Environmental and Social Dimensions of Fuel Ethanol Production in Cradock, South Africa, in the Context of the Wider Biofuels Debate

A ***case study on environmental impacts and social implementation barriers of South Africa's proposed pioneer fuel ethanol project***

Master's Thesis

by

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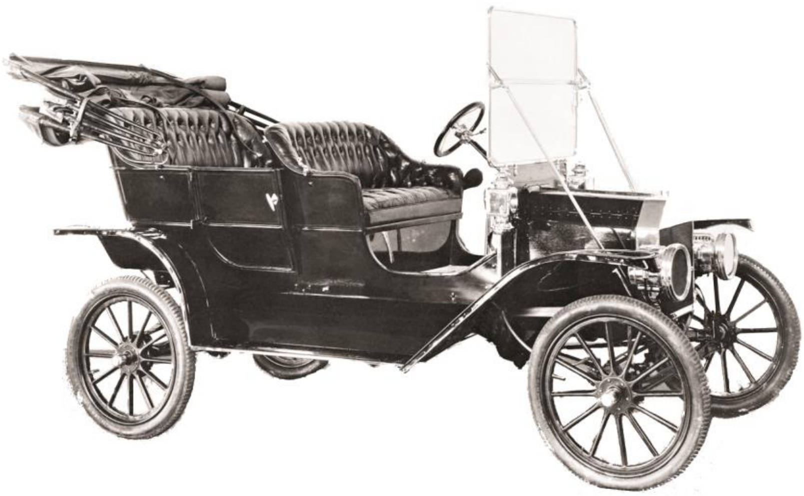

1908 Ford Model T[1]; capable of running on gasoline and ethanol

[1] Picture reference: http://media.caranddriver.com/

This thesis is presented in partial fulfilment of the requirements for the **M(PHIL) ENVIRONMENT, SOCIETY AND SUSTAINABILITY** degree and was performed under the supervision of Associate Professor Rachel Wynberg and Professor Harro von Blottnitz.

University of Cape Town
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Summary

Liquid biofuels are fossil fuel replacements in the form of fuel ethanol and biodiesel. Advocates of biofuels highlight their potential to mitigate climate change from reduced greenhouse gas emissions and socio-economic benefits for countries that achieve a higher degree of self-reliant energy supply. Critics emphasise social drawbacks from biofuel production and suggest that crop-based biofuels could jeopardise food security. The cultivation of biofuel feedstock has furthermore been reported to promote agricultural expansion and thus pose threats to biodiversity. Intense agricultural practices, coupled with land transformation, have also led to question as to whether or not biofuels reduce the carbon footprint of transportation fuels.

The South African government established a biofuels strategy in 2007. Besides having declared self-imposed renewable fuel targets, the policy paper encourages the participation of black people in this emerging industry. The proposed fuel ethanol plant in Cradock, Eastern Cape, is likely to be the first operational bioethanol project in the country. As one of the first biofuels-related Black Economic Empowerment (BEE) programmes, 25 Cradock farms have already been purchased and allocated to black emerging farmers. The intention of this initiative is to enable part of the ethanol plant feedstock to be produced by these emerging farmers.

The present dissertation aims to determine the magnitude and relevance of concerns highlighted in the global biofuels debate for fuel ethanol production at the proposed Cradock plant. This incorporates environmental impacts from agriculture, greenhouse gas emissions during the biofuel production chain, food security impacts, and the performance of socially equitable development. A total of 44 face-to-face interviews were held, comprising 22 commercial farmers, 12 emerging farmers, and representatives from the governmental, commercial and research sectors. The interviewees were questioned on the various socio-economic, environmental and agricultural aspects of the Cradock fuel ethanol project. The inputs of the interviewees were complemented with descriptive statistics on food production, fertiliser and water use, biome maps and a life-cycle assessment of the carbon footprint of the biofuel that will be produced in Cradock.

The farmers raised concerns that a drawn-out administrative process had resulted in disinterest to participate in the project, and that many had thus made their plans independent of the proposed biofuel plant. However, expectations towards the ethanol project were almost

Summary (cont.)

exclusively positive, and support for feedstock production will be assured if economic offsets are adequate. The BEE programme is seen with scepticism by the commercial farmers, and the emerging farmers face substantial problems on their allocated farms. Most of these farms are in a deteriorated condition and the emerging farmers lack crucial farming implements. Delays between purchasing and allocating the land have been identified as the main factor for the deterioration of farms. Poor training and supervision were frequently raised as potential pitfalls by the commercial and emerging farmers.

The agricultural land-use footprint of fuel ethanol production in Cradock will be small. With a projected annual production of up to 16,000 litres of ethanol per hectare from sugar beet, yields are substantially higher than in other countries. Agricultural activity takes place on existing farm land, or on biomes classified as "least concern". Because biofuel feedstock will replace some of the maize crops currently grown, the use of climatically critical nitrogen fertiliser is likely to decrease with biofuel feedstock production. Food security is unlikely to be jeopardised because of i) animal feed co-production during feedstock-to-ethanol conversion operations, ii) the scale of the project, and iii) agricultural expansion and positive yield development which offset a shortage in food crop production. Despite the high yields in the area, greenhouse gas emission savings are found to be relatively low (27 to 33 %, depending on land-use change and cultivation practice). This is mainly due to the high carbon footprints of coal and the grid electricity that will be utilised during conversion operations.

It is concluded that much of the global biofuels controversy does not apply to the specific Cradock case, and that fuel ethanol production from sugar beet has the potential for biofuel production with few negative environmental and social impacts, although initial emission reductions and net-energy benefits will be small. The future incorporation of alternative and renewable technologies to produce South Africa's grid electricity will positively impact on the carbon footprint of the produced biofuel. Separate mechanisms to protect riparian zones and biodiversity corridors from agricultural development should be established to minimise biodiversity impacts. Because delays of the proposed plant cause confusion and disinterest in the Cradock farming community, streamlined action for the commencement of the project is recommended. Challenges also arise from sustainably implementing the Cradock agrarian BEE programme. A coordinated administrative process for monetary allocations, training and supervision will be necessary to ensure the success of the emerging farms.

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Abbreviations

ARDA	Agrarian Research and Development Agency
BEE	Black Economic Empowerment
Bt	*Bacillus thuringiensis* toxin
CBA	Critical biodiversity area
CO_2eq	Carbon dioxide (global warming potential) equivalent
dLUC	Direct land-use change
EIA	Environmental impact assessment
GHG	Greenhouse gas
IDC	Industrial Development Corporation
iLUC	Indirect land-use change
K	Potassium (fertiliser; chemical symbol)
LCA	Life-cycle assessment
N	Nitrogen (fertiliser; chemical symbol)
P	Phosphate (fertiliser based on phosphorus; chemical symbol)
RSB	Roundtable on Sustainable Biofuels
SQCB	Sustainable Quick Check For Biofuels

1 Introduction

1.1 Background

Climate change, and the concomitant depletion of fossil fuels, make the utilisation of alternative and renewable energy sources critical (Puppán, 2002; Cockerill and Martin, 2008; Escobar *et al*., 2008; Balat and Balat, 2009). Biofuels are fuel substitutes based on renewable natural materials. Two forms of liquid biofuels, bioethanol and biodiesel, are already widely used but are also under debate as potentially sustainable replacements for fossil fuels in the transportation sector (Demirbas and Balat, 2006). First generation biofuels are fuels derived from agricultural crops, such as biodiesel from oil seeds, and ethanol from starch or sugar-rich plants. These crop-based fuels account for the vast majority of currently produced biofuels (Havlík *et al*., 2010).

