvesting would only be done for eight hours a day.

See Appendix A1 for more details on the assumptions and data on harvesting of IAV.

4.2.3 Transportation

The transportation of harvested IAV is once again only applicable to value chains that utilise IAVs and require transportation to a central processing site (value chains 2 and 3) and not to those utilising sawmill wastes as feedstock. Based on stakeholder consultation, a conservative maximum harvesting radius of 50 km was used for modelling and a sensitivity analysis was conducted on Value Chain 2 for a varying harvesting radius (see Section 4.3.2). An average transportation cost of R2,06 per tonne.km, derived from Road Freight Association (RFA) data, was used in the modelling. See Appendix A2 for more details on data and assumptions used in the modelling for the transportation of biomass.

4.2.4 Pre-processing and biomass conversion technologies

Pre-processing entails chipping and drying the biomass to the desired particle size and moisture content to adhere to the pyrolysis/gasification technology specifications. For all AIV, it was assumed that biomass would be dried in the field. Only for the Vuthisa Technologies mobile pyrolysis units is there no pre-processing required; chunks of wood are fed into the pyrolysis kiln without requiring chipping or drying. For the other centralised technologies

utilising either AIV or sawmill waste, the cost of drying and chipping equipment to achieve the feedstock requirements of the individual technologies has been factored into the technology capital cost.

As indicated above, technical specifications and cost information for the different biomass conversion technologies were obtained from the technology service providers. This information is presented in Appendix A3.

4.2.5 Product value and potential markets

The product value and potential markets for the char products and the energy by-products (heat, electricity and gas) are considered separately.

4.2.5.1 Sale of the char product

The financial value of biochar can be realised in one of two ways:

- Bury it in the ground for the purpose of carbon capture only, potentially with the sale of the carbon credits generated.
- Use it as a part of or total substitute for fertilizers in agriculture.

As a further case, consideration is given to burning the char product directly as charcoal, which acts as a substitute for coal in industrial applications.

At present, there is no formal market for biochar, and hence no definitive comments can be made as to the market value for the above applications. For the purpose of this analysis, therefore, a number of assumptions are made, including using the value of alternative products that biochar may replace.

The lowest potential value of biochar is likely be realised if it is buried in the ground for the purpose of carbon capture only. In this case, the value will be realised by selling the carbon offsets achieved by sequestering carbon in the biochar, and the price will be linked to the market price per tonne of CO₂e that can be achieved. Although there are various carbon markets internationally, South Africa does not currently have an established market⁸. In the proposed South African carbon tax⁹, allowance has been made for companies to offset part of their carbon tax liability with the purchase of carbon offsets. A potential South African carbon market that will trade through the Johannesburg Stock Exchange is under investigation¹⁰. Although the proposed initial carbon tax price is R120 per tonne of CO₂e¹¹, it is assumed that the market

8 Selling carbon credits into a carbon market is subjected to an approved emission reduction methodology for biochar. At present there are no internationally approved methodologies available for this purpose.

9 <http://www.bdlive.co.za/economy/2015/04/08/treasury-stands-firm-over-carbon-tax>

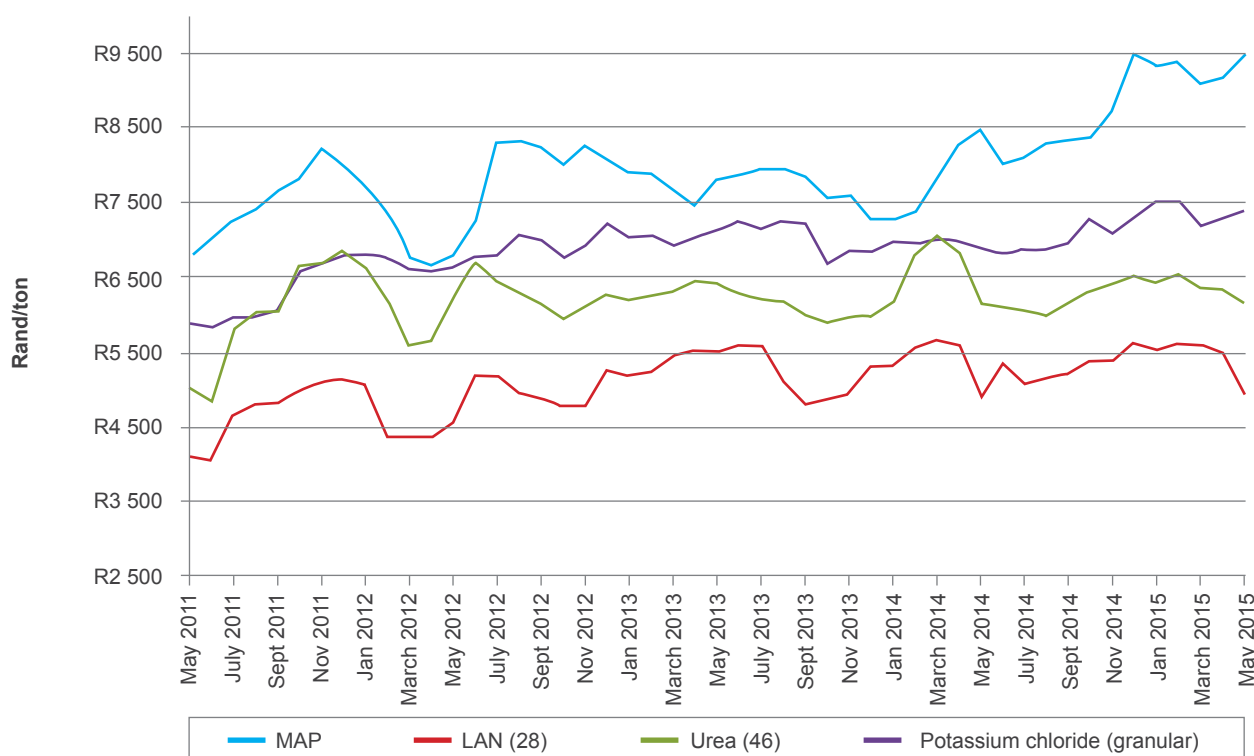
10 <http://www.sagreenfund.org.za/wordpress/wp-content/uploads/2015/04/Carbon-Trading-in-SA.pdf>

11 <http://www.treasury.gov.za/public%20comments/Carbon%20Tax%20Policy%20Paper%202013.pdf>



price for carbon trading will be slightly below the tax price to create a market demand for carbon offsets (rather than companies just paying the tax). For the modelling, the carbon price was conservatively assumed to be R100 per tonne of CO₂e in 2016, increasing with inflation annually. Based on the carbon content of the biochar from each technology supplier (see Appendix A3) and the assumption of the sequestration potential of carbon in the soil of 74% over 100 years, the value of biochar, when sold for sequestration using Vuthisa Technologies' unit, will be R197 per tonne, while using Thermex Carbontech's unit, it will be R218 per tonne. See Appendix A4 for more details on the calculation of the carbon sequestration potential of biochar.

If used to reduce the need for fertilizer application, a comparison can be made of the current price of fertilizer. If a 1:1 fertilizer replacement ratio is assumed (refer to Appendix A4 for more details on this assumption), the value of the biochar could vary between R5 000 and R9 500 per tonne, depending on the type of fertilizer replaced¹² (see Figure 11 for the historical price of the most common fertilizers in South Africa). This use of biochar will also result in carbon capture, but for the purposes of providing a conservative picture of the value of biochar, the carbon value was excluded if sold for the purpose of replacing fertilizer.



MAP: Mono-ammonium phosphate

LAN: Limestone ammonium nitrate

Source: Standard Bank, 2015

Figure 11: Fertilizer price history

The highest potential value of biochar would be realised if it were to be sold on the international markets. The average international wholesale price for biochar in 2014 was \$2,06/kg (R22 000 per tonne in 2014)¹³. This figure is, however, based on data from various international markets and is understood to have large variation associated with it, and should be treated with caution.

Finally, as indicated previously, the case was considered for using biochar as a charcoal for direct burning. Prices of charcoal vary widely. For reference here, a comparative value of R4 800 per tonne¹⁴ was assumed.

¹² Standard Bank, 2015, <http://bizconnect.standardbank.co.za/sector-news/agriculture/articles/agribusiness-price-updates-june-2015.aspx>

¹³ International Biochar Initiative, 2012, http://www.biochar-international.org/State_of_industry_2014

¹⁴ Selling prices vary widely with one stakeholder suggesting this value is for retail sales, while others suggest that this is closer to a wholesale value. For the purposes of the analysis, this is assumed to be a wholesale price.

4.2.5.2 Electricity and heat

The electricity generated as a by-product in the biochar production projects is assumed to replace grid electricity, and the selling price of electricity from these projects was assumed to be similar to the 2015 average grid electricity price of R0,90 per kWh. It is noted that this is a conservative estimate, as in the latest Renewable Energy Independent Power Producer Procurement (REIPPP) preferred bidders announcement (Bid Window 4 announced on 16 April 2015), the fully indexed power purchase price for the only approved biomass project was R1,45/kWh¹⁵. This higher price is, however, subject to the project being selected for the REIPPP project and a power purchase agreement being in place, which may be difficult conditions for biochar projects to realise. Although a project of this size will most likely fit into the Small Projects Independent Power Producer (IPP) Procurement Programme, which is for projects between 1 MW and 5 MW generation capacity, no preferred bidders have been announced for this programme to date, and therefore no electricity prices are available to use for comparison in this study. If higher prices for the electricity can be achieved, this will increase the financial viability of these value chains.

The selling price of heat will depend on what the heat is replacing, in terms of fuel used and method of generation. For coal and natural gas, which are typically used in industrial processes for heat or steam generation, the cost can range from R11/GJ (coal) to R95/GJ (gas)¹⁶. This price for energy can be even lower if sawmill waste is utilised to co-fire a coal boiler. Due to this large variation in the market for the price of energy, a conservative price of process heat in the model was assumed at the lower coal price of R11/GJ.

4.2.6 Financial input parameters and calculated output indicators

The value chains were only assessed in terms of financial performance to the point where the final product is produced for the wholesale market (similar to the carbon emissions boundary as discussed in Appendix A4). The cost of transportation of the biochar to the site of utilisation is not considered, as this will vary for each project. When interpreting the results for individual projects, the cost of the transportation of biochar to the site should be compared to the cost of transporting the product that it replaces. If the product transportation distance in the project and baseline are similar, this cost differential will be negligible.

As described previously, the financial model operates by seeking to achieve a certain IRR for each value chain,

through adjusting the selling prices of products. In the value chains with only one product (biochar or electricity), the selling price of the product is determined to obtain the desired IRR. For value chains with more than one product (biochar and electricity or biochar and process heat), an assumption was made on the price of the energy product based on current market prices. The selling price of biochar was then calculated to achieve the target IRR (see Section 4.2.5 for market prices of products). In terms of setting a target IRR, an initial value of 15% was chosen for the simulations. The rate of return required by investors in a project depends on a variety of factors, one of which is the project risk. Given that biochar production is not well established in South Africa, it is likely that a higher level of return would be required than in more proven investments – hence the choice of this value. The impact of the target IRR was also explored via sensitivity analyses, as described in the sections that follow.

All models for centralised facilities were run over a 20-year period, with the project lifetime being based on information provided by the technology providers on the lifetime of the centralised pyrolysis and gasification technology equipment.

See Appendix A for detailed financial input parameters and assumptions used in the modelling.

4.3 Model outputs

This section presents the model outputs for the different value chains, followed by an in-depth analysis of specific value chain results and sensitivities.

Table 8 presents the selling price for biochar or energy required to achieve or exceed an IRR of 15% at the harvesting densities assumed. From this table, it can be seen that value chains 1 and 2 will require selling the biochar product at a market price similar to that of fertilizer to achieve the desired IRR of 15%. Value chains 4 and 5 could well be viable at a harvesting density of 50 tonne per hectare if biochar is sold at a price similar to that assumed for charcoal or higher. The economic viability of Value Chain 5 is subject to the price that can be achieved for heat. This will vary depending on site and application. Due to the significant variability in selling prices of heat at different sites, the sensitivity of Value Chain 5 is not evaluated further.

¹⁵ <http://www.ipprenewables.co.za/#page/2183>

¹⁶ http://www.fossilfuel.co.za/articles/2013/SACPS_23-Jul-13_Dave-Collins_distribute.pdf



Table 8: Minimum product selling prices in 2015 for exceeding a 15% project IRR

No.	Feedstock	Process	Technology provider	Minimum biochar selling price [R/tonne]	Electricity [R/kWh]	Process heat [R/GJ]
1.	IAV	Pyrolysis (mobile)	Vuthisa Technologies	6 600	N/A	N/A
2.	IAV	Pyrolysis	Thermex Carbontech	7 550	0,90*	N/A
3.	IAV	Gasification	Prestige Thermal	N/A	1,57	N/A
4.	Sawmill waste	Pyrolysis	Thermex Carbontech	2 960	0,90*	N/A
5.	Sawmill waste	Pyrolysis	Thermex Carbontech	2 275	N/A	11,00*
6.	Sawmill waste	Gasification	Prestige Thermal	N/A	1,12	N/A

*Assumptions made for fixed values in 2015.

Value chains 3 and 6, utilising the gasification technology and producing only electricity, will require the electricity to be sold at a premium to the current average electricity price of 90c/kWh to achieve a 15% IRR. In the latest REIPPP preferred bidders announcement (Bid Window 4 announced on 16 April 2015), the fully indexed purchase price for the only approved biomass project was R1,45/kWh¹⁷. At this electricity purchase price, both value chains 3 and 6 can potentially be viable, provided the necessary power purchase agreements can be achieved. A carbon price for offsetting emissions associated with grid electricity can also aid in improving the economic viability of these value chains, as value chains 3 and 6 have more carbon offset potential than value chains that utilise biochar for carbon sequestration or charcoal replacement¹⁸. Value chains 3 and 6 were, however, only modelled for comparison to the pyrolysis technologies with biochar production, and will not be analysed further in this study.

The carbon emission intensities for each value chain for different product end-use scenarios are presented in Table 9. These emission intensities are expressed as reductions over the baseline in tonnes of CO₂e reduced per tonne of dry biomass consumed in the process.

Table 9: Tonnes carbon emission reductions over the baseline per tonne dry biomass consumed in the value chains

No.	Feedstock	Process	Technology provider	Biochar used for carbon capture	Biochar used as charcoal	Biochar used as fertilizer	No biochar produced
1.	IAV	Pyrolysis (mobile)	Vuthisa Technologies	0.26	-	-	-
2.	IAV	Pyrolysis	Thermex Carbontech	1.40	1.51	2.01	-
3.	IAV	Gasification	Prestige Thermal	-	-	-	1.78
4.	Sawmill waste	Pyrolysis	Thermex Carbontech	1.41	1.52	2.02	
5.	Sawmill waste	Pyrolysis	Thermex Carbontech*	1.25	1.35	1.85	
6.	Sawmill waste	Gasification	Prestige Thermal	-	-	-	1.79

*Assumed heat in the baseline is generated with a natural gas boiler with 85% overall efficiency.

From Table 9, it is clear that replacing some or all of the fertilizer used in farming has the highest carbon offset potential. In general, when utilising biochar to replace products (fertilizer or energy) previously supplied from fossil fuels, much greater emission reductions will be achieved than from just burying the biochar in the ground for carbon sequestration purposes, as was assumed for Value Chain 1.

¹⁷ <http://www.ipprenewables.co.za/gong/widget/file/download/id/279>

¹⁸ It is important that emission reductions are not counted double with the generator of electricity and the user of electricity. When selling electricity into a programme like REIPPP, the programme might already claim the emissions reduced as a result of the electricity generated from renewable sources, which means that the generator of electricity will not have the benefit of selling emission offsets into a carbon market.

Another observation is that the emissions from harvesting and transportation to site have very little impact on the overall carbon balance and final emission intensities. It is expected that the emissions associated with the distribution of the biochar will also be relatively small, with the difference between the project case and the baseline determining the net emissions as a result of the project (e.g. if the biochar is transported more or less the same distance to the point of utilisation as the fertilizer it replaces, the net effect will be zero).

Value chains 1, 2 and 4 are now unpacked in more detail to assess the sensitivity to harvesting density and feedstock transportation distance, the economic viability of selling biochar into different markets, different desired IRRs and the impact of a carbon price on economic viability.

4.3.1 Value Chain 1

As can be seen from Table 8, Value Chain 1 is only viable (at 15% IRR and 50 tonne per hectare harvesting density) if the biochar can be sold at a price higher than R6 600 per tonne. This price can only be achieved if the biochar were to be sold as a replacement for fertilizer or on export markets. Figure 12 (green line) illustrates that to sell the char into the charcoal market and achieve a 15% IRR, harvesting will need to be done at densities above 97 tonnes per hectare.

If the harvesting costs were to be zero due to the IAV already being harvested by programmes like WfW or subsidised by government, the minimum biochar selling price will be R1 526 per tonne to achieve a 15% IRR, irrespective of harvesting density (yellow line in Figure 12). If this biochar is sold as charcoal or at a higher market price, it can achieve the desired IRRs.