Much controversy has emerged from various sectors regarding the desirability of biofuel production. Advocates of biofuels argue for their potential to reduce greenhouse gas (GHG) emissions and mitigate climate change (*e.g.* Puppán, 2002; Demirbas, 2009). Amigun *et al*. (2006) highlight the socio-economic opportunities and benefits that biofuels offer, such as energy supply self-reliance, independence from oil imports and the creation of domestic employment. However, opposition to biofuels has increasingly gained momentum over the past decade (Attwell, 2011). A prominent concern amongst development researchers is that biofuels could be in direct competition with food production (IFPRI, 2008; PRI, 2008; Ewing and Msangi, 2009; Pimentel *et al*., 2009; Tilman *et al*., 2009). Furthermore, socially inequitable development and the exploitation of vulnerable groups have been linked to biofuel production (Cotula *et al*., 2008, 2009; Friis and Reenberg, 2010). Some studies have also challenged the notion that biofuels significantly lower GHG emissions, due to the extensive chemical and electricity use during cultivation and production phases, as well as the changes in land-use driven by agricultural expansion, which add to the carbon footprint of the product (Crutzen *et al*., 2008; Fargione *et al*., 2008; Searchinger *et al*., 2008; Börjesson, 2009; Stephenson *et al*., 2010). Other studies have highlighted additional negative environmental impacts that may outweigh possible benefits of biofuels, such as soil acidification and eutrophication through fertiliser use (Blottnitz and Curran, 2007; Börjesson and Tufvesson, 2011), as well as biodiversity threats and habitat destruction from agricultural activity (Wilcove and Kohl, 2010; Fletcher Jr. *et al*., 2011).

Despite these criticisms, bioethanol and biodiesel production has increased globally (Demirbas and Balat, 2006; RFA, 2013). Biofuels are already being intensively produced and widely used in the United States and Brazil, the two countries which to date have led production and consumption of renewable transport fuels (RFA, 2013). The 2000 European Union's Green Paper set an objective to replace 20 % of conventional fuels with biofuels by 2020 (EC, 2000), although this target has subsequently been lowered due to environmental concerns and the issue of food security (EC, 2009, 2012). Biofuel production on the African continent is minimal; however, in 2007, together with other sub-Saharan countries, the South African government established plans for biofuel production, which were published in the policy paper "South African Biofuels Industrial Strategy" (DME, 2007). The motivations to establish a biofuels industry in South Africa derive from the anticipated benefits, such as the socio-economic upliftment of rural areas, the strengthening and empowerment of historically disadvantaged groups, lowering GHG emissions, and promoting self-reliant energy supplies (DME, 2007). Four national biodiesel and four bioethanol plants are currently in the planning stages (DME, 2013a).

One of South Africa's first bioethanol projects is a fuel ethanol plant to be built in Cradock in the Eastern Cape. The Cradock area is semi-arid with an annual rainfall of 350 mm; however, due to additional water supplies from the Orange River scheme, irrigation farms are highly productive in this region. Plans for this biofuel project envisage locally grown sugar beet to serve as the main feedstock for ethanol production. Grain sorghum will be utilised as a supplementary feedstock and will be grown locally, or imported from various regional and national locations (Vivier *et al*., 2009).

The South African biofuels strategy encourages the participation of emerging farmers in the upcoming biofuels industry (DME, 2007). The Department of Rural Development and Land Reform manages programmes that aim to strengthen the role of black people in the South African economy ("Black Economic Empowerment", BEE). Under a directive of Land Reform, a BEE programme has been initiated in Cradock, where twenty-five farms with some 16,000 hectares of farmland have already been purchased from commercial farm owners and handed over to emerging farmers. The intention of this initiative is for part of the ethanol plant feedstock to be produced by these emerging farmers (DRDLR, 2013a).

1.2 Aims and objectives of this study

The global controversy revolving around biofuels concerns socially equitable development, environmental impacts from agricultural activity required for feedstock production, uncertain climatic benefits which are linked to the carbon footprint of the produced biofuel, and possible impacts on food security. The present study aims to determine the magnitude and relevance of these potential pitfalls for biofuel production at the proposed pioneer fuel ethanol plant in Cradock, South Africa. To ensure that biofuel production brings social and economic benefits to the region where a project is established, governments are required to make provisions for equitable and mutual benefits for those residing and working in the production area. Although other developing countries have experienced socially undesirable effects from biofuel production, such as "land grabs" and the exploitation of vulnerable groups (Cotula *et al*., 2008, 2009), the South African government has been careful to emphasise the potential link of this emergent industry to rural development and black empowerment (DME, 2007). Essential to the overall success of this endeavour, and more particularly the success of the proposed Cradock fuel ethanol project, is the support and participation of the local farming community and a successful implementation of the BEE programme on the beneficiary farms. However, previous South African agrarian land reform projects have had varied success (Ponte *et al*., 2007), with critical voices claiming a substantial decrease of production rates on emerging farms (Hall, 2004). In light of these reported drawbacks, this study investigates some of the social parameters of Cradock fuel ethanol production, and the possible barriers to its implementation in the form of the degree of commercial farmer support, and the performance of the BEE programme currently being put in place in Cradock.

Thus, in the context of the global biofuels debate, this research strives to determine the environmental and social desirability of the Cradock fuel ethanol production and incorporates five objectives:

Objective 1 – perceptions and concerns: to capture and evaluate the concerns raised by government, stakeholders, and by commercial and emerging farmers. These concerns can be of a social, environmental and economic nature.

Objective 2 – social implementation barriers: to assess the problems and prospects that emerging farmers have on their farms, and the willingness of the commercial farming community to participate in the proposed Cradock fuel ethanol project. This objective links to objective 1.

Objective 3 – food security: to estimate the impacts of the proposed project on food security, by contextualising the current plans and feedstock production circumstances in terms of regional and national agricultural production statistics.

Objective 4 – environmental impacts: to assess the environmental impacts from agricultural activity, focussing on the ecology of the Cradock area and the possible impacts of the project on habitat and biodiversity.

Objective 5 – carbon footprint: to conduct a study on GHG emissions from biofuel production at the proposed Cradock plant, given that the carbon footprint of a biofuel is a vital component of its environmental performance.

1.3 Methodological approach

The objectives of the present dissertation are addressed by collecting and analysing both qualitative and quantitative data. The qualitative data comprised of 44 face-to-face interviews which served to determine the views and perceptions in regards to the various environmental, social, economic and agricultural aspects of the proposed fuel ethanol project and the BEE programme. The interviewees included commercial farmers, emerging farmers, and relevant representatives of government, research and the private sector. Social implementation barriers were inferred from recurring themes in the commercial and emerging farmer interviews. Perceived impacts of the project on food security were captured from farmer inputs and contextualised with both regional and national food crop production statistics. Environmental aspects highlighted in the course of the interviews were supplemented with qualitative and quantitative data from biodiversity maps, and water and fertiliser statistics. Agricultural input and output variables from the latest biofuel feedstock trials in the area were used in a carbon footprint analysis that determines the extent of the GHG emissions associated with fuel ethanol production at the proposed Cradock plant.

1.4 Relevance of this study

In light of the current biofuel controversy, there is substantial scepticism and resistance both towards the proposed Cradock fuel ethanol project, and to the South African biofuels strategy in general. Given the potential negative environmental and socio-economic impacts, the desirability of biofuel production depends on the implemented technology (Wang *et al.*, 2007; Börjesson, 2009) and regional production circumstances (Puppán, 2002; Börjesson, 2009).

This study investigates the proposed Cradock biofuel plant within the context of the global biofuels debate in order to determine the significance and relevance of the various concerns relating to this South African pioneer fuel ethanol project. Given that the proposed Cradock fuel ethanol plant, and the associated BEE programme, will serve as an example for other future biofuel projects in the country, the results of this study have implications for the potential for an ecologically and socio-economically sound implementation of a biofuels policy at a national level. In terms of a broader perspective, as a case study, the present assessment offers new insights into fuel ethanol production on the African continent, where developmental pressure and food security are high priority issues (Ewing and Msangi, 2009). This study will thus i) contribute to a more comprehensive understanding of the social and environmental risks and opportunities of fuel ethanol production in Cradock, South Africa ii) deliver a *status quo* report of the first South African biofuels-related BEE programme that is currently taking place in Cradock, and iii) provide for a case analysis of fuel ethanol production in sub-Saharan Africa.

1.5 Structure of this dissertation

The literature review (chapter 2) first outlines the historical and theoretical background of biofuel production from a global perspective. It elaborates on the motivation for the search for renewable fuel substitutes on the part of governments, and reviews the literature on the debate emerging from, and revolving around, the desirability of crop-based biofuels. The relevant keynotes of the 2007 South African Biofuels Industrial Strategy paper and the aims of the national Land Reform directive are presented and discussed. The literature review concludes with a description of the theoretical framework underpinning the present study. The succeeding chapter (3) introduces the study site and incorporates a description of the proposed Cradock fuel ethanol project and the associated BEE programme. The methodology, and its possible limitations in terms of biases and explanatory power, is discussed in chapter 4. The results of the present study are presented in chapter 5. The discussion chapter (6) elaborates on these findings and contextualises the results in terms of their broader relevance to the current biofuels debate and their implications for a sustainable and desirable implementation of the South African biofuels policy. The final chapter (7) presents summarised conclusions and policy recommendations that draw on the findings of this study. The bibliography is listed in a supplementary section. Summarised statements of commercial and emerging farmers that were extracted from interviews held for this study are found in the Appendix section.

2 Literature Review

2.1 Motivating the search for fossil fuel replacements

With rapid development taking place in previously underdeveloped countries, fossil fuel demand is projected to increase further, a prediction which adds to growing concerns about anthropogenic climate change (Anderson and Bows, 2008) and resource depletion (Cockerill and Martin, 2008). The utilisation of liquid biofuels as low-carbon fossil fuel alternatives is not a new phenomenon. Plant oils have been used as lamp oil since antiquity, and some early cars, such as the 1908 Ford model T, were able to run on both petroleum and ethanol (Specht, 2011). However, large-scale production of cheaper fossil fuel oil has prevented these biofuels from obtaining a dominant position on the global diesel and petroleum markets (Pousa *et al*., 2007). The downsides of total or partial oil import dependency in consumer countries became apparent only when political instabilities in oil producer countries led to two major oil crises that had a wide-ranging impact on global economies in the 1970s (Wang *et al*., 2007). Due primarily to economic pressures, biofuels were subsequently re-discovered as a potentially sustainable replacement for fossil fuels in the transportation sector (Pousa *et al*., 2007; Wang *et al.*, 2007). The United States and Brazil were among the first to respond to these crises: to date, these countries remain the leaders in the production and consumption of fuel ethanol (RFA, 2013; Figure 1). It is now well established that much of the wealth of the developed world is founded on the exploitation of non-renewable energy technologies. Almost a quarter of current anthropogenic carbon dioxide (CO_2) emissions derive from the transportation sector, which is based largely on the exploitation of fossil fuels (IEA, 2012), and thus, worldwide, biofuels have sparked increasing interest as to their potential to alleviate resource depletion and mitigate climate change (Escobar *et al*., 2008; Balat and Balat, 2009).

2.1.1 Climate change

Advocates of liquid biofuels claim that they have the potential to reduce greenhouse gas (GHG) emissions in the transportation sector, a notion based on the perception that the amount of CO_2 emitted with their combustion equals that being absorbed over the lifespan of its biomass. The validity of this equation has been challenged (Johnson, 2008); however, it is now undisputed that the extraction and combustion of fossil energies such as coal and oil result in the release of GHGs into the atmosphere. It has come to be commonly accepted that these anthropogenic emissions contribute to the dual phenomena of climate change and global warming (Griggs and Noguer, 2002; Tripati *et al.*, 2009). Unabsorbed atmospheric CO_2 is furthermore thought to cause an acidification of the oceans, as CO_2 dissolves in water and reacts to carbonic acid (Doney *et al*., 2009). In response to growing awareness of the global warming phenomenon, a total of 192 states signed the 1992 United Nations Framework Convention on Climate Change (UNFCCC, 2007). This convention was the foundation for the development of the Kyoto Protocol that was adopted to regulate global CO_2 emission levels (Westerwinter, 2007). However, despite best efforts on the part of the United Nations, an international consensus that could result in long-term stabilised atmospheric GHG levels is far from being reached (Anderson and Bows, 2008; Olmstead and Stavins, 2012). However, many countries have taken their own measures to lower their carbon footprint and establish alternative energy policies with self-imposed objectives.

2.1.2 Resource depletion and "peak oil"

Apart from climatic challenges that emerge from the combustion of fossil fuels, increasing interest in biofuels is due to those economic pressures that arise from resource depletion. When half of the world's fossil oil reservoirs are depleted, oil production rates are projected to decrease and the crude oil price will further increase (de Almeida and Silva, 2009). The exact moment of this event, commonly referred to as "peak oil", is difficult to predict due to the uncertainties associated with the extensiveness of global oil sources and future consumption. A recent study from the United Kingdom estimates "peak oil" to occur between 2020 and 2030 (Sorrell *et al*., 2010), although other models suggest that it has already been reached (Mohr and Evans, 2008). Accompanying the issue of energy security, resource depletion, in combination with the uneven global distribution of oil and gas reserves, is furthermore suspected to underlie increasing occurrences of military conflicts (Gokay, 2002; Le Billon 2002).