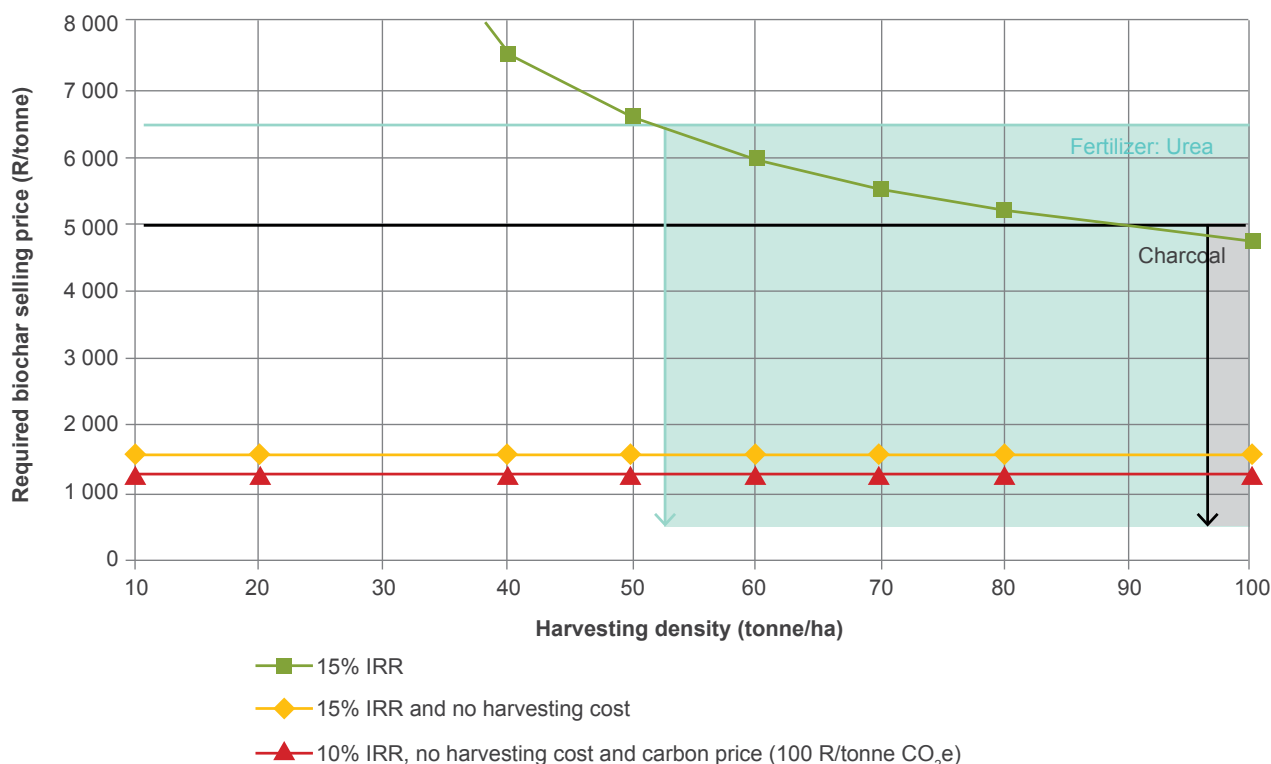


Figure 12: Value Chain 1 economic viability for different scenarios

Given that Value Chain 1 is modelled to represent a mobile unit that produces biochar at the harvesting site for burying on site for the purpose of carbon capture, it is most likely that the only value of this biochar will be that of avoided CO₂e emissions, which is in turn determined by the market carbon price. This value chain reduces 73 tonne of CO₂e a year over its baseline. Even when lowering the IRR to 10% with a zero harvesting cost and using the assumed carbon price of R100 per tonne, biochar still needs to be sold at a minimum price of R1 284 per tonne (red line in Figure 12). This means that even for a scenario with a 10% IRR and no harvesting cost, the carbon price needs to exceed about R1 330 per tonne to justify only burying the biochar for carbon capture purposes and not selling it as a value-added product – which is unlikely to be achieved.



4.3.2 Value Chain 2

The sensitivity of the biochar selling price for Value Chain 2 to a changing harvesting radius at harvesting densities of between 10 and 100 tonne per hectare is presented in Figure 13. The harvesting radii simulated corresponds to those presented in Figure 22 in Appendix A, where the green line is the theoretical minimum harvesting radius if all land were to be harvested (this is the total land area

around the pyrolysis unit, within the specified harvesting radius), and the red line is the recommended 50 km maximum harvesting radius. The yellow line represents the area for typical harvesting radii found in literature (Mugido et al., 2014) at the specific harvesting density. Also presented on Figure 13 are the wholesale market prices for two types of fertilizers, as well as half the average international biochar market wholesale price in 2013 (Jirka & Tomlinson, 2013).

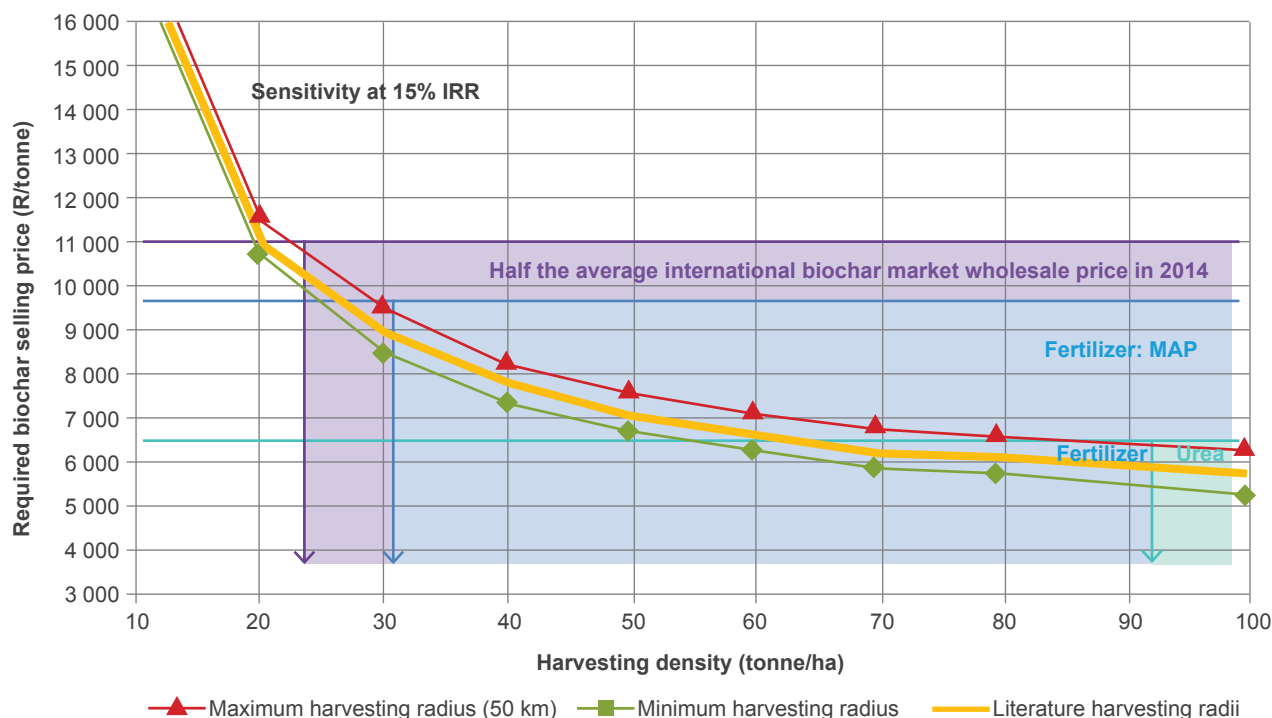


Figure 13: Value Chain 2 biochar selling price for different harvesting radii and densities

From Figure 13 it can be observed that, to achieve a 15% IRR, an exponential increase is required in the biochar selling price as the harvesting density decreases. At lower harvesting densities, the large cost of harvesting also overshadows the cost of transportation, and the impact of the difference between the maximum and minimum transportation distance on the biochar selling price becomes insignificant. At higher densities and lower biochar selling prices, the effect of a changing harvesting radius is more prominent due to the lower relative harvesting cost. For example, for the replacement of urea fertilizer at R6 200 per tonne, the viable biomass harvesting density can vary between 60 and 93 tonne per hectare depending on the harvesting radius. To be conservative, the recommended harvesting density is indicated at the 50 km maximum harvesting radius (downward arrow). This is shown separately for each type of biochar market, which is based on the commodity that biochar will be replacing.

Therefore, for Value Chain 2 to have a 15% IRR if biochar is sold at the urea fertilizer price, harvesting must be done at densities above 93 tonne per hectare. As the potential selling price increases with different markets, the minimum viable harvesting density lowers. The highest market price indicated is half the international biochar wholesale market price in 2014, which requires the harvesting of biomass above 23 tonne per hectare. This shows that if the correct market is created for biochar, areas of lower biomass density will become viable for harvesting IAV to produce biochar.

The sensitivity of Value Chain 2 to different minimum IRR requirements at the fixed conservative harvesting radius of 50 km, and for harvesting densities between 10 and 100 tonne per hectare, is presented in Figure 14. The minimum biochar selling price is determined to obtain an IRR of 10%, 15% and 20% respectively, and to obtain a 15% IRR with the price of carbon included.

An IRR of 10% might represent a project that is subsidised by government, whereas a 20% IRR can be desired by very conservative investors concerned about the risk of new projects.

For the carbon price case, it was conservatively assumed that the biochar would only be put in the ground for carbon capture purposes and not to be utilised as charcoal to replace coal or for agricultural purposes to potentially reduce consumption of fertilizer. This assumption results in this value chain reducing 28 000 tonne of CO₂e a year over the baseline.

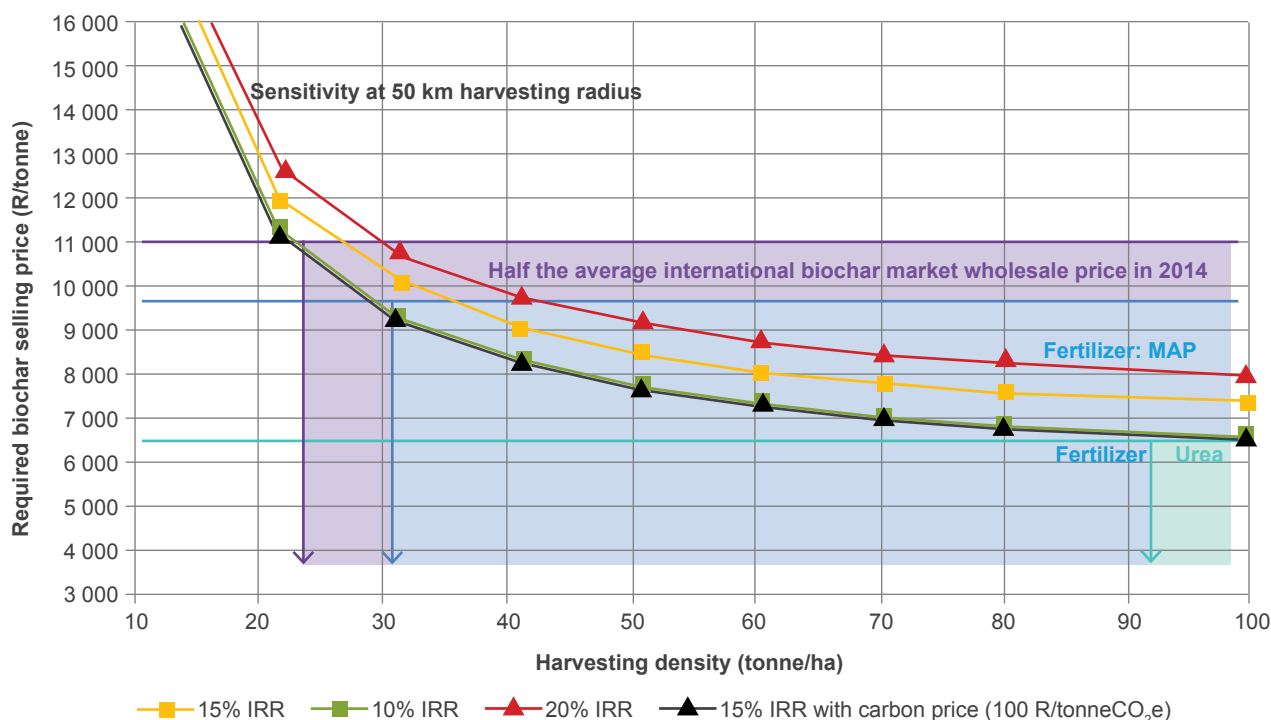


Figure 14: Value Chain 2 biochar selling price for different IRRs and harvesting densities

It can be seen from Figure 14 that the impact of changing the IRR that the project needs to meet becomes more significant at higher harvesting densities where lower biochar selling prices are required. Biochar can be sold as a replacement for urea fertilizer at a minimum harvesting density of 60 tonne per hectare if a 10% IRR is acceptable, but if a 20% IRR is desired, a harvesting density above 100 tonne per hectare will be required. The impact of the R100 per tonne carbon price with a 15% IRR yields similar results to that of the 10% IRR line, showing the big impact that a carbon price can have on the economic viability of a project.

If biochar from Value Chain 2 were to be sold into the charcoal market at R4 800 per tonne, assuming an average 50 tonne per hectare harvesting density, the IRR will be 2.3% with an electricity price of 0,90 per kWh. Alternatively, if a minimum electricity price of R1,40 per kWh can be secured through a power purchase agreement, a 15% IRR can be achieved.

In the case where the harvesting costs were to be zero due to the IAV already being harvested by programmes like WfW or subsidised by government, Value Chain 2 would yield similar results to that of Value Chain 4, which is discussed below.

4.3.3 Value Chain 4

As indicated in Figure 15, Value Chain 4 can sell biochar at the low price of R860 per tonne to still provide an IRR of 15%, as the feedstock comes at no cost. In addition to the biochar, electricity is produced, which assists in improving the economic viability of the project. If it is assumed that the electricity price remains unchanged, Figure 15 illustrates the IRR that can be achieved for different selling prices of biochar. Even if sold at the low price of charcoal in the market, this project will achieve an IRR of 40%. This is before the price of carbon is included, which will further increase this IRR to 46% for a biochar selling price similar to that of charcoal.

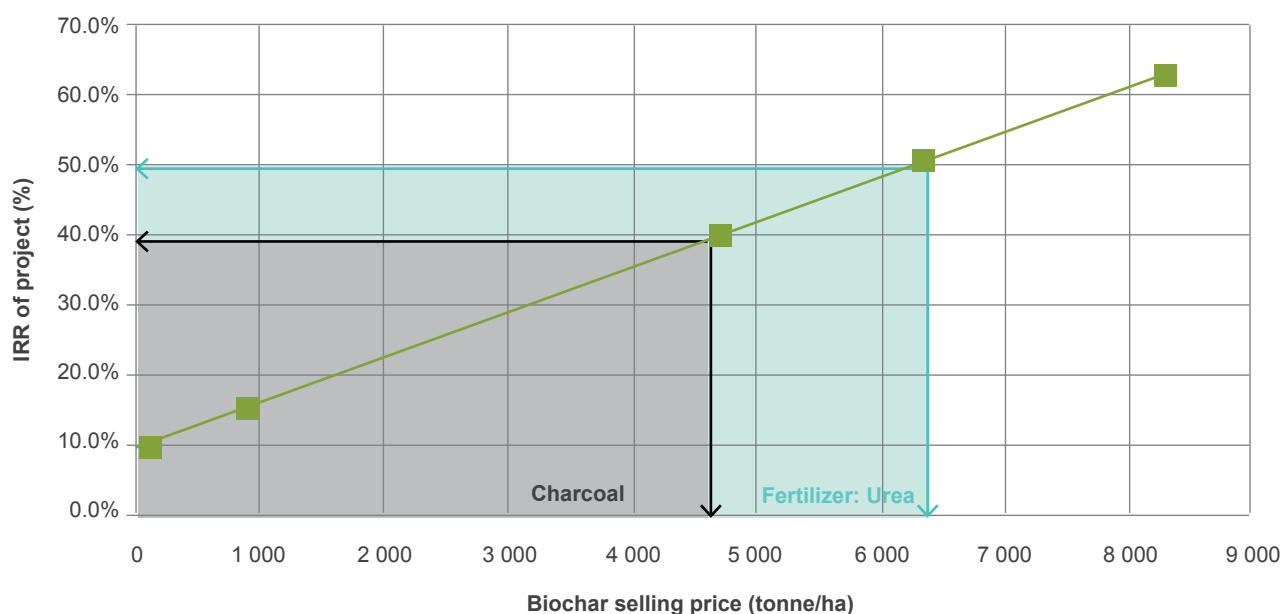


Figure 15: Value Chain 4 projected IRR for different biochar selling prices

4.4 Summary of the model outcomes and implications for biochar production and application in South Africa

4.4.1 Economic feasibility

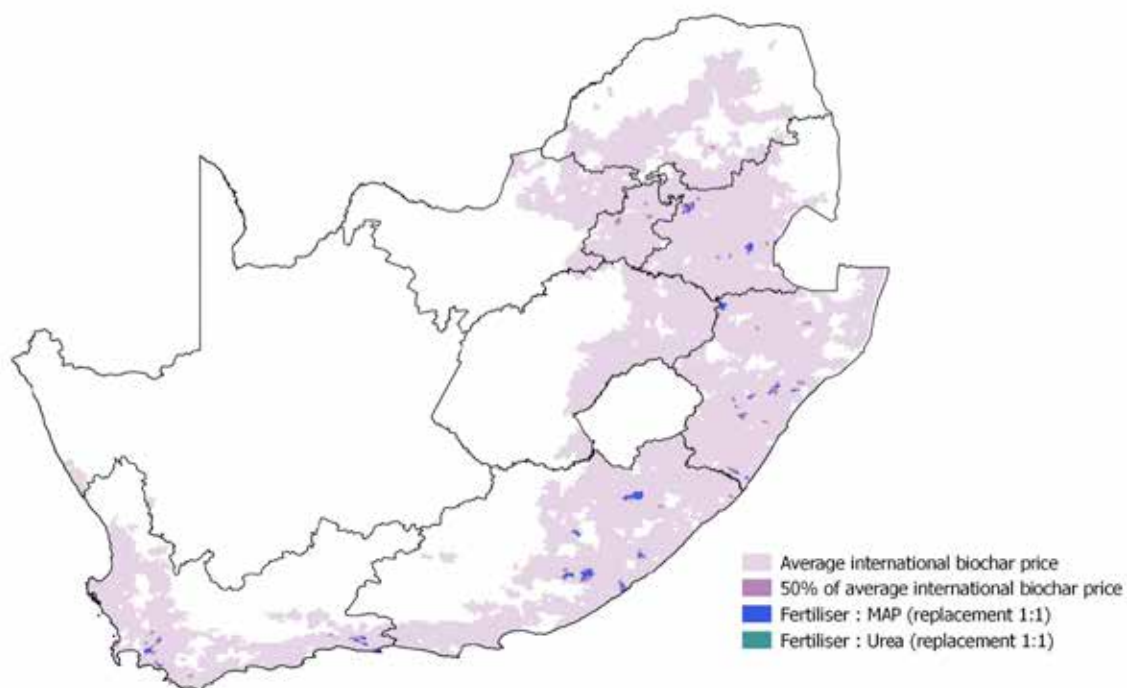
The modelling results from this study illustrate the economic feasibility of biochar and energy production in South Africa from different biomass feedstocks and harvesting scenarios, thermal biomass conversion technologies and for sale into different product markets.