2.1.3 Socio-economics of biofuels

In addition to possible climatic and resource-preserving benefits, advocates of biofuels highlight social and economic advantages, such as the reduction of agricultural surplus stock, the promotion of rural development and the creation of domestic employment (Puppán, 2002). Others mention that opportunities from biofuel production are particularly appealing to developing countries, as rural upliftment and oil independency offer chances for sustainable and self-reliant development (Amigun *et al*., 2006; Balat and Balat, 2009).

In summary, three main factors lead policy makers around the globe to promote seeking independence from fossil fuels by utilising liquid biofuels in the transportation sector: i) anthropogenic climate change caused by the release of GHGs, ii) the accelerated depletion of fossil fuels, and iii) the desire for self-reliant energy supplies and improved trade balances (Puppán, 2002; Cockerill and Martin, 2008; Escobar *et al*., 2008; Balat and Balat, 2009).

2.2 The three generations of liquid biofuels

Liquid biofuels can be crudely classified as bioethanol and biodiesel. Biofuels of the first generation are based on agricultural crops and are either produced by fermenting carbohydrates to ethanol or by processing plant oils to produce biodiesel (Koonin, 2006). Popular first-generation biofuel feedstock comprises *inter alia* sorghum (*Sorghum* spec.), sugar cane (*Saccharum* spec.), sugar beet (*Beta vulgaris*) and maize (*Zea mays*) for bioethanol, and oil palm (*Elaeis guineensis*), sunflower (*Helianthus annuus*), soybean (*Glycine max*) and canola (*Brassica napus*) for biodiesel (Balat and Balat, 2009; Demirbas, 2007, 2009). Today, most marketed liquid biofuels derive from crop-based feedstock (Havlík *et al*., 2010). Second generation biofuels are produced from organic waste material (*e.g.* bagasse and chipped wood) but the fermentation of cellulose is costly due to the necessary pre-treatment of biomass and the production of enzymes to break down the cellulose fibres to their sugar components (Himmel *et al*., 2007).

The use of genetically modified (GM) plants is debated as a potential way to enhance biofuel production (Ragauskas *et al*., 2006). For example, efficiency of second generation biofuels could be increased by minimising the lignin components of feedstock material (due to the chemically stable nature of the molecule), overexpression of cellulases (to harvest the key enzymes to break down cellulose), and increasing the overall biomass (Sticklen, 2006). To date, second-generation biofuels play an insignificant role on the biofuels market, although extensive research, together with the rapid development of technology, hold promising results for the future use of these fuels (Sims *et al*., 2010; Kumar *et al*., 2013). Biofuels from marine algae (the so-called third generation) are perceived to be a potent source of renewable energy as well, but as for second-generation biofuels, there is no commercial large-scale production to date (Deng *et al*., 2009).

2.3 Bioethanol production: a global perspective

Given the potential environmental and economic benefits, it is not surprising that many governments promote renewable energy policies. For decades now, both biodiesel and bioethanol production have increased steadily (Demirbas and Balat, 2006; Figure 1A). However, the global production of bioethanol – which is a prime focus of the current assessment – significantly exceeds that of biodiesel (OECD, 2011). According to the United States Renewable Fuels Association (2013), most fuel ethanol is produced in North America, followed by South America, Europe, Asia, Australia and, lastly, Africa (Figure 1B). With more than 54 billion litres of fuel ethanol in 2011, North America produced more than 10 times the amount produced by Europe (4.4 billion litres) and roughly 380 times that of Africa (143 million litres), thus holding a share of 64 % of global bioethanol production (Figure 1B; RFA, 2013).

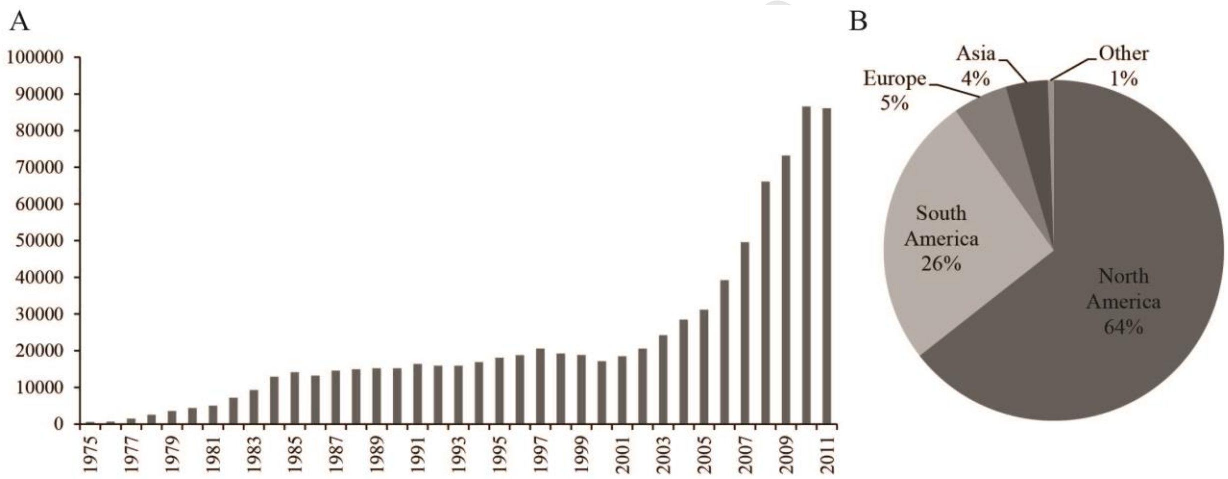

FIGURE 1 **Global fuel ethanol production from 1975 to 2011 (A) and shares of fuel ethanol production by continent in 2011 (B)**

All amounts in million litres. Sources: Earth Policy (2012); Renewable Fuels Association (2013). Production in 2011: North America: 54,515; South America: 21,849; Europe: 4,420; Asia: 336; Australia: 330; Africa: 145. Australia and Africa are displayed as “Other” in graph 1B

Despite the availability of arable land, large-scale biofuel production on the African continent is minimal, due to political, financial and technical hurdles limiting the adaptation of biofuel technologies in African states (Amigun *et al*., 2006). However, growing interest on the part of foreign and national investors has resulted in significant growth of biofuel markets in developing countries (Demirbas, 2008).

The feedstock for first generation fuel ethanol production varies widely across countries. The United States produces fuel ethanol from maize, Brazil utilises sugarcane, and France sugar beet. Sugarcane exceeds maize in yields of ethanol per hectare, but is restricted to tropical and subtropical geographies (Quintero *et al*., 2008). Sorghum has recently been discovered as a potential biofuel crop as it is resistant to drought and produces similar biofuel yields to maize (Xin and Wang, 2011). The highest yields per hectare can be expected from sugar beet, but the yields per harvested crop mass are lower than those for maize, sorghum and sugar cane (Brown, 2006; PGBI, 2008). As a result, feasibility of long transportation distance is lower for sugar beet than for other crops, and thus the producing fields are required to be located closer to the processing plant. The choice of biofuel feedstock is therefore dependent on local climatic, agricultural and infrastructural conditions (Yuan *et al*., 2011).