The first observation from the analysis is that, as expected, the value chains are sensitive to the cost of biomass. For this reason, the value chains that utilise sawmill waste, which is assumed to be available at no cost, yielded relatively high IRRs for current market prices of products. Of the value chains that utilise IAV as feedstock, Value Chain 2 holds the greatest potential to be economically viable, with feasibility being dependent on harvesting density and the market into which the product is sold. The economics of the production of a char product is also generally more favourable if combined with the co-production of an energy stream (e.g. electricity or process heat). The production of multiple products has the added advantage of making the project less susceptible to fluctuating markets for the char product.

Figure 5 showed the geographic distribution of woody IAV in South Africa. After assessing the comparative economics of the different value chains, however, it is clear that it is not economically feasible to produce char from all of this feedstock at current market prices. The relative density of IAV biomass was therefore spatially analysed to give an indication of which geographic areas

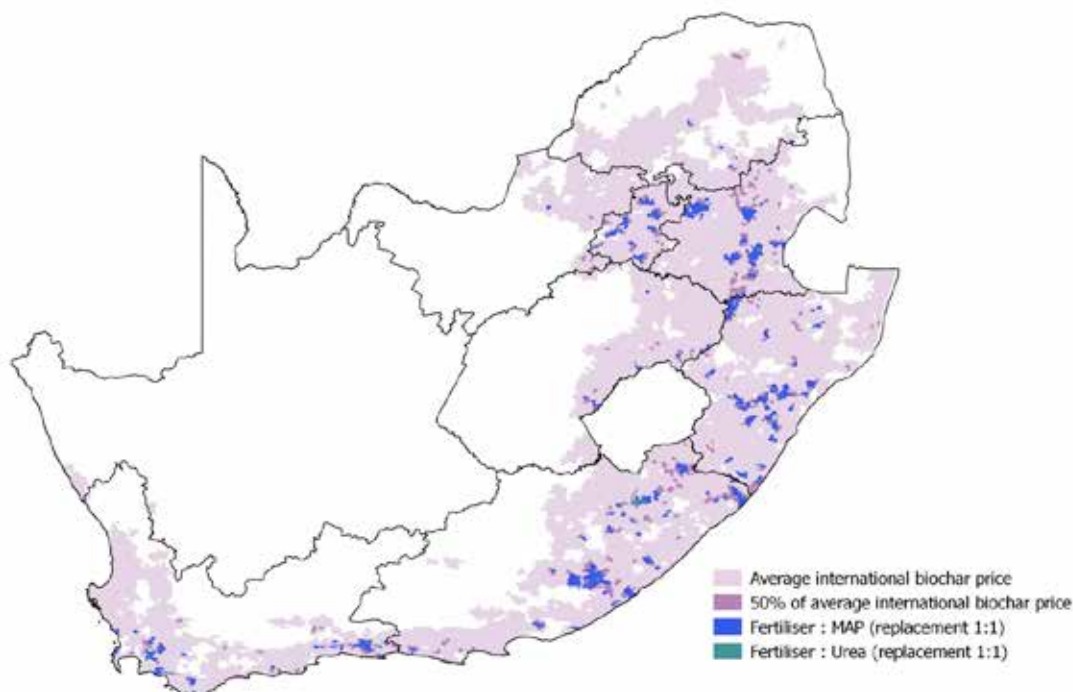
may offer the greatest potential for the production of char. Value Chain 2 seems to offer the greatest potential to be economically viable, and so the densities that are required to achieve a 15% IRR for the sale of the different products assessed in the economic model were extracted and plotted as a map layer for this value chain.

Figure 16 shows the geographic distribution of IAV in South Africa in terms of the densities that make it viable (at a 15% IRR) to produce a char product in a centralised pyrolysis facility for the product markets explored in the model. It must be noted that Figure 16 assumes that only 50% of the available biomass is harvested (as in the economic model). This gives a conservative estimate of biochar production potential, given that the underlying data on IAV density has been aggregated to a coarser spatial resolution from the original estimates of Kotzé et al. (2010). It is likely that the actual densities of IAV in South Africa are slightly higher. For this reason, a further sensitivity was run assuming that 100% of available biomass could be harvested. Figure 17 shows the distribution of available IAV in terms of the densities that make it viable (at a 15% IRR) to produce a char product for the product markets explored in the model if all the biomass was available for harvesting. Again, this represents Value Chain 2. Although achieving this extent of material recovery is unlikely, it does help illustrate how the higher available densities of IAV broaden the potential areas in which the production of a char product could be feasible in a centralised pyrolysis facility.



Source: Map developed for this study using data provided by the CSIR for the compilation of the SAEON/DST Bioenergy Atlas¹⁹.

Figure 16: Map showing available IAV for sale into different markets to achieve a 15% IRR when 50% of available biomass is harvested at a 50 km harvesting radius. Product is from a centralised pyrolysis plant (Value Chain 2).



Source: Map developed for this study using data provided by the CSIR for the compilation of the SAEON/DST Bioenergy Atlas²⁰.

Figure 17: Map showing available IAV for sale into different markets to achieve a 15% IRR when 100% of biomass is harvested at a 50 km harvesting radius. Product is from a centralised pyrolysis plant (Value Chain 2).

¹⁹ Provided by William Stafford (CSIR) (personal communication).

²⁰ Provided by William Stafford (CSIR) (personal communication).



From Figure 16 and Figure 17, it is clear that there are certain areas of South Africa that are likely to offer a greater potential for the production of char from IAV in a centralised pyrolysis unit than others, with the coverage increasing as the char is sold into lower value markets. However, when harvesting 50% of the biochar, over most of the country, relatively high prices need to be achieved for the biomass for it to be financially feasible. As cautioned previously, these figures should only be used as a guide to determine where further, more localised feasibility studies should be conducted.

4.4.2 Carbon sequestration potential

The results presented in Table 10 indicate that all the value chains will result in significant GHG emission reductions over their baseline scenarios, with those where biochar replaces fertilizer having the largest reduction potential. By looking at the total available biomass in South Africa, it is possible to give a broad indication of GHG emission reductions that can be achieved, assuming all of the biomass is harvested and used in char production. As the selling price of the products increases, it becomes viable to harvest into areas with a lower biomass density. Hence, a greater volume of char can be

produced, and carbon sequestered, for the higher-value products than for the lower-value products.

Table 10 and Table 11 show the GHG sequestration potential if char can be sold into the different product markets. The sequestration potential is expressed against the baseline emissions per tonne of dry biomass for two different harvesting scenarios, namely harvesting 50% of the biomass in an area and harvesting 100% of the biomass in the area. The methodology for the carbon emission reductions of different value chains is explained in Appendix A4, and the resultant emission reduction potential in each value chain is presented in Table 10.

It is noted that the emission reduction potential of biochar sold in the international market is unknown (as it depends on what the biochar is used for and the country-specific baseline) and so, to be conservative, the emission reduction factor for carbon sequestration in South Africa was used. If fertilizer use is being offset in overseas applications, the reduction potential will be significantly greater. **Note that all of these values are indicative only and serve to give a sense of the order of magnitude of mitigation potential. Further research is required to refine these numbers.**

Table 10: Indicative GHG emission reductions for biochar produced from IAV when sold into different markets at 50% harvesting efficiency

Biochar end-use	Total IAV biomass available (tonnes)	CO ₂ reduction potential (tonnes)
Charcoal market price	0	0
Fertilizer: urea (replacement 1:1)	0	0
50% average international biochar price	10 205 000	14 287 000
Average international biochar price	168 403 000	235 764 000

Table 11: Indicative GHG emission reductions for biochar produced from IAV when sold into different markets at 100% harvesting efficiency

Biochar end-use	Total IAV biomass available (tonnes)	CO ₂ reduction potential (tonnes)
Charcoal market price	0	0
Fertilizer: urea (replacement 1:1)	3 028 000	6 086 280
50% average international biochar price	66 959 000	93 742 600
Average international biochar price	168 403 000	235 764 000

These tables suggest that the emission reduction potential could be substantial, particularly if higher prices could be achieved for the biochar. It is also noted that the figures presented here are of a similar order of magnitude to that of the MPA, even when correcting for the differing harvesting efficiencies. However given that the full set of assumptions used in the MPA is not available in the published literature, the reasons for the discrepancy cannot be determined.

Table 12 shows the annual emission reduction potential for biochar produced from sawmill waste using the same assumptions.

Table 12: Indicative annual carbon emission reductions for biochar produced from sawmill waste when sold into different markets

Biochar end-use	Total sawmill waste available (tonnes/ annum)	CO ₂ reduction potential (tonnes/annum)
Charcoal market price	1 000 000	1 520 000
Fertilizer: urea (replacement 1:1)	1 000 000	2 020 000
50% average international biochar price	1 000 000	1 410 000
Average international biochar price	1 000 000	1 410 000

4.5 Final comments: factors potentially limiting the application of biochar in South Africa

In this final section, the findings from Section 3.3 are combined with the model findings to present an indication of the key factors that will limit the extent of biochar application potential in South Africa. The key factors that are explored here to determine if they are limiting are the following:

- Cost of transportation of the char product
- Emissions associated with transportation and whether they offset the emission savings from using the char product
- The availability of suitable soils for biochar application

With respect to the first of these, it is recognised that the cost for transporting the biochar product from the production facility to the site of utilisation was not included in the economic evaluation. When considering the impact of transport costs on the viability of the different value chains and product uses, two factors are taken into account. Firstly, the transportation distance should be compared to that of the product it is replacing. So, if biochar is offsetting a proportion of the fertilizer that is used in say Mpumalanga, cost savings might be seen if the fertilizer would have been transported from Gauteng. Nevertheless, an initial calculation suggests that the cost of transporting biochar for use as a fertilizer a distance to the order of 1 000 km would represent less than 10% of the selling price of the product. Based on this rough analysis, it is proposed that the cost of the biochar product, particularly as a fertilizer replacement and for export, is not expected to be a limiting factor. The transportation costs of char used as a charcoal replacement may become more significant over such large distances, but it is unlikely that a charcoal product would be transported more than 100 km, incurring a proportionally low transportation cost. On this basis, transport cost is not considered to be a limiting factor in determining the areas in which biochar could be used.

A similar observation holds for the emissions associated with the transportation of the char product. The emissions associated with char transportation are negligible, relative to the savings demonstrated previously.

The key limiting factor that determines the potential application areas for biochar is the availability of suitable soils for application. Section 3 explored some of the preferred conditions for biochar application to South African soils. Although biochar could theoretically be applied to any cultivated land, its value in acidic soils has been widely demonstrated given its potential buffering impact on these soils. Figure 18 shows an overlay of the distribution of cultivated land with that of acidic soils. The cultivated regions with acidic soils are mainly focused in the Western Cape, Eastern Cape, KwaZulu-Natal, Mpumalanga, Limpopo and Gauteng, as well as some areas of the Free State. Note that the darkness of shading represents a higher concentration of these regions, while lighter shaded areas mean that that land is more widely distributed.



Source: Map developed for this study using data from the ARC (Agricultural Research Council, 2014).

Figure 18: Distribution of cultivated land with acidic soils

In addition to the potential buffering impact on acidic soils, some further benefits in terms of crop yields have been demonstrated for sandy soils and those with a low WHC, as well as soils that have a low potential for erosion. Figure 19 shows the spatial relationship between cultivated land and favourable soils (i.e. soils that are acidic, not prone to erosion, and sandy with a low WHC). It is clear that this reduces the potentially favourable areas in terms of soil types significantly. Having said this, the distribution of these areas is well correlated with the areas of the country that show the greatest feasibility for biochar production (see Figure 19), namely KwaZulu-Natal,



Limpopo and Mpumalanga, as well as smaller areas of the Western Cape and Eastern Cape. These findings provide an indication of the areas in South Africa where localised studies into the potential for biochar production and application could be focused. Again, note that the darkness of shading represents a higher concentration of these regions, while lighter shaded areas mean that that land is more widely distributed.



Source: Map developed for this study using data from the ARC (Agricultural Research Council, 2014).

Figure 19: Distribution of areas likely to have the greatest benefit from biochar application

Finally, the question was raised as to whether there may be potential limits to the total amount of biochar that could ultimately be used in South Africa if biochar was to be ploughed into any cultivated lands (not necessarily to improve crop yields). A very high-level analysis was used to indicate whether the amount of available cultivated land in South Africa could limit the potential for application, or whether feedstock availability was limiting. South Africa has approximately 12 033 000 hectares of cultivated land. If it is assumed that all the available woody IAV in the country is harvested for biomass production (see Section 3.1), a total biochar production of around 34 000 000 tonnes (at 20% yield) would be achieved.

At an application rate of say 10 tonnes per hectare, around one quarter of the cultivated land in South Africa would need to be available for the deployment of biochar. Similarly if all the available sawmill waste in South Africa (approximately 1 000 000 tonnes) is used to produce biochar, there is a potential to produce around 200 000 tonnes per year (using the assumption of 20% char yield). This would require a deployment of biochar at 10 tonnes per hectare into about 2% of cultivated land per year. While these numbers are purely indicative, it does suggest that there is land available for burying biochar – particularly given that only a small proportion of the AIV in the country will actually be used for biochar production.

5. Socioeconomic impacts of biochar production and supply

The IBI has been active in developing guidelines for assessing the sustainability of biochar production, which includes socioeconomic and environmental considerations (Appendix B). Environmental considerations have been discussed in detail in Section 2. The socioeconomic considerations are discussed further in this section.

The production and application of biochar on South African soils can have both positive and negative socioeconomic impacts. Four parameters were considered in this study:

- Employment
- Increased productivity of agricultural land and food security
- Fuel security
- Health and safety

The first two impacts were identified in the Terms of Reference. After consulting the guidelines put forward by the IBI, the second two were also felt to be important within the South African context.

5.1 Employment

The harvesting, production, storage and transportation of feedstock and the soil application of biochar is labour-intensive and thus represents an opportunity to create employment for unskilled, semi-skilled and skilled workers. Direct employment would result from the construction, operation and management of production equipment, and indirect employment would be created through secondary industries, services and activities. Furthermore, the production and application of biochar could diversify and increase the income and consequently the spending power of employees, thus contributing to economic development in local communities (Domac, Richards & Risoviv, 2005). The production of biochar presents opportunities to develop rural economies, especially since the feedstock is located in areas where jobs are much needed.

5.1.1 Employment in harvesting alien vegetation

As indicated in Section 4, stakeholders have indicated that, on average, 500 kg of biomass can be harvested per person per day, although it is recognised that this will vary vastly, depending on the terrain and type of biomass. It was further assumed that harvesting would only be done for eight hours a day. This figure can be used to provide an indication of the employment per installation:

- A small-scale decentralised unit (Value Chain 1 considered previously) requires a feedstock of

2 240 kg a day of fresh biomass.²¹ This indicates that five people would be required for harvesting to supply each unit, with some additional time still being available from these five people for loading and unloading the unit. Plants would likely operate five days a week when harvesters are working.

- The centralised plants considered require a feedstock in the order of 15 200 kg an hour or 365 tonnes a day of fresh biomass. These plants will likely operate on a continuous basis seven days a week. This suggests that 243 people would be required to work for eight hours every day to harvest biomass to feed each plant. The actual number of people employed would be higher, as people would have to work shifts to account for days off, and there is potential to create more employment through the chopping and drying of feedstock at the centralised plant.

Obtaining an indication of what this means in terms of national potential for employment in AIV harvesting for biochar production specifically is impossible as there are multiple competing uses for the various forms of AIV, clearing rates vary widely, not all AIV is suited to biochar production, and not all sites lend themselves to transporting cleared vegetation to a biochar facility (or the biochar from an in-situ plant to market). Having said that, some indication of the total national employment creation potential from clearing AIV species could be drawn from the estimates provided by the WfW Programme. The programme already works in partnership with local communities, government departments, research foundations and private companies. Since its inception in 1995, the programme has cleared more than one million hectares of AIV and provides jobs and training to approximately 20 000 people per annum. It is estimated that the WfW Programme could employ 111 600 people by 2025 (Mugido et al., 2014). Thus, even if a fraction of these jobs were created for clearing AIV for biochar production, the job creation potential is substantial.

5.1.2 Manufacturing in decentralised pyrolysis units

As indicated above, it is likely that the five people clearing biomass for biochar production in a decentralised unit would be able to operate it at the same time (loading and emptying the unit). One or two additional people may be required for aggregating the material and transporting it to the point where the product could be distributed.

5.1.3 Manufacturing in a centralised pyrolysis unit

Biochar manufacture in the centralised pyrolysis units is more complex than the distributed small-scale systems, requiring both skilled and unskilled labour (Maia, Giordano, Kelder, Bardien, Bodibe, Du Plooy, Jafta,

²¹ This biomass is assumed to have a moisture content of 50%. It is then dried to 20% moisture content that provides the 700 kg per batch indicated Table 18.



Jarvis, Kruger-Cloete, Kuhn, Lepelle, Makalule, Mosoma, Neoh, Netshitomboni, Ngozo & Swanepoel, 2011). Table 13 shows some examples of operational staff requirements at a sample of centralised pyrolysis units of different sizes, according to the information supplied by the technology providers that were consulted for this study. The unit types represent the same units that were used for the different value chains that were modelled in the previous section.

Table 13: Potential job creation at centralised production plants (data provided by technology suppliers)

Unit type	Biomass required (tonnes/ha)	Power out (MWh)	Biochar out (tonnes/ha)	Jobs on plant
Unit producing 12 MWh (thermal)	3.2		0.48	26
Unit producing 2.2 MWh (electricity)	3.2	2.2	0.48	42
Gasification unit producing 5.5 MWh (electricity)	4.2	5.5	-	51

5.1.4 Increased productivity of agricultural land and food security

When applied to suitable soils and under appropriate conditions, biochar may have the potential to improve and sustain crop productivity and reduce the need for irrigation through enhanced nutrient availability and moisture retention in soils (Barrow, 2012; Gwenzi, Chaukura, Mukome, Machado & Nyamosoka, 2015). Biochar also has the potential to support nitrogen fixation, increase the pH of acidic soils, stimulate microbial diversity and increase agricultural resilience against climate change effects like the increased frequency of droughts and floods (Barrow, 2012). As a result, the use of fertilizer, compost and liming agents can be reduced, which is particularly important for subsistence farmers who cannot afford chemical fertilizers (Gwenzi et al., 2015).

In South Africa, small-scale and subsistence farming often occurs in areas with poor/low crop yields due to the presence of infertile sandy soils that have a poor WHC and are naturally acidic (Gwenzi et al., 2015). Increased agricultural growth as a result of more productive smallholder farming has a role to play in the short and medium term in poverty reduction (Prasad, 2010), and biochar can contribute towards cutting input costs (e.g. fertilizer and irrigation), while enhancing productivity. Similarly, as indicated above, biochar can be beneficial for commercial farmers as it may support intensive agriculture and increase farm profitability by reducing the need for fertilizers (Barrow, 2012). Furthermore, improved water retention may reduce the leaching of nutrients and agricultural chemicals from the soil (Laird et al., 2010).

Quantifying this benefit for the country as a whole is difficult at this stage, as there is little conclusive research locally and globally to correlate soil productivity and biochar application for different types of soils. It is unlikely that such a correlation could be developed, given the wide range of soil types, extents of degradation and crop responses. It must be expected that actual benefits will vary on a location-by-location basis.

Although the potential positive benefits for food security are clear, biochar production also has the potential to impact negatively on food and water security and biodiversity, and could potentially result in the loss of land tenure, resulting from land transfers to biochar investors for feedstock expansion if the intervention is not properly managed and controlled. The impact on food security can occur due to the conversion of agricultural land from food production to biomass production for biochar. The conversion of natural ecosystems to farmland to supply biomass for biochar production adds to existing threats to biodiversity through direct habitat destruction and the introduction of new, potentially invasive species (Blanchard, Richardson, O'Farrel & Von Maltitz, 2011). The two feedstocks included in this study are, however, considered to have zero risk in this regard.

5.1.5 Provision of alternative fuels

Many people in South Africa do not have access to electricity and burn biomass to meet their energy needs. Unsustainably harvested biomass can contribute to deforestation and remove organic carbon from the soil. As a result, there is growing concern regarding the sustainable harvesting of trees and shrubs for fuel, and its impacts on biodiversity (Prasad, 2010; Gwenzi et al., 2015). In East Africa, for example, the unsustainable harvesting of biomass is a big problem because use of biomass from natural forests is among the major contributors to deforestation and the destruction of biodiversity and habitat for other living organisms. On the other hand, in South Africa, the production of biochar from IAV or waste products may present an opportunity to address global change challenges such as biodiversity loss and waste management, while preventing the unsustainable harvesting of other biomass. Furthermore, the proliferation of trees in the grasslands and savannas of South Africa offer another potential feedstock for the production of biochar.

While the focus of this study is only on biochar production for carbon sequestration, the potential for

sustainably produced biochar to replace unsustainably harvested biomass as an energy source should also be acknowledged. Biochar has energy and heating values comparable or higher to traditional energy sources, and does not have the same concerns that are associated with the traditional combustion of biomass (Gwenzi et al., 2015). In many African countries, char is already replacing wood as fuel for cooking stoves, particularly in urban areas (Maia et al., 2011). Over time, biochar could increasingly replace wood as fuel in biomass cooking stoves in South Africa, thereby presenting an opportunity for small-scale biochar producers in South Africa (Maia et al., 2011).

Although the value chains considered here produce biochar using dedicated equipment, there are other scaled-down versions of equipment that can produce biochar, including clean cook stoves that produce biochar as a by-product that can be used as either an energy carrier or soil amendment. One study has suggested that if half of the current wood-burning households in Africa used biochar-producing cook stoves, over 100 Mt of CO₂ could potentially be sequestered annually (Whitman & Lehmann, 2009).

5.1.6 Health and safety considerations

The production and application of biochar has a number of potential health and safety risks that need to be managed, including the following:

- Biochar production equipment is associated with high temperatures, mechanical moving parts and the generation of volatile gases. These all pose human health and safety risks in the workplace (Downie, Munroe, Cowie, Van Zwielen & Lau, 2011).
- If not controlled properly, biochar production can have substantial negative local air pollution impacts, largely associated with the production of particulates.
- A risk of fire is associated with the flammability of biochar, and powders in particular may spontaneously combust if exposed to moisture and oxygen during storage (Laird et al., 2009). Storage and transportation practices need to be designed to mitigate this risk. Various options are available to reduce the risk of spontaneous combustion and prolonged exposure to biochar dust, including pelletising biochar or mixing it with water or manure. However, this can lead to an increase in the cost of handling and applying biochar to agricultural soils (Laird et al., 2009).
- Fine dust from the biochar can cause air pollution and result in respiratory ailments if inhaled. Protective masks can help reduce health risks during biochar production, while the production of biochar pellets or briquettes can help reduce dust during production and transportation (Laird et al., 2010).
- Similarly, long-term exposure to particulates generated during the surface application of biochar to agricultural soil can pose a health risk (Laird et al., 2009).

- Certain biochar feedstocks may contain high levels of heavy metals that can end up in the gas, liquid or solid products. In particular, wood wastes that have been treated with copper-chromium-arsenate (CCA) timber are a concern since they may release heavy metals during the process of conversion to biochar (Downie et al., 2011). This is an important consideration to take into account when regulating the production of biochar from feedstocks other than native vegetation.

It is noted that, in terms of health and safety, the use of char as a cooking and heating fuel is preferred to the combustion of coal or other biomass in traditional stoves. Coal is used as a domestic source of energy by low-income households in South Africa, especially in areas close to coal mines (Balmer, 2007), and results in extremely high levels of air pollution and respiratory diseases. Because burning char results in lower particulate and other hazardous emissions (Joseph, 2009; Gwenzi et al., 2015), it presents an opportunity to switch to a less polluting energy fuel.

6. Business model for biochar production

The business model for biochar production considers the following factors for the different value chains:

- Financial viability
- Capital investment requirements and ease of financing
- Employment-creation potential
- The skills profile of employees
- Potential risk to the business
- Linkages to the rest of the economy in terms of indirect employment potential
- Balance of payment considerations (dependency on imports vs. the ability to export)
- Technology commercialisations
- Public-sector resources required to develop the industry
- The current and potential future ownership of biomass, and current and competing markets for the different streams
- Potential use trade-offs
- Potential alternative revenue streams, such as carbon finance, technology grants, funding for small and medium enterprises (SMEs), etc.
- Other requirements, such as sales channels of electricity production

The mapping against these variables is done for two cases:

- Value Chain 1: The small-scale, distributed production of biochar from IAV.
- Value Chain 2: The centralised production of biochar from IAV; and value chains 4 and 5: the centralised production of biochar from sawmill waste.



All three of these value chains have concurrent production of electricity or process heat. The key distinction between Value Chain 2 and value chains 4 and 5 is that there is a need for the harvesting and transportation of feedstock in the case of IAV. The sawmill waste will be generated on site, and so there are no harvesting or transportation costs associated with the feedstock. Where relevant in the assessment, this difference is highlighted.

The value chains for the production of electricity via gasification (value chains 3 and 6) are not analysed in detail here as they are not considered to be the focus of this study.

6.1 Business model considerations for Value Chain 1

Table 14 shows the mapping of the various business model considerations for the first value chain.

Table 14: Business model considerations for Value Chain 1

Consideration	Findings
Financial viability	The economic model suggests that, in order for this value chain to be financially viable at an IRR of 15%, a selling price of biochar nearly one and a half times the current bulk charcoal price will need to be achieved – which may suggest at first glance that this value chain model is not inherently financially viable. However, prior to rejecting this option outright, further consideration needs to be given to its context. This model provides an effective complement to the WfW Programme. As such, rather than seeing this as a stand-alone, profitable business, the sale of biochar from this value chain could be seen as a way of cross-subsidising or reducing some of the costs of the clearing programme, while at the same time providing benefits of improved soil quality and carbon sequestration. As such, lower returns may be considered acceptable. It is further noted that these findings are highly dependent on harvesting costs. In areas with higher biomass density, the selling price that needs to be achieved from biomass sales will be reduced, potentially making this option profitable.
Capital investment and ease of financing	Capital investment requirements per processing unit are low, with the Vuthisa Technologies unit that is available commercially costing R21 000 for a three-drum biochar retort. Indications are that homemade units can be produced at an even lower cost, although issues occur here with approvals and licensing. At these costs, consideration could be given by government to subsidising the initial capital outlay for small businesses. It needs to be recognised that many of the components of these small systems have short lifetimes (of less than a year), and hence cash flow needs to be reserved for constantly replacing parts of the equipment.
Employment-creation potential	As indicated in Section 5.1, the rate at which biomass can be cleared, and hence the associated employment, is a function of biomass density, type, topography, etc. However, indications are that employment per unit is to the order of five people for harvesting and extraction and only one person for operating the pyrolysis unit. As such, the large-scale rollout of units would be required to achieve any meaningful employment creation.
Skills profile of employees	Skills requirements are low for these mobile units, with in-situ training being sufficient for both harvesting and biochar production.
Potential risks to the business model	Risks include the marginal economic viability of these systems and low returns for each individual unit, the constant requirement for components of the equipment to be replaced, the need for moving the systems from site to site, and challenges with bringing the product to market. Policy and regulatory requirements may also present a significant challenge for these systems.
Linkages to the rest of the economy (indirect employment potential)	The linkages to the remainder of the economy are relatively small for each individual unit. There will be some benefits from the sale of the biochar. Furthermore, people employed on each unit will have additional income that can be injected into the economy. With larger-scale rollout, however, the indirect linkage benefits can be multiplied.

Consideration	Findings
Balance of payment considerations (dependency on imports vs. ability to export)	No significant impact is foreseen here.
Technology commercialisation	At present, there is only one supplier of commercially available small-scale biochar production units in South Africa: Vuthisa Technologies. The other stakeholders consulted to date on this project typically design and build their own production units. The advantage of technology commercialisation is that certain licenses, standards and approval assessments can be done for the technology as a whole, rather than for individual installations. However, certain requirements for environmental impact assessments (EIAs) and air quality licences may still be required for installations at individual sites.
Public-sector resources required to develop the industry	As indicated previously, the public-sector resources that may be required are to support small business owners to purchase equipment and possibly subsidise the cost of harvesting through the WfW Programme to make the biochar competitive. Scale of investment is thus a function of the extent of support per unit and the number of units that are supported.
Current and potential future ownership of biomass and current and competing markets for the different streams	Access to biomass varies depending on its location, with different arrangements being made with different landowners as to the ownership and cost structures for clearing. There are also potentially competing demands for the biomass being developed as government seeks further value-add opportunities for cleared biomass. In line with the waste hierarchy, char production is considered a less-preferred option for the use of biomass resources, with options such as product manufacture being preferred. Biochar production may, however, be able to play a role within the larger value hierarchy by utilising biomass that is not suitable for other value-added industries.
Potential use trade-offs	Although the focus of this study is on biochar for carbon sequestration, it has been clear during the stakeholder consultations that biochar can potentially be used in a wide range of applications, ranging from energy recovery to water purification, odour control and the remediation of oil spills. It is suggested that any project to pursue the production of biochar should be considered alongside the range of potential uses to determine where the maximum possible benefit can be achieved, rather than limiting the options to carbon sequestration and soil amendment.
Potential alternative revenue streams, such as carbon finance, technology grants, funding for SMEs, etc.	If the use of biochar is proven and approved as a carbon sequestration opportunity under a future international emissions trading scheme (or nationally as part of the carbon offsets discussions that are occurring under the carbon tax), the sale of the offsets would represent an additional revenue stream. As indicated above, the establishment of these value chains will likely require some sort of support in the form of grants or funding to make them financially viable.
Other requirements such as sales channels for electricity.	The only requirement here is a channel for the producers to bring their biomass to market.



6.2 Business model considerations for value chains 2, 4 and 5

Table 15 shows the mapping of the various business model considerations for the remaining value chains.

Table 15: Business model considerations for value chains 2, 4 and 5

Consideration	Findings
Financial viability	Value chains 4 and 5 are considered financially viable when comparing the price that needs to be achieved for biochar to the current selling price of charcoal. Value Chain 2 requires a selling price of nearly double the charcoal price to be achieved, which comes about as a result of the costs of harvesting and transporting the feedstock. The most profitable value chain is Value Chain 4, which co-produces electricity. It is important to note that, as with Value Chain 1, the profitability of Value Chain 2 is highly sensitive to the cost of clearing and transporting the biomass.
Capital investment and ease of financing	Capital investments are in the tens of millions of rands, which suggests that a large private-sector investor will be required. However, the amounts are not beyond the ability of such an investor to finance through either equity or debt investment.
Employment-creation potential	The key employment opportunity for Value Chain 2 is that of clearing biomass (as for Value Chain 1). The employment on individual plants is relatively low, being around 20 to 40 employees, depending on the technology and size of the installation.
Skills profile of employees	As with Value Chain 1, low-level workers are required for biomass harvesting. The production plants require a variety of skills levels, ranging from labourers to plant operators and engineers who require higher levels of skills. The absolute number of employees per plant is, however, relatively small, as indicated in the previous point.
Potential risks to the business model	Risks include the need for a constant feedstock supply and an ongoing market for the product. Furthermore, if the project depends on carbon finance, the uncertainty of the carbon markets is a potential risk.
Linkages to the rest of the economy (indirect employment potential)	The linkages to the remainder of the economy are relatively small for each individual installation. There will be some benefits from the sale of biochar, as well as the people employed on each unit having additional income that can be injected into the economy.
Balance of payment considerations (dependency on imports vs. ability to export)	No significant impact is foreseen here. The relative contribution to the overall energy balance, and hence the need for energy imports from each individual installation, will be relatively small.
Technology commercialisation	Pyrolysis technologies, including those for biochar production, are already commercially available both globally and locally. Having said that, there may still be opportunities for advancements on technologies to be made. Similarly, it is likely that there will be newer technologies, such as vacuum and microwave pyrolysis systems entering the market in the future.
Public-sector resources required to develop the industry	If capital investment is sourced from private companies, no public-sector resources will be required for constructing the plant. However, given that the technologies are not well established at scale in South Africa, there may be a need to provide incentives for establishment, at least for the first few plants.
Current and potential future ownership of biomass, and current and competing markets for the different streams	In terms of IAV, as for Value Chain 1, access to biomass varies, depending on its location, with different arrangements being made with different landowners as to the ownership and cost structures for clearing. Sawmill waste belongs to the sawmill operators. Access to the biomass will vary between operating companies. Clearly, if the biochar units are established by the companies, there will be no access issues. Where biochar installations are owned by outside parties, some sawmill operators will be willing to provide the waste biomass for free, given the waste management problem it represents, while others will seek payment for the biomass. For IAV, there are potentially competing demands for the biomass being harvested, as government seeks further value-add opportunities for cleared biomass. There appears to be an oversupply of sawmill waste, with no competing markets. In many cases, sawmills face challenges in dealing with their waste.

Consideration	Findings
Potential use trade-offs	As with Value Chain 1, although the focus of this study is on biochar for soil amendment and carbon sequestration, it has been clear during the stakeholder consultations that biochar can potentially be used in a wide range of applications, ranging from energy recovery to water purification, odour control and the remediation of oil spills. It is suggested that any project to pursue the production of biochar should be considered alongside the range of potential uses to determine where the maximum possible benefit can be achieved, rather than limiting the options to soil amendment and carbon sequestration.
Potential alternative revenue streams, such as carbon finance, technology grants, funding for SMEs, etc.	Clearly the sale of electricity represents a co-product of biochar, which provides an additional revenue stream to this value chain. In the latest round of the REIPPP preferred bidders announcement, electricity produced from biomass achieved high prices relative to other forms of renewables, which helps to make this technology viable. It is possible that green finance may be procured for the establishment of these projects on the basis of carbon sequestration benefits, recognising that green finance globally is in a state of flux.
Other requirements, such as sales channels for electricity produced.	Electricity produced as a co-product may be purchased by a local off-taker located adjacent to the site, which would be the preferred option. Other options may be to register the production facility as a small IPP for sale into the grid, or to wheel the electricity through the grid to a purchaser. Both of these latter options have cost and licensing or approval requirements, which can be substantive. Where process heat or steam is the co-product, the pyrolysis plant will have to be located close to where this is used, as heat cannot be transported over long distances.