Fuel ethanol can be used in its pure form, but is more commonly blended with conventional fuel in specific ratios to produce a marketed (bio-) fuel. Common blending ratios are 5, 10, and 85 % ethanol mixes (referred to as E5, E10, and E85) (Puppán, 2002), but there are no technical constraints with regard to blending ratios. E5, commonly used as standard fuel in many European countries, is suitable for all marketed cars. Depending on the car model, blending ratios higher than E10 may require engine modifications.

2.4 Bioethanol production in South Africa: policy and plans

2.4.1 The 2007 South African Biofuels Industrial Strategy

South Africa is the thirteenth largest CO_2 emitter in the world (Boden, 2011). The country has acceded to international initiatives, such as the 1992 United Nations Framework Convention on Climate Change, and the Kyoto Protocol (OECD, 2002), but has only recently initiated attempts to reduce CO_2 emissions after announcing voluntary relative emission reductions at the 2009 Copenhagen Conference of the Parties. Much of the country's CO_2 emissions can be traced to the combustion of coal, which is the country's primary energy source for electricity generation. The energy requirements for South Africa are also higher than for most equally developed countries because energy-intensive mining operations form an economic cornerstone of the country (Winkler, 2007). However, a substantial amount (almost 12 %) of the total CO_2 emissions in South Africa derives from the burning of fossil oil-based fuels in the transportation sector (Boden *et al*., 2011).

In 2007, the government released the policy paper "Biofuels Industrial Strategy of the Republic of South Africa" (DME, 2007). The paper lists the anticipated benefits from a national biofuels industry, which include the upliftment of rural areas, the strengthening of the position of historically disadvantaged groups, lowering GHG emissions, and promoting self-reliant energy supplies (DME, 2007). Because of the potential of a biofuels industry to trigger development in rural areas, government plans to situate biofuel projects in the poorest regions of the country. The policy document was released after a series of changes from the original draft, including the rejection of maize as bioethanol feedstock for food security reasons (Attwell, 2011), and a lower initial biofuel target (DME, 2007). Currently, the aim is to replace 2 % of transportation fuels with biofuels on a national level (DME, 2007). It is proposed that ethanol be blended in an E8 fuel, which would be suitable for all marketed cars without engine modifications. Originally, it was planned for this aim to be achieved by 2013. However, this has not proved to be achievable in the given timeframe due to delays in the programme, although serious attempts are now being made to produce first generation biofuel on a large scale. The construction of four biodiesel and four bioethanol plants is proposed to take place in the near future (DME, 2013a). The proposed Cradock plant in the Eastern Cape is likely to be the first operational fuel ethanol plant (DME, 2013b).

2.4.2 Land Reform and Black Economic Empowerment

The aim to strengthen the economic role of black[1] people through participation in an emerging biofuels industry is manifested in the 2007 Biofuels Industrial Strategy paper (DME, 2007). During the 20th century, under the Apartheid regime, blacks were oppressed under a racial segregation system which included forced removals of communities, restricted access to land, and dispossession (Greenberg, 2006). A negotiated political settlement ended white supremacy and resulted in the establishment of a democratic state in 1994. The new post-Apartheid government established the Department of Rural Development and Land Reform which manages restitution, redistribution and tenure reform to redress past inequalities. While land reform projects were embarked upon shortly after the establishment of the new democratic government, the legislation for broad-based economic upliftment of black people was only formulated and implemented through the Black Economic Empowerment Act no 53 of 2003. The term “Black Economic Empowerment” describes the efforts on the part of the government to enable historically disadvantaged groups to play a bigger role, and have a more equitable share, in South Africa’s economy by becoming business owners. The allocation of property on the basis of BEE is done on a contractual basis according to a concept of mutual agreement between the buyer (the government), the seller

[1] The term is commonly used for a wider variety of historically disadvantages groups in South African policy papers, also incorporating “coloured” and Indian people

(the property owner), and the beneficiary (emerging entrepreneur). The new business is commonly managed under an initial lease agreement that can be converted to ownership over time (Hall, 2004). The Cradock farmland redistribution is among the first of the biofuels-related BEE programs in South Africa. Although in principle the need for BEE is generally accepted by the electorate and various stakeholders, as it offers potential for equitable and socially sustainable development through poverty elimination, the overall success of previous South African BEE projects has been contested (Greenberg, 2006; Ponte *et al*., 2007; O'Laughlin *et al*., 2013). A variety of problems and malpractices in the execution of BEE have been highlighted in previous case studies. These problems include insecure funding of the programme management, uncertain profitability of the new businesses, and shortages of operating skills of the beneficiaries (Fauconnier and Mathur-Helm, 2008). Critical voices, raised mainly by the commercial farming community, claim substantial decreases of production rates on emerging farms (Hall, 2004).

2.5 The biofuels controversy: environmental impacts associated with biofuel production

The South African government has adhered to the plans it made in 2007 to establish a biofuels industry, despite the fact that the rapid uptake of biofuels worldwide has been accompanied by controversy. Potential environmental pitfalls that derive largely from feedstock cultivation and conversion operations have recently been highlighted in academic debates as well as by environmental activist groups (Pye, 2010). The following section describes the environmental concerns frequently raised in the global biofuels debate, which include developmental pressure to expand agriculture, habitat and biodiversity impacts from agricultural activity, and GHG emissions that arise from feedstock and biofuel production.

2.5.1 Environmental impacts from agricultural activity

The requirement for biomass cultivation, with its associated agricultural component, sets the environmental impacts of biofuels apart from those of conventional fuels. The feasibility and desirability of biofuel production therefore largely depends on the extent and number of agricultural impacts that accrue from feedstock cultivation. Environmental impacts, such as eutrophication and eco-toxicological effects from chemical and fertiliser use, have therefore become a focus of the biofuels debate (Blottnitz and Curran, 2007; Börjesson and Tufvesson, 2011; Yang *et al*., 2012). The production of crop-based biofuels implies the rededication of existing agrarian areas to biofuel feedstock production, and the potential for agricultural expansion to ensure sufficient feedstock in addition to food crop supplies. In response to economic developmental pressures created by new and increasing demands for agricultural crops, growing biofuel markets have been reported to trigger agricultural expansion, thus causing environmentally damaging land transformation, habitat destruction, and posing potential risks to biodiversity (Niven, 2005; Groom *et al*., 2008; Wilcove and Kohl, 2010; Fletcher Jr. *et al*., 2011). These impacts gain additional significance in the context of extensive species losses over the last decades. The extent of these losses has come to be seen as a new mass extinction event (*e.g.* Pimm and Brooks, 1997; Wake and Vredenburg, 2008), with habitat destruction and fragmentation constituting the main cause (Fahrig, 1997).