7. Conclusion and Identification of further research opportunities

The absence of clear scientific evidence demonstrating biochar's carbon sequestration potential or its benefits as a soil amendment, as well as the product- and site-specific interactions, makes it difficult to make definitive comments as to the extent to which biochar production and application for soil amendment and as a GHG mitigation measure are either viable or desirable at the national level.

The results of this study do, however, suggest that there is potential for biochar production and application in South Africa with likely positive benefits for carbon sequestration, particularly in certain parts of Limpopo, Mpumalanga, KwaZulu-Natal, Eastern Cape and Western Cape. The results of this study can provide some insights that can be used to guide further work.

7.1 Potential for biochar production in South Africa

The production of biochar at various scales and levels of technological sophistication from a wide range of feedstocks is a well-established practice globally. In South Africa there is already a small selection of projects in which biochar is being manufactured, largely in small-scale mobile units.

Of the various feedstocks that are available for the production of biochar in South Africa, the study has identified IAV and sawmill waste as those with the greatest potential, warranting further exploration. The motivation behind these choices is as follows:

- IAV is causing billions of rands of damage annually to South Africa's economy through the negative impacts on water resources and biodiversity, among others, and efforts are underway to clear this vegetation at great cost through the WfW Programme. Biochar production could add value to this resource and recover some of the cost of clearing.
- Residues from sawmills typically present a huge waste management challenge, and the practices currently used (dumping and open burning) result in deterioration of air quality and an increase in water pollution, with the associated secondary impacts. Recovery of energy and the production of biochar are potential solutions to manage these wastes, which not only address the environmental issues, but recover value from an otherwise wasted resource. This waste stream has a further advantage in that it is already concentrated at central locations, which thus reduces both harvesting and transportation costs.



Other potential feedstocks were discounted due to considerations such as competing markets or preferred options for value recovery, the potential for introducing contaminants and the potential to impact on food security.

While biochar production from the two target feedstocks is considered to be technically viable, with a high availability of feedstocks, its economic viability is less certain. The economic model developed as part of this study suggests that it is not economically feasible to produce biochar for carbon sequestration purposes only, as the returns are too low to justify the investment. If the simultaneous benefit of improving crop yields can be demonstrated and a consequent reduction in fertilizer use could be achieved, various biochar production routes could potentially become financially justified. Biochar for sale into the export markets may also prove to be a viable option. A further option demonstrated as an alternative market for the char product is as a substitute for charcoal.

There are, however, a number of factors that determine the extent of economic viability – with the primary consideration being the cost of the feedstock. As the harvesting density decreases (and hence feedstock extraction and transportation costs increase), the viability of the project decreases and the prices that need to be achieved for the products increase. Sawmill waste avoids the need for harvesting and transporting the feedstocks, and so shows far greater economic viability. What this suggests is that viability needs to be assessed on a case-by-case basis, making it difficult to draw generic conclusions for the country as a whole.

A further consideration relates to the licensing requirements for biochar production. Depending on the plant configuration, the operations could have negative local air pollution impacts. A full Scoping and Environmental Impact Report (S&EIR) is required for biochar production installations, of any scale, product or type, and an Atmospheric Emission Licence (AEL) is required for production installations producing more than 20 tonnes of biochar a month. It must be noted that in April 2015, DEA released a draft declaration that sought to make the same emission limits applicable to char plants and charcoal plants with a design production capacity of less than 20 tonnes of product a month. If this declaration comes into effect unchanged, the result will be that all biochar installations, regardless of production capacity, will require an AEL in order to operate legally.

If the biochar industry in South Africa is going to be commercially viable on a scale that can have significant sequestration potential, a regulatory framework may be required to support the production and use of biochar. Government policies to help ensure continuity of feedstock supply to pyrolysis enterprises could assist in establishing the industry. Subsidy arrangements could be adopted that favour the use of biochar in soil. It may,

however, be premature and unwise in the South African context to make any policies that promote biochar until further research has been conducted.

7.2 The potential for biochar application in South African soils as a mitigation measure

The focus of this study was to explore the potential of biochar application in South African soils as a GHG mitigation measure. While biochar can theoretically be applied to any soil for the sole purpose of carbon sequestration, soils that have low potential for erosion would be more likely to retain higher proportions of the carbon. Furthermore, given that biochar is likely to provide additional benefits to the soil in cultivated lands, it was proposed that the areas for application be restricted to these areas. The choice of applying biochar to cultivated land is further motivated by the fact that biochar needs to offer more value than purely carbon sequestration to be financially viable.

Depending on the soil properties of these regions, some areas may be better suited than others. Biochar used as an amendment in acidic and sandy soils has been widely demonstrated to have positive effects on crop yields. While adding this filter to cultivated lands significantly reduces the potentially favourable areas in terms of soils types, it is noted that the distribution of these areas is well correlated with the areas of the country that show the greatest feasibility for biochar production. The data on these target soil types was combined with the results from the economic model to provide an indication of areas with the greatest viability for biochar production.

Despite these generalisations, there is still a need to conduct further research into the mechanisms by which biochar could provide beneficial functions to the soil and the wider agricultural system, which are currently poorly understood. Biochar application seems to generally enhance crop growth and the nutrient status of the soil, but little has been published about how these interactions occur and why the effects are so variable according to crop, soil and biochar type. Current studies, such as those being conducted at the University of Stellenbosch and the University of Limpopo, which focus on the use of biochar in South African commercial farming land and ecosystems, will help resolve some of the questions about its benefits. Appendix C also describes a potential pilot project that will support further research. Furthermore, there is value in monitoring international activity in this area, while recognising that these developments may not be directly transferable to South Africa.

Finally, it is noted that, although the focus of this project was on biochar production and application to South African soils as a mitigation measure, the economic analysis shows that it might be more economically viable

to use a feedstock like IAV to create a char product for use as an energy source or in the other applications discussed in this report.

7.3 Socioeconomic benefits of biochar production and application in South Africa

The results of the study suggest that the production and application of biochar to South African soils can have positive socioeconomic impacts. The harvesting, production, storage and transportation of feedstock and the application of biochar to soils is labour-intensive and thus represents an opportunity for creating employment for unskilled, semi-skilled and skilled workers. This employment would be likely to result from the construction, operation and management of production equipment, and further employment would be created through secondary industries, services and activities. Furthermore, the production and application of biochar could diversify and increase income, and consequently the spending power of employees, thus contributing to economic development in local communities. The production of biochar can therefore present opportunities for developing rural economies, especially since it has been shown that feedstocks are often located in areas where jobs are much needed. Further benefits relate to increased food security and the productivity of agricultural lands due to the soil amendment benefits of biochar, which can contribute to increased food security, and the provision of alternative fuels where the char product is used for applications other than burying it in the soil. Certain negative health and safety considerations were also identified, including those related to air pollution and safety when using the equipment necessary to produce the biochar.

7.4 Recommendations for future work

Throughout the research process, a number of knowledge gaps and future research opportunities were identified. Prior to presenting these, it needs to be reiterated that one of the key challenges in conducting research towards supporting a national biochar agenda is the very site-specific set of considerations that needs to be taken into account with respect to feedstock type, technologies used in production, application approaches, soil types and crops. Each combination of these provides a unique set of interactions that will result in specific behaviours, which may not necessarily be transferable to other situations.

Firstly there is a need to understand the stability and fate of biochar, with stability being of particular importance when considering the use of biochar carbon as a GHG mitigation measure. The loss of biochar through vertical or lateral flow, for example, is not quantified, and only recently have studies started to look at biochar movement

through soil profiles and into waterways. These processes complicate the task of estimating the mean residence time of biochar in soil. Long-term monitoring is therefore required in South Africa to assess the long-term stability and dynamics of biochar in soil.

Additional research is necessary within the South African context to fully understand the location-specific effects of biochar application on crop yields. These include those related to geographic variations in soil type, climate, cropping and pyrolysis feedstock.

There is also a need for project-specific LCAs in the South Africa context. LCAs have been conducted for some biochar case studies, but GHG balances, for example, are very project-specific, and so the opportunity to assess the benefits over a large range of feedstocks, processes and biochar application scenarios is difficult.

It has also been identified that a complete assessment of the impacts of toxic substances within feedstocks and biochar has not been made globally, and that an assessment of the risks of combustion products on terrestrial or aquatic ecosystems is required. Further research is required into toxic materials that could be formed during pyrolysis. Key compounds will be polycyclic aromatic hydrocarbons, the products of partial combustion, and residual oils and acids. Further work in this area could be supported in South Africa, although this may not necessarily be a top priority in this area.

It is suggested that mixing biochar with other soil amendments such as manure or compost before soil application may improve the efficiency of biochar as a soil amendment. Further research in this area is also warranted.

Some other areas where further research is required both locally and internationally include the following:

- The interaction between biochar and microbial communities and their symbiotic interaction with plants, and possibly enhanced nutrient-use efficiency, is not currently understood.
- While many studies report the positive effects of biochar application on WHC, the specific mechanism that biochar exerts on water retention and soil stability is poorly understood. This is important in water-scarce countries like South Africa, where drought mitigation is essential.
- The mechanisms of if and how biochar can reduce N_2O emissions still remain unclear, and further research is required, as this may prove that biochar can provide significantly higher GHG mitigation potential.
- Decreases in crop yields under very high application rates have been reported, and the reasons for these decreases could be further explored to determine at



which rates biochar should be applied to soils in South Africa (although again this may not be a top priority as such issues can be avoided by using lower application rates).

- The environmental impact of gases produced in open combustion associated with biochar production needs to be evaluated.
- Socioeconomic constraints relevant to the production application of biochar must be assessed and understood in a South African context.

The pilot project presented in Appendix C seeks to begin the research process on the short-term effects of biochar, and also to inform the design and timing of long-time monitoring. At the same time, the need to assess potential uses for biochar other than solely as a soil amendment, such as using biochar for energy recovery, in water purification or as a livestock feed additive, is highlighted.

8. References

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APPENDIX A: TECHNO-ECONOMIC MODELLING: ADDITIONAL INFORMATION

This appendix provides additional information on data and assumptions used for the techno-economic modelling done in this study.

A1 Harvesting

Figure 20 shows the relationship between harvesting density and cost for a number of sites, based on recent research done for the harvesting and extraction of various types of AIV species in South Africa (Mugido et al., 2014). The yellow data points in Figure 20 show the average harvesting cost for the ranges of costs recorded by Mugido et al. (2014), with the range at each harvesting density illustrated with error bars.

This average harvesting cost data from the literature in rand per hectare was converted to rand per tonne, which is also presented in Figure 20 (green data points). Despite the large variability observed, a trend of decreasing harvesting cost (in rand per tonne) with increasing harvesting density was identified.

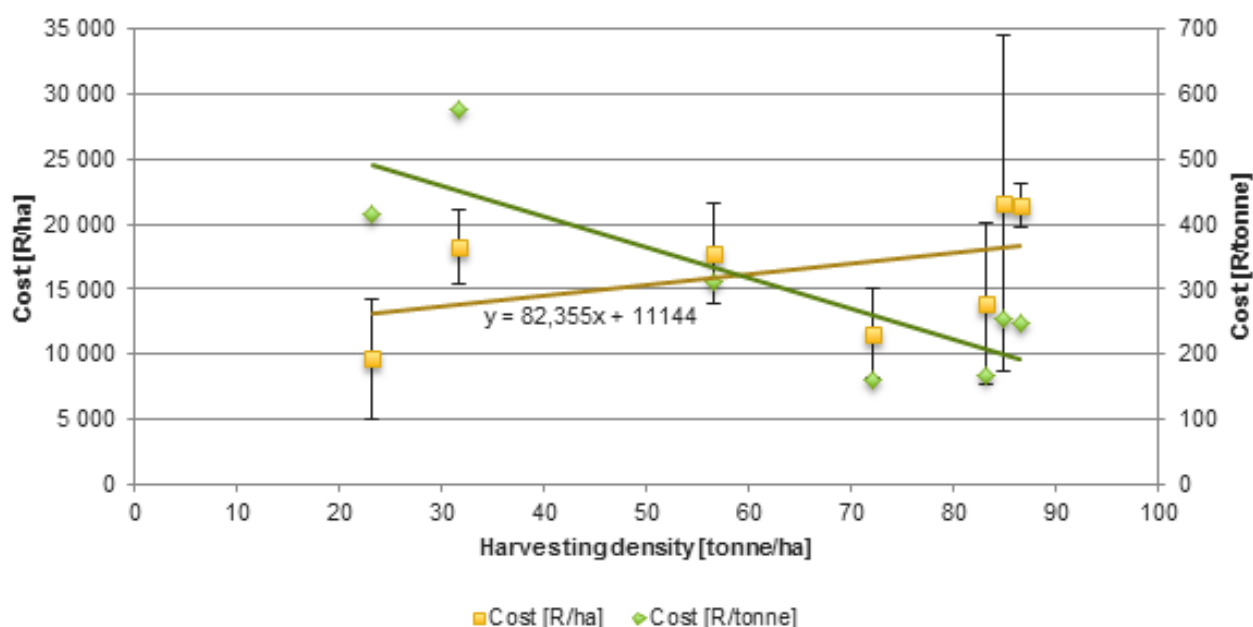


Figure 20: The relationships of harvesting and extraction cost to harvesting density of IAV species

For the purpose of the modelling, a straight line was fitted to the harvesting cost data (in R/ha) in Figure 20 and used to estimate harvesting cost based on the modelling input parameter of biomass harvesting density (in tonnes per hectare). This harvesting cost was inflated using the average Consumer Price Index (CPI) of 5.5% per year to obtain a value for 2015.

It is recognised that there is large variability in the data presented in Figure 20 and that it is limited to harvesting densities between 23 and 87 tonne per hectare, but this data was the most recent and applicable cost data for IAV species in South Africa that was publicly available at the time. Although a high-level trend was identified for the purpose of modelling, it is clear from the discussions thus far that harvesting cost is area- and site-specific and a more detailed site-specific assessment will need to be done to determine the harvesting cost in a specific area before individual projects are developed.

Value Chain 2 is the only route simulated utilising IAV at a centralised pyrolysis site to produce biochar, and therefore the only route that was tested for the sensitivity of the results to varying harvesting densities. Although IAV biomass density in South Africa ranges between 0 and 228 wet tonne/hectare (Von Maltitz & Stafford, 2012), there are only a few areas where it is available at densities above 100 tonne/ha. For this sensitivity analysis, it was assumed that the fitted linear relationship between harvesting density and cost (as presented in Figure 20) would hold for harvesting densities in the range of 10 to 100 tonne/ha. See Section 4.3.2 where the results of this assessment are presented.

A summary of the data and assumptions used in the modelling for this value chain stage are presented in Table 16.

Table 16: Harvesting process assumptions and data

Parameter	Value	Units	References/comments
Harvesting density	50	tonne/ha	Assumption
Harvesting cost at 50 tonne/ha density	17 000	R/ha	Calculation based on harvesting cost and density relationship
Percentage of biomass that can be guaranteed for harvesting and extraction	50	%	Assumption
Hours of harvesting per day	8	hours	Assumption
Biomass harvested per person per day	500	kg	Stakeholder information Source: Personal communication: Kobus Venter (Vuthisa Technologies), June 2015.

A2 Transportation cost and distance

Mugido et al. (2014) observed an average transportation cost of R2,50 per tonne.km (ranging between R1,09 and R4,63 per tonne.km) in their project. The latter study also reported a national average biomass transportation cost for 2013 of R1,10 per tonne.km, which was obtained from the RFA, but claimed that the actual observed costs were much higher due to the utilisation of outsourced contractors with non-customised bins (Mugido et al., 2014). Due to the lack of additional information on what costs were included in the figures reported by Mugido et al. (2014), RFA data from 2014 was used for the modelling done in the current study. A Type-11 TIP truck was selected as the transport vehicle, which has an average payload of 31.1 tonne and consumes 59 litres of fuel per 100 km. The average cost of operating this vehicle is R1,95 per tonne.km (including capital cost, fuel, maintenance and labour). This value was inflated with the average CPI of 5.5% per annum to obtain a value of R2,06 per tonne.km for 2015. Although this value is higher than the average 2013 RFA value of R1,10, it is still lower than the actual average observed transportation costs of R2,50 reported by Mugido et al. (2014).

The transportation distance for each project will differ on a daily basis, but for the purpose of modelling, an average harvesting radius is used. This average harvesting radius is the average one-way distance that the truck will travel to collect biomass over the lifetime of the project, and will vary depending on the landscape and biomass density of IAV in the area.

From literature (Mugido et al., 2014) and feedback from stakeholders, 50 km is typically used as a guideline for the maximum harvesting radius to ensure the economic viability of a harvesting operation for a centralised pyrolysis unit. The minimum harvesting radius was also calculated for harvesting densities between 1 and 100 tonne per hectare to determine the minimum land area required at specific biomass harvesting densities if 100% biomass cover within the radius were to be harvested to sustain the pyrolysis site for 20 years. Anywhere between the minimum and maximum harvesting radius is typically where biomass will be harvested, depending on the actual biomass densities in the area and its proximity to the pyrolysis site. An illustration of the different harvesting radius possibilities is presented in Figure 21.

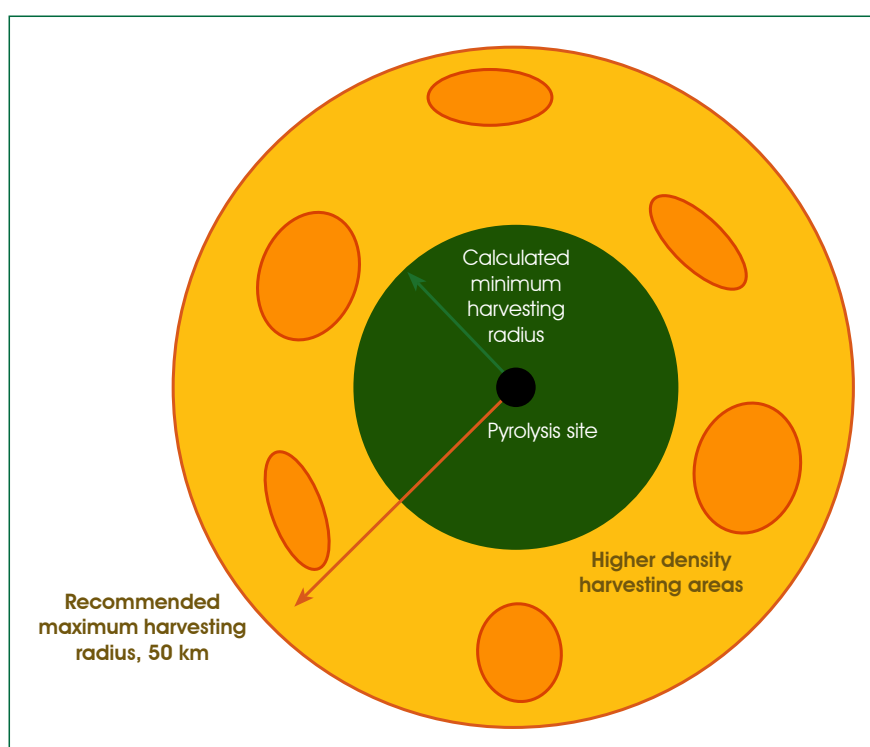


Figure 21: Harvesting radius illustration



Harvesting densities, along with the corresponding harvesting radius to the pyrolysis unit, as reported by Mugido et al. (2014), are plotted in Figure 22 (yellow data points). The error bars indicate variance in the harvesting radii at specific harvesting densities as reported in Mugido et al. (2014). Also plotted in Figure 22 is the recommended maximum harvesting radius and the calculated minimum radius for Value Chain 2 (this is the only centralised pyrolysis site simulated in the model that utilises IAV and produces biochar). It can be observed that the typical harvesting radii from literature for the various harvesting densities between 23 and 87 tonne per hectare fall between the minimum and maximum harvesting radii (yellow shaded area in Figure 22).

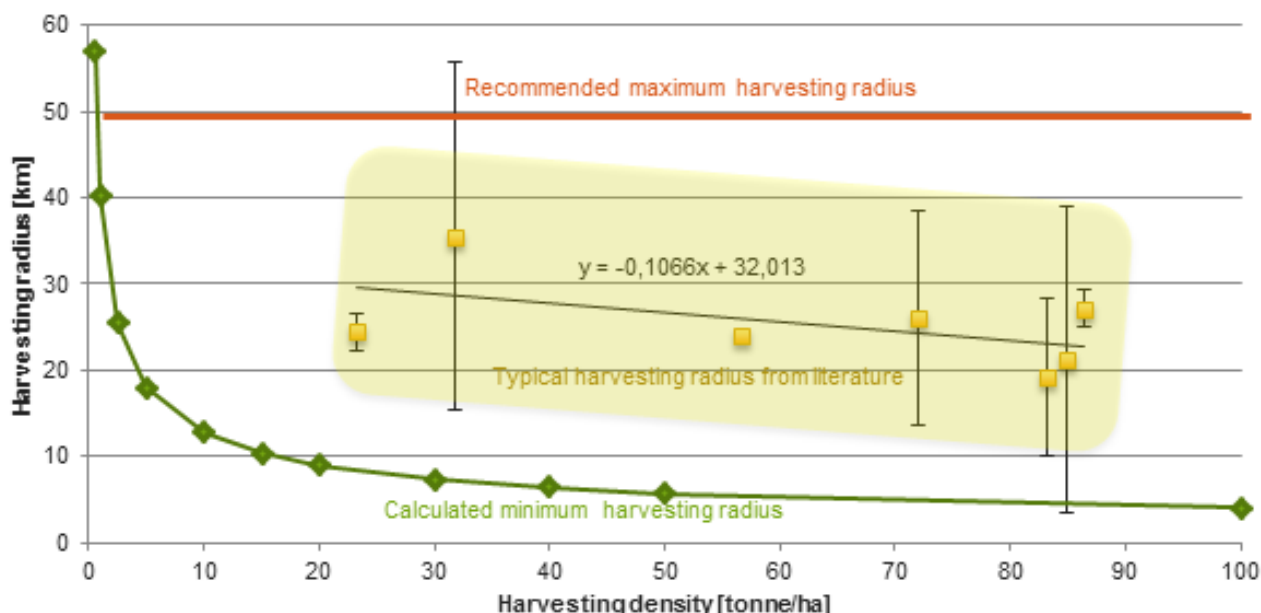


Figure 22: Harvesting radius and density

In the modelling, only value chains 2 and 3 require the transportation of harvested IAV to the site (Value Chain 1 operates at the harvesting site).

The biomass transport information used in the modelling is summarised in Table 17.

Table 17: Transport process assumptions and data

Parameter	Value	Units	References/comments
Transport cost	2,06	R/tonne.km	RFA 2014 document not publicly available: original value inflated with 5.5% CPI to obtain 2015 value
Conservative maximum harvesting radius	50	km	Assumption
Average payload	31.1	tonne	RFA 2014 document not publicly available
Average fuel consumption	59	litre/100 km	RFA 2014 document not publicly available
Jobs	1	person	Calculated based on number of trips with a 25-tonne truck; driver only

A3 Biomass conversion technologies

The information used for modelling the various biomass conversion routes (small- or large-scale pyrolysis and gasification) is provided in tables 18, 19 and 20.

Table 18: Mobile pyrolysis unit data and assumptions based on data supplied by Vuthisa Technologies

Parameter	Value	Units	Reference/comments
Feed rate	58	kg/hour	Vuthisa Technologies information This is based on a 700 kg batch process where 350 kg is used as fuel and 350 kg is converted to biochar; the process takes 12 hours per batch
Moisture content of feed	20	%	Vuthisa Technologies information
Biochar production	6.25	kg/ha	Vuthisa Technologies information
Concentration of carbon in biochar	72	%	Assumption to achieve the biochar output as per Vuthisa Technologies information
Capacity factor	68	%	Assumption based on working days in a year
Lifetime of equipment	2	years	Vuthisa Technologies information: this is an average value for the various pieces of equipment
Capital cost	21 514	Rand	Vuthisa Technologies information: this is only capital cost for equipment and does not include costs for the feasibility study, EIA or operating licences
Fixed operating and maintenance cost	15 615	Rand	Vuthisa Technologies information: average annual value for equipment needing to be replaced
Salary per person per day	100	Rand	Assumption
Jobs per site	1	number	Vuthisa Technologies information

Table 19: Centralised pyrolysis technology data and assumptions based on data supplied by Thermex Carbontech

Parameter	Value	Units	Reference/assumption
Feed rate	3 167	kg/hour	Thermex Carbontech information
Moisture content of feed	20	%	Thermex Carbontech information
Biochar production	475	kg/ha	Thermex Carbontech information
Concentration of carbon in biochar	80	%	Assumption to achieve the biochar output as per Thermex Carbontech information
For equipment without ORC: Process heat generated	3.6	MWh thermal	Thermex Carbontech information
For equipment with ORC: Electricity generated	2.2	MWh electrical	Thermex Carbontech information
Capacity factor	92	%	Assumption
Lifetime of equipment	20	years	Thermex Carbontech information
For equipment without ORC: Capital cost	17 000 000	Rand	Thermex Carbontech information: this cost is for a greenfields site and includes costs for the feasibility study, EIA and operating licences
For equipment with ORC: Capital cost	77 500 000	Rand	Thermex Carbontech information: this cost is for a greenfields site and includes costs for the feasibility study, EIA and operating licences
Fixed operating and maintenance cost as a percentage of capital cost	8	%	Thermex Carbontech information
Salary per person per day	500	Rand	Assumption
Jobs per site	42	number	Thermex Carbontech information



Table 20: Gasification technology data and assumptions based on data supplied by Prestige Thermal

Parameter	Value	Units	Reference/assumption
Feed rate	6 000	kg/hour	Prestige Thermal information
Moisture content of feed	30	%	Prestige Thermal information
Biochar production	0	kg/ha	Prestige Thermal information
Electricity generated in gas engine	4.96	MWh	Prestige Thermal information
Electricity generated in steam turbine	2.3	MWh	Prestige Thermal information
Parasitic load	0.76	MWh	Prestige Thermal information
Capacity factor	92	%	Assumption
Lifetime of equipment	20	years	Prestige Thermal information
Capital cost	230 000 000	Rand	Prestige Thermal information: this cost is for a greenfields site and includes costs for the feasibility study, EIA and operating licences
Fixed operating and maintenance cost as a percentage of capital cost	2	%	Prestige Thermal information
Salary per person per day	500	Rand	Assumption
Jobs per site	51	number	Thermex Carbontech information

A4 Carbon balance

The GHG emissions for each value chain are calculated for the purpose of comparing the carbon offset potential of the different value chains and to evaluate the impact of incorporating a carbon price into the economic assessment.

In calculating the emissions from a particular value chain, the boundaries must first be set for the assessment. The boundary for the life cycle GHG emissions of all the value chains was set as cradle-to-gate, i.e. all the upstream emissions from the sourcing of raw materials to the point of wholesale. Transportation to the site where the final product (charcoal or fertilizer for the baseline and biochar in the project case) is utilised is not included in the boundary. The GHG impact of transportation to the site of biochar utilisation versus transportation in the baseline of the product it replaces will differ on a project-by-project basis, and in calculating the net carbon benefit, the baseline should be compared to the project case. In other words, if biochar is transported approximately the same distance to the point of utilisation as the fertilizer it replaces, the net effect of transportation-based emissions will be zero.

The emissions associated with the individual value chains are compared to those from a baseline that would have happened in the absence of the project. The GHG baseline is defined separately for the feedstock utilised and the products produced in the value chains. A simplified carbon accounting approach was followed for the modelling presented, under which it is assumed that during the growth of biomass, CO₂ is absorbed from the atmosphere and converted into plant material (see Section 2.1.1). The carbon is assumed to be converted back to the same amount of CO₂ either by natural aerobic decomposition or by thermo-chemical oxidation if the biomass is burned.

Given this baseline, emissions in the value chains modelled resulting from the burning of biomass to provide energy to the process or emissions resulting from the utilisation of the final products produced from the biomass are considered to be equal to those in the baseline, and the biochar is assumed to be carbon-neutral. Although in reality, the process is more complex, this approach is universally accepted in GHG reduction programmes, as reflected in measurement and legislative proposals, implemented regulations and voluntary programmes surrounding biomass more broadly than just biochar.

For the products from the different value chains, the baseline is that of the product or energy source it displaces, i.e. the source of energy or product that would have been utilised in the absence of the products produced in the value chains (see Section 4.2.5). If the biochar is buried for the purpose of carbon capture, it will reduce CO₂ emissions by the equivalent amount of stable carbon that can be captured in the biochar, and be buried and remain in the ground. The amount of carbon in the biochar varies depending on the feedstock and technology used to produce it. Data used in this model related to the carbon concentration in the biochar produced in the different production processes is presented in Appendix A3.

As discussed, the stability of biochar is also important as it determines how long the carbon applied to the soil will remain sequestered. This is determined by a number of different factors, including feedstock type, soil type and climatic conditions. As a result, the amount of stable carbon that can be captured in the soil will be project- and site-specific. For the purpose of obtaining a high-level estimate of the carbon sequestration potential in the modelling, however, the decomposition rate of biochar from a recent study by Kuzyakov, Bogomolova and Glaser (2014) was used. This study, conducted in a controlled environment

over an eight-year period, found that the decomposition rate of biochar was 0.0007% per day. For this model, the decomposition rate was extrapolated over a 100-year period, assuming that this rate will stay constant, yielding 26% loss of biochar, and 74% of the carbon in the biochar will thus be sequestered. This is a very conservative assumption, as literature suggests that biochar in soil is very stable and that the decomposition rate will most likely reduce over time.

Based on the carbon in the biochar from each technology supplier (see Appendix A3) and the assumption of the sequestration potential of carbon in the soil, the mass of CO₂ sequestered per kg of biochar can be calculated. This calculation is based on the molecular weights of the molecules and the assumption that all released carbon will be converted to CO₂ in the atmosphere. Carbon has an atom mass of 12 g/mole and CO₂ a molecular mass of 44 g/mole. Each kg of carbon sequestered will therefore be equivalent to 3.67 kg of avoided CO₂ emissions. Multiplying this value with the value of carbon in the biochar from each technology supplier, and taking the sequestration potential of this carbon in the soil (74%), the calculated biochar CO₂ mitigation potential for the Vuthisa Technologies unit will be 1.97 kg CO₂e/kg of biochar, while for the Thermex Carbontech unit it will be and 2.18 kg CO₂e/kg.

Biochar has also been proven to improve soil quality and assist in restoring the nutrients in the soil, thereby reducing the need to use fertilizers. If biochar is used to replace fertilizers by adding it to agricultural soils, it will reduce emissions by capturing carbon in the soil, and avoid the emissions associated with the production of fertilizers. It is, however, unclear how much fertilizer can be offset by the use of biochar, and this will again be soil- and crop-dependent. For demonstration purposes, in the modelling, it was assumed that a 1:1 ratio could be used for replacing fertilizer with biochar (William & Qureshi, 2015). This is a conservative assumption, as biochar will

stay in the soil and reduce the fertilizer requirements over subsequent years.

In addition to the potential of biochar to sequester carbon and reduce the requirement for fertilizers when used in agricultural land, biochar also has the potential to reduce soil N₂O emissions, which will further increase the GHG mitigation potential of biochar. There is, however, uncertainty regarding the quantification of this potential in the literature, and this consideration was therefore conservatively excluded from this study.

If biochar is used as a charcoal to replace coal for combustion, it will reduce the emissions associated with the burning of coal. Biochar typically has a similar or higher calorific value than coal and is, therefore, conservatively assumed to replace coal at a 1:1 ratio. This is, however, subject to the quality of biochar utilised and the type of coal it will be replacing, which should be assessed on a project-by-project basis.

In addition to the biochar product, some value chains produce electricity and/or heat, which will further reduce project emissions by offsetting the emissions in the baseline associated with the generation of energy from fossil fuels. These offsets are included in the model.

Additional GHG emissions can result from the burning of diesel or petrol consumed during harvesting, extraction and transportation, as well as any fossil fuels used as start-up fuel or co-combusted in the pyrolysis process. For the value chains simulated in this model, diesel consumed for transportation is accounted for, although the emissions associated with harvesting and extraction are assumed to be negligible. There are also assumed to be little or no co-combustion or start-up fossil fuel requirements for the selected pyrolysis or gasification technologies.

All emission factors and assumptions used in the modelling of carbon emissions are presented in Table 21.

Table 21: Carbon balance input parameters

Parameter	Value	Units	Reference/assumption
Percentage of biochar loss over 100 years	26	%	Daily rate from Kuzvakov et al. (2014); assumed applicable for 100 years
Biochar carbon emissions avoided by carbon sequestration – Vuthisa Technologies	1.97	kg CO ₂ e/kg	Calculation
Biochar carbon emissions avoided by carbon sequestration – Thermex Carbontech	2.18	kg CO ₂ e/kg	Calculation
Diesel direct-burning emission factor	2.67	kg CO ₂ e/litre	Defra, 2015
Diesel well-to-wheel emission factor (emissions associated with the production of petroleum diesel)	0.58	kg CO ₂ e/litre	Defra, 2015
Coal direct-burning emission factor	2 356.62	kg CO ₂ e/tonne	Defra, 2015



Parameter	Value	Units	Reference/assumption
Coal upstream emissions (emissions associated with the mining of coal)	376.80	kg CO ₂ e/tonne	Defra, 2015
Grid emission factor for South Africa	0.94	kg CO ₂ e/kWh	(Unaudited) data provided by the National Business Initiative (NBI) – update of the figures contained in a Marginal Abatement Cost Curve (MACC) consulting publication.
Grid emission factor for transmissions and distribution losses	0.09	kg CO ₂ e/kWh	Defra, 2015
Grid emission factor for the upstream emissions associated with the production of electricity (all emissions upstream of the power plant)	0.12	kg CO ₂ e/kWh	Defra, 2015
Urea fertilizer cradle-to-gate emissions (emissions associated with the production of urea fertilizer to the point of the finished product at the production facility)	3.21	kg CO ₂ e/kg	Ecoinvent database

A5 Financial input parameters

A summary of the financial input parameters used in the modelling is presented in Table 22.