2.5.2 Carbon emissions, net-energy benefits, and land-use change

Biofuels have been promoted as carbon neutral energy sources, based on the perception that the CO_2 emitted in combustion equals that being absorbed by the growing crop. However, cultivation, processing, production and distribution of biofuels require significant resource and energy inputs in the form of chemicals, water and electricity (Koh and Ghazoul, 2008, Figure 2). Some studies have concluded that, as a result of these inputs, the carbon footprint of biofuels exceeds that of conventional fuels (*e.g.* Wang *et al*., 2007; Crutzen *et al*., 2008; Stephenson *et al*., 2010). In addition, studies have challenged the net-energy benefits of biofuel production. For example, Shapouri *et al*. (2002) calculated a positive net-energy value of 1.34 for the fuel ethanol from maize, and argued that yield increase and efficiency improvements of biofuel plants will improve the net-energy value of future fuel ethanol. On the other hand, Pimentel (2003) calculated that the energy input of ethanol production in the United States exceeds the energy value of the produced fuel by 29 %. The author points out methodological flaws in the Shapouri *et al*. (2002) calculations, which Pimentel (2003) argues, deliver misleadingly optimistic results. A more recent study suggests that the high variation found in net-energy and emission studies is mainly due to different accounts for labour, non-CO_2 GHGs and by-products (Bureau *et al*., 2010). Because of the plurality of methodological approaches, organisations such as the European Roundtable on Sustainable Biofuels (RSB) came into existence with the attempt to harmonise and standardise methodologies to assess net-energy values and GHG emissions of biofuels.

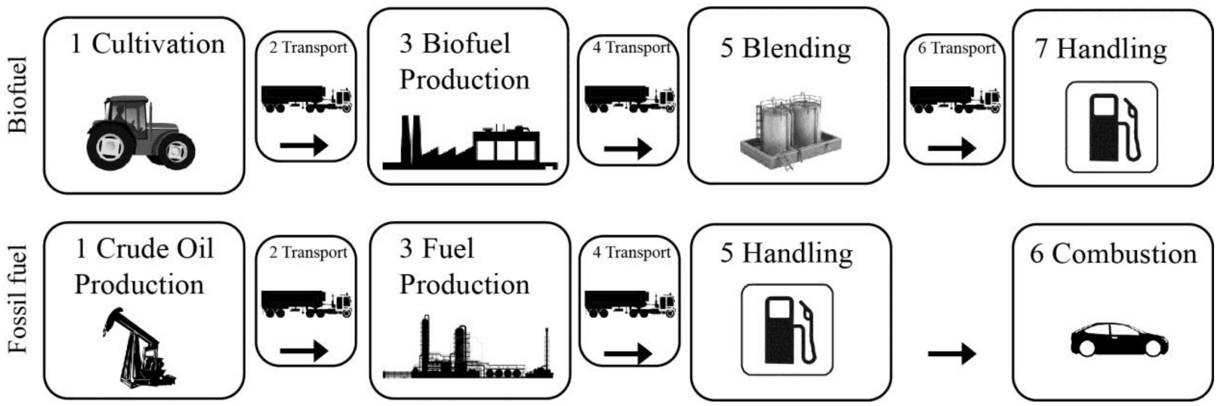

FIGURE 2 **Stages in the biofuel and fossil fuel life-cycles that result in the release of greenhouse gases**

Source: EPFL, 2011a, b. Unlike fossil fuels, the emissions of biofuel combustion are effectively zero, since the carbon that is released has been accumulated by the plant during the cultivation phase. Greenhouse gases are released during cultivation (1), transport (2, 4, 6), production (3), blending (6) and handling (7) of the product

Life cycle assessments on biofuels − The carbon footprint (and the net-energy benefits) of a biofuel is determined in a life-cycle assessment (LCA), which is a tool used to analyse environmental impacts from the production phase of a product to its consumption or disposal, and is commonly referred to as a “cradle to grave” approach. Interlinked with the debate on net-energy benefits of biofuels, the results of previous LCA studies on the carbon footprint of biofuels have had polarising results (Blottnitz and Curran, 2007). It became apparent that the results of the environmental performance of a biofuel depended on the implemented technology (Wang *et al*., 2007; Börjesson, 2009), regional production circumstances (Puppán, 2002; Fargione *et al*., 2008; Börjesson, 2009), and assessment methodology (Bureau *et al*., 2010). Stephenson *et al*. (2010) identify crop yield, irrigation and land transformation as the most significant factors determining the carbon footprint of biofuel feedstock production. In a best case scenario of (hypothetical) first-generation biodiesel production in South Africa, the authors calculated 36 % less global warming potential and 62 % less fossil energy demand in producing biodiesel. However, when using virgin land for cultivation and high irrigation levels, global warming potential and fossil energy demand from biodiesel were projected as being considerably higher than those from the fossil fuel equivalent. Wang *et al*. (2007) investigated the carbon footprint of different maize biofuel production scenarios and concluded that coal-fired fuel ethanol plants have a substantially higher carbon footprint than natural gas or woodchip-fired factories. Therefore, depending on the heating source, the authors found that biofuels can exceed the carbon footprint of the conventional fuel that they are intended to replace. Börjesson (2009) concluded that environmentally sound biofuel production requires i) the plants to be fuelled by biomass, ii) that carbon-rich grounds (such as peat land) should be avoided in the cultivation process, iii) that by-products be used efficiently, and iv) that nitrous oxide emissions from fertilisers should be avoided as far as possible.

Land-use change – A component of LCAs that has only recently been gaining increasing interest is that of land-use change. Direct land-use change (dLUC) appears when virgin land is transformed into (biofuel) plantations. In the case of deforestation, carbonaceous substances bound by soil and vegetation are oxidised and released, and thus add to the carbon footprint of the product. Acknowledging that this process constitutes a one-time carbon release, Fargione *et al*. (2008) and Searchinger *et al*. (2008) describe the emissions of land conversion as a “carbon debt”. Once land is cleared for agricultural purposes, biofuels can only compensate for their carbon debt over time, given that their production involves a lower carbon footprint than their fossil equivalents. Fargione *et al*. (2008) calculated that the CO_2 released from land conversion is 17 to 420 times higher than the total annual emission reductions from biofuels, depending on former land use and production circumstances. Havlik *et al*. (2010) calculate an average carbon debt repaying period of 25 years for first-generation biofuels.

While the incorporation of dLUC is seen as a relatively straight-forward approach in carbon-emission studies, various controversies have emerged on the phenomenon of indirect land-use change (iLUC) (Wang and Haq, 2008; Harvey and Pilgrim, 2011; Yang *et al*., 2012). Indirect land-use change describes the phenomenon of land being converted to agricultural land as a means to offset a gap in food supply, or a shortage in the new biofuel market (Chalmers *et al*., 2011). This implies that cultivation of biofuel crops in one region can trigger land conversion elsewhere in the world. For instance, sugar cane monoculture for biofuel production in the centre of Brazil is suspected to lead to deforestation for food crop production in the Amazon region (PRI, 2008). Searchinger *et al*. (2008) argue that the growing conversion of maize into biofuel in the United States will lead to land conversion around the world in order to produce the crop for human consumption. To illustrate the significance of this effect, they calculated a 20 % reduction of GHG emissions from maize ethanol compared to gasoline in exclusion of iLUC, but a 93 % increase when the environmental effects of iLUC are taken into account: a carbon debt that would take more than 160 years to repay. The methodological approach adopted by Searchinger *et al*. (2008) was challenged by Wang and Haq (2008), who claimed moderate GHG emission reductions for the same biofuel. Hertel *et al*. (2010) adjusted the calculations of Searchinger *et al*. (2008), but estimated that the United States' production of ethanol from maize offers no climatic advantages.