Table 22: Financial input parameters

Parameter	Value	Units	Reference/assumption
Average electricity price (2015)	0,90	R/kWh	Assumption
Average cost of process heat (2015)	11	R/GJ	Assumption
Annual electricity price increase	8	%	Assumption based on the National Energy Regulator of South Africa (NERSA)-approved 8% annual price increases as per the original Multi-year Price Determination (MYPD) 3 decision
CPI	5.5	%	Assumed as an average, based on historical trends: http://www.inflation.eu/inflation-rates/south-africa/historic-inflation/cpi-inflation-south-africa.aspx
Interest rate on debt	9.25	%	http://www.tradingeconomics.com/south-africa/bank-lending-rate
Cost of equity	15	%	Assumption based on IRR required by investors
Debt repayment period	15	years	Assumption
Debt ratio	90	%	Assumption
Equity ratio	10	%	Assumption
Depreciation for value chains generating electricity	50/30/20	%	Accelerated depreciation as per South African Revenue Service (SARS) allowance for renewable energy projects: http://www.thesait.org.za/news/98547/Depreciation-of-supporting-structures-for-renewable-energy-projects.htm
Depreciation for Value Chain 1	50/50	%	Straight-line depreciation over lifetime of equipment (assumption)
Depreciation for Value Chain 5	20/20/20/20/20	%	Straight-line depreciation over five years (assumption according to allowed write-off period for generators by SARS)
CO ₂ e price	100	R/tonne CO ₂ e	Assumption

APPENDIX B: SUSTAINABILITY CONSIDERATIONS

The IBI has developed guiding principles for assessing the sustainability of biochar production, which include socioeconomic and environmental considerations. These are as follows:

Environmental outcomes

- **Soil health:** Biochar should be used to maintain and enhance soil fertility, particularly in marginal or degraded agricultural soils, and should not lead to soil degradation by nutrient export via feedstock removals or other management practices.
- **Climate stability:** Biochar systems should be at least GHG-neutral and preferably GHG-negative, and should be used to draw down atmospheric carbon by creating and enhancing stable soil carbon sinks, to alleviate GHG emissions associated with the decomposition and combustion of biomass residuals, and to offset fossil fuel use through bio-energy production.
- **Energy efficiency and conservation:** Biochar production systems should result in neutral or preferably net energy export, and, when appropriate, should recover and use process heat and syngas and/or bio-oil by-products for energy production.
- **Feedstocks:** Biochar systems should prioritise the use of biomass residuals for biochar production.
- **Biochar production:** Biochar production systems should be safe, clean, economical and efficient, and should meet or exceed the environmental standards and regulatory requirements of the regions where they are deployed.
- **Biochar quality:** Biochar should be characterised to demonstrate carbon stability, and to identify properties for matching biochar to complementary cropping systems.
- **Biological diversity:** Biochar should promote above- and below-ground biodiversity by enhancing the ecological conditions for biodiversity at the local and landscape level, and biochar systems should avoid the conversion of native ecosystems and high conservation-value habitats.
- **Water:** Biochar systems should not pollute or degrade water resources, and should promote the efficient utilisation of water resources in agricultural production, and respect customary water resource rights, where applicable.

Social outcomes

- **Food security:** Biochar systems should not jeopardise food security by displacing or degrading land grown for food, and should seek to complement existing local agro-ecological practices.
- **Local communities:** Biochar systems should involve stakeholders fully and transparently in planning and implementation, respect local land-use rights, and not result in the displacement of people from their ancestral lands.
- **Biochar knowledge societies:** Biochar operations and the biochar industry should be continuously improved through research, education and the open sharing of scientific and traditional knowledge.

Economic outcomes

- **Labour rights:** Biochar systems should not violate labour rights, and should commit to safe and fair labour practices, including equitable compensation, benefit-sharing, and training and development opportunities.
- **Economic development:** Biochar systems should contribute to the economic development of local communities, especially in regions of poverty.

Source: <http://www.biochar-international.org/>



APPENDIX C: SCOPING OF A PILOT PROJECT

C1 Description of the pilot site

The aim of this pilot project is to address some of the research gaps that have been identified by this study. A pilot project aims to add to ongoing research specific to the South African context, and should provide insights not only into the potential for the large-scale production and application of biochar in the country, but also into the local economic, social and environmental impacts of biochar production.

C1.1 Location

The proposed pilot site is located in George's Valley on the R528 between Polokwane and Tzaneen in the Mopani District Municipality (Limpopo). It is located on the Great Letaba River that flows between Ebenezer Dam and Tzaneen Dam. The surrounding area is a fertile high-rainfall region with tropical and subtropical agriculture taking place. A wide variety of fruit is grown in the region, notably mangoes, bananas, oranges, tomatoes and avocados. The area is also the biggest timber-producing region in Limpopo, with Pine and Eucalyptus plantations supplying a number of sawmills in the valley.

C1.2 Overview of the Sustainable People's Project

The Sustainable People's Project (SPP) is a cooperative of land owners based in and around George's Valley with the stated goal of building relationships between government, industry and local communities to create sustainable solutions to existing challenges around food, energy and waste. The pilot study would take place at one of the sites in the project that already acts as a central hub for stakeholders and currently provides education, training and various workshops around sustainability issues. Furthermore, there are already biochar production and application activities at the site, as discussed below.

C1.3 Motivation for pilot study

There are a number of reasons why this site was selected as a potential location for a pilot study. Firstly, there are numerous anthropogenic challenges currently facing the area, including the following:

- Waste management challenges, particularly waste from the sawmills
- Deterioration of air quality from the open burning of sawmill waste
- Water pollution from sawmill waste
- Water consumption and biodiversity loss due to encroachment of IAV in the area

George's Valley has about 35 sawmills, which generate waste in the form of timber and sawdust in the range of 50 to 100 tonnes a day. Currently, the sawmill waste is burnt daily, thereby contributing to environmental deterioration. The manufacture of biochar from sawmill waste presents the opportunity to address these challenges. The area is also infested with IAV. The harvesting of IAV and using it as feedstock to produce biochar could contribute to arresting biodiversity loss and improving stream flow in the area.

As described earlier, there are also multiple land-use activities in the area, and so it offers an opportunity to set up a long-term research experiment to assess the soil/biochar/crop interactions, possibly in partnership with the University of Limpopo.

Finally, the pilot study would present an opportunity to show the socioeconomic potential of a biochar industry. These include skill and job creation, as well as the development of the rural economy.

C2 Activities to date

As indicated above, the SPP has already begun producing biochar on a small scale. While in this study the term biochar is used to refer to a product that is used as a soil amendment, the team at SPP have also been experimenting with a number of other potential uses for the char product. These include using it for one of the following purposes:

- An additive to chicken feed to reduce ammonia emissions in broilers
- Feedlot bedding
- A filter in aquaponics systems
- Hazardous waste/sewage clean-up materials
- An additive to compost

It should also be noted that the SPP is already involved in a number of activities, including compost production, agriculture, permaculture and aquaculture, as well as a number of social development projects.

C3 Description of the pilot project

The pilot project will consist of two main activities:

- Construction and operation of pyrolysis equipment for biochar production, which includes two sub-activities:
 - The construction of a large centralised facility for the production of biochar using waste from the surrounding sawmills
 - The construction of a workshop and training centre that will manufacture mobile pyrolysis

units and rocket stoves for the production of biochar from IAV

- The long-term monitoring of biochar, soil and crop interactions.

The large centralised biochar facility will be constructed on property owned by one of the participants in the SPP. This property has good access to roads and is close to a number of large sawmills. The plant will have a maximum design capacity of 120 tonnes of sawmill waste per day. Initially, the plant will be constructed to maximise the production of biochar and bio-oils, as the SPP has already identified a large commercial client who is willing to purchase the project's bio-oil to use as a replacement for creosote for wood preservation. There is also the option of producing electricity from the syngas product in the future, but the cost of a generator was not included in this initial scope. The biochar product will be sold to the commercial agriculture and forestry market.

The second facility, which includes the establishment of a workshop and training centre, will also be constructed on the property with the aim of developing skills and creating jobs by manufacturing mobile pyrolysis units. Skills taught will include practical construction and welding skills, as well as pyrolysis technology development and manufacture. This would include equipment procurement. In total, the workshop will manufacture 30 mobile units for in-situ biochar production from IAV over a one-year period, with the possibility of manufacturing another 30 units over the next year if the project is demonstrated to be successful.

The workshop will also build 1 000 rocket stoves. A rocket stove is a small, clean-burning and efficient cook stove. These will provide people in the surrounding community with alternative stoves that can simultaneously produce biochar on a small scale for local use, for either cooking or applying the biochar to their own gardens. This, in turn,

has the potential to contribute to rural food production and food security.

The pilot study will also aim to begin developing a local market for biochar. Target customers include large-, medium- and small-scale farmers for the biochar product, and the sawmills in the area for the bio-oil products. The SPP will advertise through several key media sources and will construct a website for educational purposes and online sales.

For the second activity, which focuses on researching and monitoring the long-term interactions of biochar, soil and crops, a partnership with an academic institution is envisioned. The University of Limpopo has already expressed an interest in working with the SPP to monitor various aspects of the effects of using biochar as a soil amendment and mitigation measure. This component of the work has not been scoped further here, but will need to be developed in conjunction with the University.

C4 Funding requirements

Tables 23, 24 and 25 show the breakdown of the required funds for the components of the pilot study related to biochar manufacture. The total cost is estimated to be to the order of R4 925 000 including VAT for both activities over a period of two years. For the centralised pyrolysis unit, two phases of funding would be sought, the first being for preparation and site licensing, and the second for project implementation, which would be contingent on successful completion of the first phase. Similarly, for the workshop construction and mobile units, funding would be sought for the first year, with the option to renew funding for a second year if the training of artisans and the construction and running of the mobile units is successful. Ideally, however, in order to streamline communication and reporting, all funding would be procured from a single funder.

Table 23: Funding requirements for centralised pyrolysis unit

Description	Cost
Labour	R2 184 000
Transport	R120 000
Electricity	R42 000
Administration	R77 000
Materials	R900 000
Total	R3 323 000

Table 24: Funding requirements for workshop and mobile units

Description	Cost
Labour/training	R649 000
Administration	R10 000
Materials/tools	R693 000
Total	R1 352 000



Table 25: Regulatory requirement costs

Description	Cost
Licensing and regulations	R250 000

It is noted that the cost of research for conducting the soil/biochar/crop interactions has not been included, as this will need to be determined in conjunction with the University of Limpopo. Similarly, the cost of any consultant fees and laboratory work that may need to be conducted with regard to the licensing and regulatory requirements is also excluded.

C5 Project time lines

It is estimated that the pilot project would run over a two-year period with the long-term research and monitoring continuing into the future. Table 26 shows a breakdown of the pilot study time line.

For the centralised pyrolysis unit, the first 18 months would be a preparatory phase. This would include the preparation of a detailed project design, business plan and the fulfilment of all permitting requirements – with the latter being the key bottleneck in moving into the construction phase. The following six months would see the construction and testing of the large centralised unit. The workshop construction and manufacture of the mobile units would run concurrently during the first year, and if successful, will be continued for the second year.

Table 26: Project implementation

Activity	Month								
	1–6	7–12	13–18	19	20	21	22	23	24
Centralised unit (Phase 1)									
Design, preparation and licensing									
Centralised unit (Phase 2)									
Ground preparation									
Slab/foundation									
Construction									
Assembly									
Testing									
Workshop and mobile units									
Workshop construction/mobile unit manufacture									

C6 Expected benefits and success criteria

A number of benefits are expected from this pilot study. Most importantly, the project aims to demonstrate the technical and economic potential for the production of biochar in South Africa. Hopefully, this will drive the industry forward in South Africa and pave the way for future technology development and commercial growth. It is also expected that this study will demonstrate whether there is potential to scale biochar production and, from the results of the field research study, determine if there is potential to sequester carbon at a meaningful level.

The pilot study also aims to demonstrate the socioeconomic benefits that can potentially be created through the production and application of biochar as a mitigation measure in South Africa. A small number of

jobs will be created by the large centralised pyrolysis unit, with five people being employed for the construction of the unit and ten people to operate the unit. The workshop will employ six people. These people would then be able to train others to construct or operate their own mobile pyrolysis units. The mobile units built in the workshop will need one operator for every three units. This would result in a total of 20 people being employed as operators of the mobile units during the pilot study.

Another important expected benefit of the project will be a greater understanding of how biochar interacts with the soil once it has been added to it, and what impacts this will have on crop yield, through the research component in collaboration with the University of Limpopo.

C7 Licensing and regulatory considerations

There are a number of prerequisites that will have to be met for this pilot project to move ahead. These are the licensing and policy requirements that relate to the production of any char, charcoal or carbon black product in South Africa.

Firstly, the pilot project will require a full S&EIR in terms of the EIA Regulations. It is understood that the services of a consultant to conduct the EIA will be obtained through the SPP consortium at no cost. If this is not the case, provision will need to be made for this cost component of the project. Further costs may also be incurred to draft the specialist reports required to complete the assessment.

The pilot study will be producing more than 20 tonnes of product per month, and will therefore also need an AEL, as the production of char is included in the listed activities under the National Environmental Management: Air Quality Act (NEM: AQA). The AEL needs to be renewed every five years. The storage and treatment of biomass and agricultural waste for the production of biochar on the scale presented in the report also requires a waste management licence.

If biochar is to be sold as a soil amendment and marketed as a compost or fertilizer, it may need to be registered under the Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act. Although the regulations do not specifically make reference to char, biochar or carbon as a soil amendment, if biochar is sold under any of the product names defined in the regulations it will need to meet specific requirements. A Group 3 fertilizer, for example, is defined as a fertilizer containing natural or synthetic substance(s) or organism(s) that improve(s) or maintain(s) the physical, chemical or biological condition (fertility) of the soil; and “soil improver” has the same meaning. It takes about three to six months for a Group 1 fertilizer application to be processed, and the registration must be renewed every three years.

Finally, consideration should be given to the fact that there might be design standards that need to be met with regard to the rocket stoves. If they are to be sold to the general public, addition costs may be incurred to achieve a rating by the South African Bureau of Standards (SABS).

C8 Risks

A selection of risks has been identified. The first of these is that the production of biochar at scale is unproven in South Africa at this time. Secondly, there is a risk associated with this particular project in that all the intellectual property is currently vested in one or two people, although this will be mitigated over time through the workshop's skills development programme and training, which will bring about technology transfer. Finally a good project manager is required to drive this project to completion.

In terms of biochar application, it is recognised that soil-biochar interactions are complex, and not very well understood. The pilot project will only go some way in taking the advancement of this knowledge forward. Large-scale, multi-year research projects are required to contribute to the advancement of this understanding.



APPENDIX D: DETAILS OF STAKEHOLDER ENGAGEMENT

A number of stakeholders were consulted in order to inform this study. These included technology providers, researchers and practitioners. Table 27 indicates the extent of stakeholder engagement that took place during this study. A workshop on value-added industries around IAV, organised by the DEA and hosted at the CSIR in Stellenbosch, was also attended on 22 April 2015.

Table 27: Stakeholder engagement

Stakeholder	Organisation	Date of meeting	Topics discussed
Ailsa Hardie	University of Stellenbosch, Department of Soil Science	22 July 2015	Biochar as a soil amendment
Ahmed Khan	DEA	22 April 2015	IAV
Marius van der Merwe	PM Consult	22 April 2015	IAV
David Phillips	Private	22 April 2015	IAV
William Stafford	CSIR	26 February 2015	IAV Biochar and soil interactions Available data Potential business models Biochar projects in South Africa Potential stakeholders
Sarah Polonsky	DEA	16 March 2015	IAV Biochar projects in South Africa Potential stakeholders
Ahmed Khan	DEA	16 March 2015	IAV Biochar projects in South Africa Potential stakeholders
Grant Trebble	SANParks/WESSA – KwaZulu-Natal	20 March 2015	IAV Eco-furniture and waste Socioeconomic benefits Potential business models Stakeholders Data availability
Kobus Oosthuizen	Casidra	25 March 2015	IAV Western Cape.
Michael Braack	DEA	22 April 2015	IAV Technical data
James Blignaut	University of Pretoria	22 April 2015	IAV Technical data
Luanita van der Walt	CSIR	22 April 2015	Biochar
Loutjie Theron	Wood@Heart	22 April 2015	Biochar production

Stakeholder	Organisation	Date of meeting	Topics discussed
Kobus Venter	Vuthisa Technologies	15 May 2015	Pyrolysis technology Economic data Technical data Socioeconomics
Jan Davel	OneGreen	16 May 2015	Pyrolysis technology Economic data Technical data Socioeconomics
Richard Bingham	Prestige Thermal	17 May 2015	Pyrolysis technology Gasification technology Economic data Technical data
Brian Barnard	Thermex Carbon	18 May 2015	Pyrolysis technology Economic data Technical data
Janine Abrams	SPS	25 to 27 May 2015	Feedstock availability Business model
Alwyn van den Berg	SPS	25 to 27 May 2015	Technical data
Amie van der Walt	SPS	24 May 2015	Pyrolysis technology
Peter Mudau	University of Limpopo (Risk and Vulnerability Centre)	27 May 2015	Technical data Biochar and agricultural productivity Potential research groups



APPENDIX E: POLICY AND REGULATORY FRAMEWORK CONSIDERATIONS

This section considers the national policies and legislation that may be applicable to the production of biochar in South Africa. Provincial legislation and municipal by-laws are not discussed, although it is noted that biochar projects may be subject to additional provincial and municipal regulations, depending on the location and nature of the project.

E1 National Environmental Management Act (Act No. 107 of 1998)

The National Environmental Management Act (NEMA) covers all aspects of environmental management in South Africa, including air quality, pollution and waste management (Republic of South Africa, 1998). Under Chapter 5 of NEMA, activities that affect the environment require an environmental authorisation from a competent authority before they may proceed. EIA is the principal tool for assessing listed activities. The application for an environmental authorisation is managed by an environmental assessment practitioner.

The most recent EIA Regulations were published by DEA in December 2014 (Republic of South Africa, 2014a). The listing notices associated with the Regulations identify the activities for which an environmental authorisation is required. Activities contained in Listing Notice 1 and Listing Notice 3 (which related to activities taking place in specific geographical areas) require a basic assessment. A basic assessment takes about six to nine months to complete. Activities contained in Listing Notice 2 require a full S&EIR, which can take about 12 to 18 months to complete.

Biochar production processes may fall under Listing Notice 2, Activity Number 28, which applies to:

Commencing of an activity, which requires an AEL in terms of section 21 of the National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004), excluding:

- Activities that are identified and included in Listing Notice 1 of 2014
- Activities that are included in the list of waste management activities published in terms of section 19 of the National Environmental Management: Waste Act, 2008
- The development of facilities or infrastructure for the treatment of effluent, wastewater or sewage where such facilities have a daily throughput capacity of 2 000 m³ or less.

A biochar project that falls under this description would therefore require an S&EIR. Fees for the consideration and processing of applications for environmental authorisations are as follows (Republic of South Africa, 2014b):

- Application for an environmental authorisation for which a basic assessment is required in terms of the EIA Regulations: R2 000
- Application for an EA for which an S&EIR is required in terms of the EIA Regulations: R10 000

These costs do not include consultant fees, which will vary depending on the nature of the project and the number of specialist reports required to complete the assessment.

E2 National Environmental Management: Air Quality Act (Act No. 39 of 2004)

The objective of the National Environmental Management Act: Air Quality Act (Act No. 39 of 2004) is to protect the environment by enhancing air quality, preventing air pollution and securing ecologically sustainable development (Republic of South Africa, 2004). The NEM: AQA identifies a list of activities, which result in atmospheric emissions that have a significant detrimental effect on the health of people and the environment (Republic of South Africa, 2013a), as amended in the amendments to the NEM: AQA (Republic of South Africa, 2015c). Associated minimum emission standards are defined for each of these listed activities, and an AEL or provisional atmospheric emissions licence is required to conduct a listed activity. The production of biochar is included in the listed activities under section 21 of NEM: AQA, Category 3 (carbonisation and coal gasification), Subcategory 3.4 (char, charcoal and carbon black production). Details pertaining to this subcategory and the associated minimum emission standards are given in Table 28.

Table 28: Description, applicability and minimum emission standards for char, charcoal and carbon black production as given in section 21 of the National Environmental Management: Air Quality Act

Description:	Production of char, charcoal and the production and use of carbon black		
Application:	All installations producing more than 20 tonnes of char or charcoal per month Installations consuming more than 20 tonnes per month of carbon black in any processes		
Substance or mixture of substances	Chemical symbol	Plant status	Limit value (dry mg/Nm ³) under normal conditions of 273 Kelvin and 101.3 kPa
Common name			
Particulate matter	N/A	New	50
		Existing	100
Polycyclic aromatic hydrocarbons	PAH	New	0.1
		Existing	0.5

In April 2015, DEA released the draft declaration of small-scale char and small-scale charcoal plants as controlled emitters under section 23(1) of the NEM: AQA, for which comments had to be submitted by 4 May 2015 (Republic of South Africa, 2015a). The declaration seeks to make the same emission limits, as given in Table 28, applicable to char plants and charcoal plants with a design production capacity not exceeding 20 tonnes of product per month. If this declaration comes into effect unchanged, the result will be that all biochar installations, regardless of production capacity, will require an AEL in order to operate legally. The holder of an AEL is required to monitor emissions and submit an Annual Emissions Report to the national air quality officer in the required format.

Draft regulations prescribing the AEL processing fee were published by DEA in June 2015 (Republic of South Africa, 2015b). The following processing fees are prescribed for activities listed under Category 3 in section 21 of the NEM: AQA:

- New application: R150 000
- Review: R75 000
- Renewal: R150 000
- Transfer: R2 000 (this is applicable in the event that ownership of an activity is transferred to a new owner)

It is not clear whether the same processing fees would apply to small-scale char producers, since this activity is defined under section 23(1) of the NEM: AQA. These costs do not include the fees charged by consultants contracted to compile an atmospheric emissions inventory. Renewal needs to be done every five years, and the review is conducted by an air quality officer. This happens when there has been a change in technology or production quantities.

E3 National Environmental Management: Waste Act (Act No. 59 of 2008)

The National Environmental Management: Waste Act (Act No. 59 of 2008) (NEM: WA) regulates the management of waste in South Africa for the prevention of pollution and ecological degradation (Republic of South Africa, 2008). Under the NEM: WA, waste management activities identified in section 19 require a waste management licence (Republic of South Africa, 2013b). Waste management activities requiring a waste management licence are divided into three categories:

- Category A: Activities listed under this category require a basic assessment procedure as set in the EIA Regulations.
- Category B: Activities listed under this category require a full S&EIR procedure as set in the EIA Regulations.
- Category C: Activities listed under this category require compliance with the Norms and Standards for Storage of Waste (2013), the Standards for Extraction, Flaring or Recovery of Landfill Gas (2013) and the Standards for Scrapping or Recovery of Motor Vehicles (2013).

These requirements must be met as part of the application for a waste management licence. The storage and treatment of biomass and agricultural waste for the production of biochar may fall under one of the categories for which a waste management licence is required, depending on the material being treated and the scale of the activity. Activities that may require a waste management licence in the context of biochar production are summarised in Table 29.



Table 29: Waste management activities that may be applicable to the production of biochar that require a waste management licence under the National Environmental Management: Waste Act

Category	Type of waste management activity	Specific waste management activity
Category A	Storage of waste	The storage of general waste in lagoons.
	Recycling or recovery of waste	The sorting, shredding, grinding, crushing, screening or bailing of general waste at a facility that has an operational area in excess of 1 000 m ² .
	Treatment of waste	The treatment of general waste using any form of treatment at a facility that has the capacity to process in excess of 10 tonnes, but less than 100 tonnes (note that the time period is not specified in the legislation, but it is assumed to be per day).
		The treatment of hazardous waste using any form of treatment at a facility that has the capacity to process in excess of 500 kg, but less than 1 tonne per day, excluding the treatment of effluent, wastewater or sewage.
	Construction, expansion or decommissioning of facilities and associated structures and infrastructure	The construction of a facility for a waste management activity listed in Category A (not in isolation to an associated waste management activity).
	Disposal of waste on land	The disposal of general waste to land covering an area of more than 50 m ² , but less than 200 m ² , and with a total capacity not exceeding 25 000 tons.
The disposal of inert waste to land in excess of 25 tonnes, but not exceeding 25 000 tons, excluding the disposal of such waste for the purposes of levelling and building, which has been authorised by or under other legislation.		
Category B	Storage of hazardous waste	The storage of hazardous waste in lagoons, excluding the storage of effluent, wastewater or sewage.
	Reuse, recycling or recovery of waste	The recovery of waste, including the refining, utilisation, or co-processing of the waste at a facility that processes in excess of 100 tonnes of general waste per day or in excess of 1 tonne of hazardous waste per day, excluding recovery that takes place as an integral part of an internal manufacturing process within the same premises.
	Treatment of waste	The treatment of hazardous waste in excess of 1 tonne per day, calculated as a monthly average, using any form of treatment, excluding the treatment of effluent, wastewater or sewage.
		The treatment of general waste in excess of 100 tonnes per day, calculated as a monthly average, using any form of treatment.
	Construction of facilities and associated structures and infrastructure	The construction of a facility for a waste management activity listed in Category B (not in isolation to an associated waste management activity).
	Disposal of waste on land	The disposal of any quantity of hazardous waste to land.
		The disposal of general waste to land covering an area in excess of 200m ² , and with a total capacity exceeding 25 000 tonnes.
The disposal of inert waste to land in excess of 25 000 tons, excluding the disposal of such waste for the purposes of levelling and building, which has been authorised by or under other legislation.		
Category C	Storage of waste	The storage of general waste at a facility that has the capacity to store in excess of 100 m ³ of general waste at any one time, excluding the storage of waste in lagoons or the temporary storage of such waste.
		The storage of hazardous waste at a facility that has the capacity to store in excess of 80 m ³ of hazardous waste at any one time, excluding the storage of hazardous waste in lagoons or the temporary storage of such waste.

The following definitions from the NEM: WA are applicable to the waste management activities described in Table 29:

- **Hazardous waste** is defined as any waste that contains organic or inorganic elements or compounds that may, owing to the inherent physical, chemical or toxicological characteristics of that waste, have a detrimental impact on health and the environment. This definition may apply to certain biochar feedstocks, although most feedstocks are likely to be classified as general waste.
- **General waste** is defined as waste that does not pose an immediate hazard or threat to health or to the environment. It includes domestic waste, building and demolition waste, business waste, inert waste and any waste classified as non-hazardous.
- **Lagoons** refer to the containment of waste in excavations and include evaporation dams, earth cells, sewage treatment facilities and sludge farms.
- **Temporary storage** means the once-off storage of waste for a period not exceeding 90 days.

Waste feedstocks used in the production of biochar may be classified as hazardous or general waste, depending on their properties. The types of waste listed in Table 30 are defined under the NEM: WA and may be relevant in the context of biochar production.

Table 30: Waste types defined under the National Environmental Management: Waste Act, which may be applicable in the context of biochar production

Waste type	Applicability to biochar production
Waste from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing	This includes waste such as animal manure that may be used for the production of biochar.
Waste from wood processing and the production of panels and furniture, pulp, paper and cardboard	Sawmill waste may fall under this category – in a basic assessment report done for Sappi in 2012, bark, shavings and sawdust from wood processing were defined as general waste in a judgement by the competent authority (WSP Environment & Energy, 2012).
Waste from waste management facilities (including the hazardous portion of waste from incineration or the pyrolysis of waste)	This definition may be applicable to ash from the biochar production process, which cannot be used as biochar or charcoal.

It is noted that IAV and plant residues from the clearing of IAV do not appear to be covered under any of the waste categories defined under the NEM: WA. Nonetheless, a waste management licence may still be required for activities using IAV as a feedstock, depending on the amount of waste produced from biochar production and how it is managed.

For biochar feedstocks that fall under the categories defined under the NEM: WA and that are classified as general waste, a waste management licence should not be necessary, provided that the following conditions apply:

- Feedstocks are stored, if necessary, in a facility with a capacity of under 100 m³ (excluding lagoons)
- The processing of feedstocks (such as shredding and grinding) takes place in an operational area of under 1 000 m², if necessary

- Less than 10 tonnes per day of feedstock are processed to produce the biochar
- General waste produced from biochar production occupies less than 50 m² of land

These conditions are likely to be applicable to small-scale or mobile biochar production units such as Vuthisa Technologies' mobile pyrolysis unit, which can process 700 kg of feedstock in 12 hours.

For the consideration and processing of waste management licence applications, a fee of R2 000 is charged for applications for which a basic assessment is required (Republic of South Africa, 2014c). Applications that require a full S&EIR are charged a fee of R10 000 to process. Renewing a waste management licence will cost R2 000.



E4 Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act No. 36 of 1947)

If biochar sold as a soil amendment is marketed as a compost or fertilizer, it will need to be registered under the Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act No. 49 of 1996), Regulations Regarding Fertilizers (Republic of South Africa, 2012). The Regulations do not specifically make reference to char, biochar or carbon as a soil amendment, but if biochar is to be sold under any of the product names defined in the Regulations, it will need to meet specific requirements.

Fertilizer is defined in the Regulations as any substance that is intended or offered to be used for improving or maintaining the growth of plants or the productivity of the soil. The Regulations categorise fertilizers in the following groups:

- Group 1, which is a fertilizer containing a total equal to or greater than 100 g/kg of nitrogen (N), phosphorus (P) or potassium (K), or any combination thereof
- Group 2, which is a fertilizer containing a total of less than 100 g/kg of N, P or K or any combination thereof, or any other recognised plant nutrient(s) in acceptable amounts
- Group 3, which is a fertilizer containing natural or synthetic substance(s) or organism(s) that improve(s) or maintain(s) the physical, chemical or biological condition (fertility) of the soil, and a “soil improver”, which has the same meaning.

Organic fertilizers are defined as fertilizers manufactured from substances of animal or plant origin, or a mixture of such substances, and that are free of any substances that can be harmful to man, animal, plant or the environment, containing at least 40 g/kg of prescribed plant nutrients.

Compost is defined as a stabilised, homogenous, fully decomposed substance of animal or plant origin to which no plant nutrients have been added, and that is free of substances or elements that could be harmful to man, animal, plant or the environment. The Regulations give specific requirements for compost particle size, ash content, moisture content and appearance, and for plant performance when compost is applied to soils.

Any product for which requirements are specified in the Regulations must be registered under the Act. The registration application must be accompanied by the results of an analysis from an independent ISO 17025-accredited laboratory or Agri-Laboratory Association of Southern Africa (AgriLASA)-affiliated laboratory. Applications for Group 3 fertilizers must also be accompanied by experimental results showing the biological efficacy of the fertilizer, and a risk assessment satisfying that the fertilizer has no adverse

effect on animal health, human health or the environment. The Regulations also prescribe requirements for how fertilizer products must be labelled and how products may be advertised.

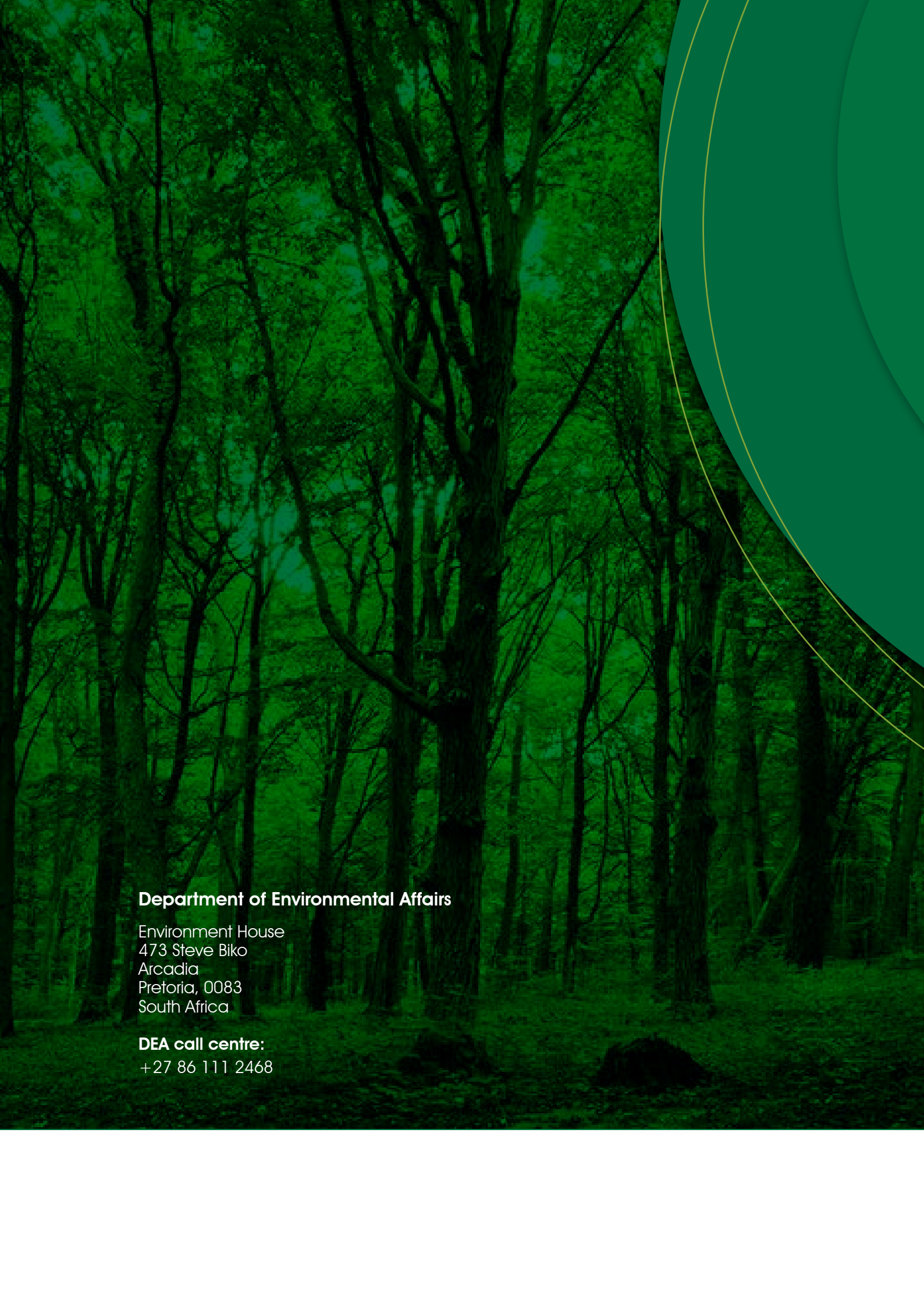
From April 2015, an application to register a fertilizer product will cost R3 731 to process (Republic of South Africa, 2015d). This does not include the cost of the laboratory analysis. It takes about three to six months for a Group 1 fertilizer application to be processed, and the registration must be renewed every three years.

E5 Carbon offsets

The South African government has suggested that a carbon offsets scheme be introduced to complement the proposed carbon tax for addressing climate change. In April 2014, the South African National Treasury published the Carbon Offsets Paper for public comment (National Treasury, 2014). The paper proposes that carbon offsets developed under the CDM, the VCS, the Gold Standard and the Climate, Community and Biodiversity Standard should be considered eligible for a South African carbon offsets scheme. It also suggests that the development of a South African carbon offsets standard be considered in future.

None of the proposed carbon offset standards listed in the Carbon Offsets Paper has an approved methodology for estimating carbon offsets from biochar incorporation in soils. Although a number of methodologies have been proposed under various standards, none of these methodologies have yet been approved. In March 2015, the Methodology for Emission Reductions from Biochar Projects, submitted for approval by the American Carbon Registry, was listed as inactive following an anonymous peer review, which concluded that there was insufficient scientific evidence to support the proposed method for estimating biochar carbon stability (Biochar International, 2015).

The current lack of methodologies for biochar carbon sequestration led, in part, to the unfavourable ranking of biochar for climate change mitigation in the South African NTCSA (Department of Environmental Affairs, 2015). The assessment notes that the high cost of directly monitoring changes in soil carbon stocks is one of the principal reasons for the limited uptake of soil carbon sequestration activities through the CDM and VCS.

The background of the page is a photograph of a dense forest with tall, thin trees and a thick canopy of green leaves. A semi-transparent teal circle is positioned in the upper right corner, with a thin gold-colored line tracing its inner edge. The text is located in the lower-left quadrant of the image.

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