Controversies about iLUC emerge from the uncertainties around the number and extent of these effects, and the methodology used in their assessment (Yang *et al*., 2012), problems caused *inter alia* by the complexities that underlie the global trade systems (Plevin *et al*., 2010). Critics of the iLUC approach argue that the boundaries of indirect effects are poorly defined, and that the incorporation of iLUC in traditional biofuel LCAs is flawed (Mathews and Tan, 2009; Zilberman *et al*., 2010). Some researchers are of the opinion that the effects of iLUC, although real, are in practice unable to serve as guidelines for policy making, and that controllable measures, such as forest protection and certification schemes in the biofuel industry, constitute more efficient means to mitigate indirect environmental impacts from biofuels (Mathews and Tan, 2009). Similarly, other researchers have argued that dLUC and iLUC effects can be lowered by avoiding agricultural development of high-carbon stock land, such as with peat soils (Börjesson, 2009) and forests (Melillo *et al*., 2009).

Although second-generation biofuels do not require land transformation and also avoid clashes with food security, as the feedstock is produced from organic waste materials, their improved environmental performance is by no means secured. In a hypothetical study on the transformation of bagasse into ethanol, Melamu and von Blottnitz (2011) found that, without efficiency improvements at the waste-producing mills, GHG emissions would not be reduced.

2.6 Biofuels and food security – the "food versus fuel" debate

Crop-based biofuels link the debate over renewable and potentially clean energy supplies to an apparent dilemma between possible environmental benefits and food security (Tilman *et al*., 2009). If existing cropland is used for biofuel feedstock production, biofuels can stand in direct conflict with food crop production (Ewing and Msangi, 2009; Pimentel *et al*., 2009; Tilman *et al*., 2009). Plant Research International (2008) reports that an estimated one billion people on Earth are malnourished, while at the same time millions of hectares are being globally earmarked for biofuel feedstock production. Some studies therefore attribute food shortages and rising food prices to the growing biofuel markets (FPRI, 2008; PRI, 2008). Others have challenged the perceived relationship between biofuel production and rising food prices, arguing that steadily improving agricultural yields and increased overall production offset possible losses in food crop production (Ajanovic, 2011). However, a study conducted by the International Food Policy Research Institute (2008) identified biofuel production as a major factor influencing rising food prices, although other factors, such as increasing crude oil prices, droughts in key production areas, and growing demand through rapid development in Asia and sub-Saharan Africa were found to contribute to higher grain prices as well. There have also been reports of a tendency of farmers to change from food crops, such as rice and wheat, to more profitable biofuel feedstock cultivation (IFRI, 2008; PRI, 2008). In this context, food importing and developing countries in particular may struggle with price changes on the global food market (Ewing and Msangi, 2009).

2.7 Biofuels and rural development

In both the agricultural and manufacturing sectors, biofuels have been predicted to generate potential for rural development and for domestic employment creation. However, the social impacts and general social desirability of biofuel production have been under-represented in the biofuels debate, which has focused mainly on environmental and economic concerns (Ribeiro, 2013). In some cases biofuel production has been reported to cause socially undesirable effects, particularly in terms of reallocating land to the cultivation of biofuel feedstock. The term “land grab” describes national or trans-national transactions and rededications of (mostly) agrarian land for commercial purposes that negatively affect people whose livelihoods depend on these lands (Borras Jr. and Franco, 2012). The phenomenon of “land grabs” is in direct opposition to desirable social development. Most significantly in developing countries, the earmarking of indigenous lands for an emerging biofuels industry has been found to cause social tension due to displacements of people living and farming the land, and to reduced access to land, resources and heritage sites (Cotula *et al.*, 2008, 2009). There is evidence throughout the African continent of “land grabs”, which are often attributed to foreign investors, and linked to both food and biofuel production (Friis and Reenberg, 2010).

A study from Brazil suggested that biofuel demand triggers the development of large-scale farming practices and excludes small-scale farmers from participation in the agricultural sector (Hall *et al.*, 2009). In cases of indigenous small-scale farmers being incorporated in biofuel feedstock production in the tropics, it has also been argued to have negative ecological and social consequences: biofuel feedstock mono-cropping can displace more ecological subsistence farming (Joseph and Montefrio, 2012).

2.8 Conceptual framework of this study

As presented in this chapter, the global biofuels controversy encompasses i) the agricultural footprint of feedstock cultivation, ii) the carbon footprint of biofuels and land-conversion, iii) food security, and iv) the social desirability of cultivating and processing biofuel feedstock in terms of sustainable development with equitable benefits. The present study takes the criticism of biofuels, as present in the literature, as a theoretical basis to assess the applicability of global biofuel concerns to the proposed fuel ethanol plant in Cradock, South Africa. A combined analysis of biodiversity and food security impacts, GHG emissions, social aspects, and implementation barriers aims to measure and determine the environmental and social performance of this project. The social aspects of the project differ to some extent from the global debate on “land grabs”, as they reflect South Africa’s particular demographics and history. Potential implementation barriers deriving from commercial farmer support and the performance of an initiated biofuels-related BEE project in Cradock determine the challenges and social desirability of this fuel ethanol project. Figure 3 shows the interrelationships of anticipated environmental and social aspects from the Cradock biofuels project; they form the conceptual framework of the present dissertation. The following section describes this approach, and the interrelationships shown in figure 3, in more detail.

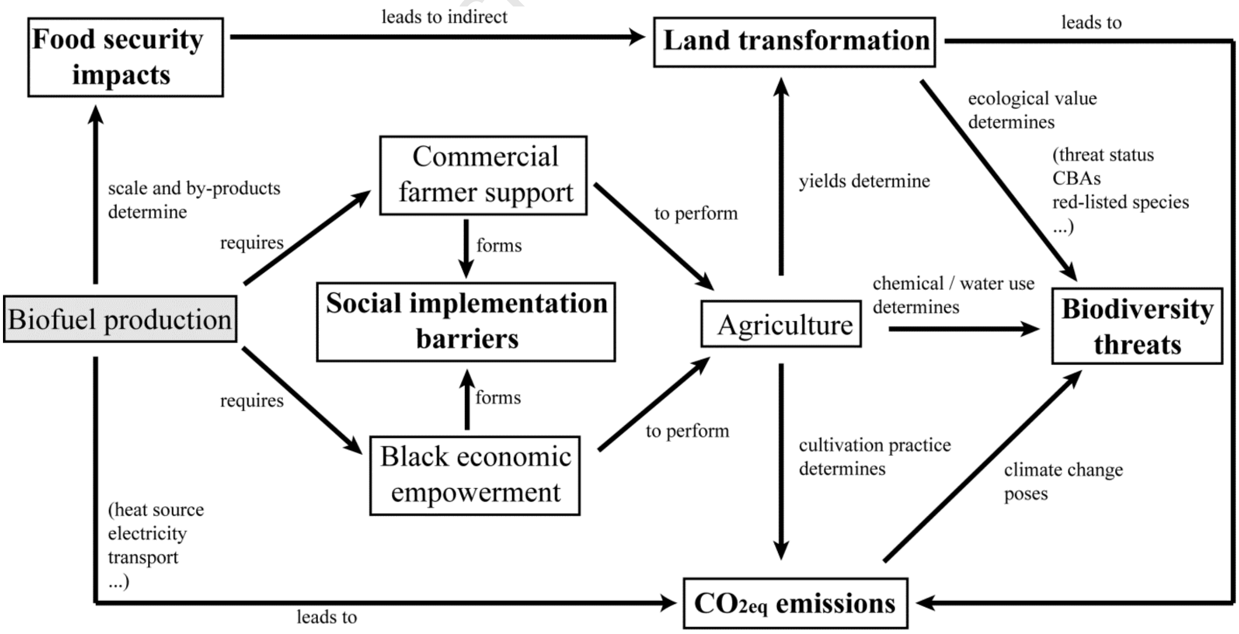

FIGURE 3 **Conceptual framework of the present study**

Abbreviations used: CBA, Critical Biodiversity Area; eq, equivalent. Reading from “Biofuel production”, the diagram shows the interrelationships between Cradock biofuel production, agriculture and the various environmental and social components assessed in this dissertation

2.8.1 Social implementation barriers – Black Economic Empowerment, stakeholder cooperation, and feedstock supply

Instances of socially undesirable effects of biofuel projects on a global scale are well-documented (Cotula *et al*., 2008, 2009). The social aspects of Cradock fuel ethanol production that are assessed in the present study comprise the local farmers' willingness to participate in the fuel ethanol project, and the performance of the BEE programme. The incorporation of BEE performance into an assessment such as this is an issue that is specific to the South African case, but nevertheless significant, as both the commercial farmer support and the success of the emerging farms are necessary for the successful implementation of the proposed Cradock fuel ethanol project. This performance essentially determines the social barriers of the fuel ethanol / BEE aspects of the proposed project.

2.8.2 Food security

Earmarking (existing) agricultural land from that dedicated to food crops to biofuel feedstock production will inevitably have an impact on food production. However, it is the scale of the project and the magnitude of the outcome that determines the socio-economic and environmental consequences. Possible impacts on food security on a local, national and / or international level determine the potential of Cradock fuel ethanol production to trigger a land conversion process for offsetting losses of food crop production elsewhere. In the process of examining food security impacts, socio-economic impacts have to be discussed in the context of the overall desirability of the proposed plant. In addition, should food security be jeopardised, iLUC considerations would need to be incorporated into the carbon footprint analysis.

2.8.3 Agricultural footprint: land-use and biodiversity

Ideally, in the context of establishing a biofuels project, the agricultural footprint, created through chemical inputs, GHG emissions during cultivation and land conversion, should be minimised, and returns in terms of feedstock and ethanol yields should be maximised (Childs and Bradley, 2007). The various impacts on habitat and biodiversity are characterised and determined by the extent of the area that biofuel feedstock fields occupy, cultivation practice (in this case: chemical and water use), and the ecological value of the original state of the land. The estimate for the amount of land that is needed to produce sufficient feedstock for a given project is based mainly on the potential yields. Cultivation practices of biofuel feedstock incorporate chemical and water use, which differs from, for example, organic, conventional, and GM crop farming. Key criteria used in the present study to describe and measure the ecological value of land are i) the threat status of the biomes that are utilised for agriculture, indicated *inter alia* by the presence of Critical Biodiversity Areas (CBAs), which are areas declared by the Eastern Cape Biodiversity Conservation plan of 2007 to be of significant ecological importance, and ii) the occurrence of (threatened) species that may be affected by agricultural activity.

2.8.4 Carbon footprint

In order to maintain the potential of biofuels to mitigate GHG emissions, the carbon footprint of a biofuel should not exceed the footprint of a fossil fuel reference. Cultivation practice, land-use change (both direct and indirect) and feedstock yields form vital parts of the carbon footprint of a biofuel (*e.g.* Stephenson *et al*., 2010). For conversion operations, the energy source for the ethanol plant contributes significantly to the carbon footprint of the produced fuel (Wang *et al*., 2007). Estimating the extent of the carbon footprint of the proposed Cradock fuel ethanol project therefore potentially allows for the identification of improvement measures in the biofuel production chain. The present evaluation incorporates Börjesson's (2009) four criteria for environmentally sound biofuel production: i) plant emissions, ii) land conversion, iii) by-product use, and iv) fertiliser impacts.

2.8.5 Conceptual framework: summary

The conceptual framework depicted in Figure 3 demonstrates how the various social and environmental components of biofuel production are interlinked. For example, impacts on food security from biofuel production can trigger iLUC processes elsewhere and hence lead to additional carbon emissions. Biodiversity can be affected by land transformation, chemical / water use, and, indirectly, by climate change. At the same time, cultivation practice determines emissions during the cultivation phase. It is due to the complexity of these matters, that this study takes a broad and comprehensive approach for the determination of the various social and environmental impacts. As demonstrated in this literature review, biofuels are contested in terms of each of the given components (that is: food security, social performance, GHG emissions, land transformation, and biodiversity threats). Taking into account the interrelationships of these aspects, the present study assesses anticipated impacts from biofuel production in Cradock. The determination of the relevance of the concerns highlighted in the global biofuels debate for the specific Cradock case forms the overarching goal of this dissertation.

3 Study Site and Project Description

3.1 The proposed Cradock bioethanol plant – geographical description and water schemes

Having outlined the research aims, the theoretical background and the conceptual approach of this dissertation in the previous chapters, this section introduces the study site and the current plans of this proposed pioneer fuel ethanol project in Cradock (Inxuba Yethemba municipality, Eastern Cape). The town of Cradock has a population of roughly 30,000 people, and its economy is based largely on agriculture. The poverty rate is high: more than 40 % of the adult population in the project area is unemployed (Vivier *et al*., 2009). Being situated in the Great Fish River Valley of the Eastern Cape, South Africa (Figure 4A), the Cradock area is part of the Karoo formation and semi-arid with an annual rainfall of 350 mm.

Due to the regional climate, crops are grown exclusively under irrigation and are thus restricted to the proximity of the river systems (Figure 4B−C). Most of the valley's irrigation water (more than 80 %) is supplied from the Gariep dam that accumulates water from the Orange River. A tunnel that connects the Gariep dam with the Great Fish River scheme has been operational since the early 1970s (Figure 5, green dashed line). This additional water flow has had substantial effects on the valley's ecology and economy: the Great Fish River went from ephemeral to perennial, with effects on the aquatic invertebrate composition (O'Keeffe and Moor, 2006) and riparian vegetation (Masubelele, 2012). As a result, many of the Cradock farms shifted production from livestock-orientated to irrigated agriculture farms. The remaining livestock is diverse, comprising cattle, sheep and some ostrich farms. Frequently grown crops are lucerne, maize, wheat and more recently tree nuts. Currently, the main agricultural production of Cradock is focused on dairy and meat, and most of the local agricultural products are used as animal feed (ARDA administration, 2012, personal communication).

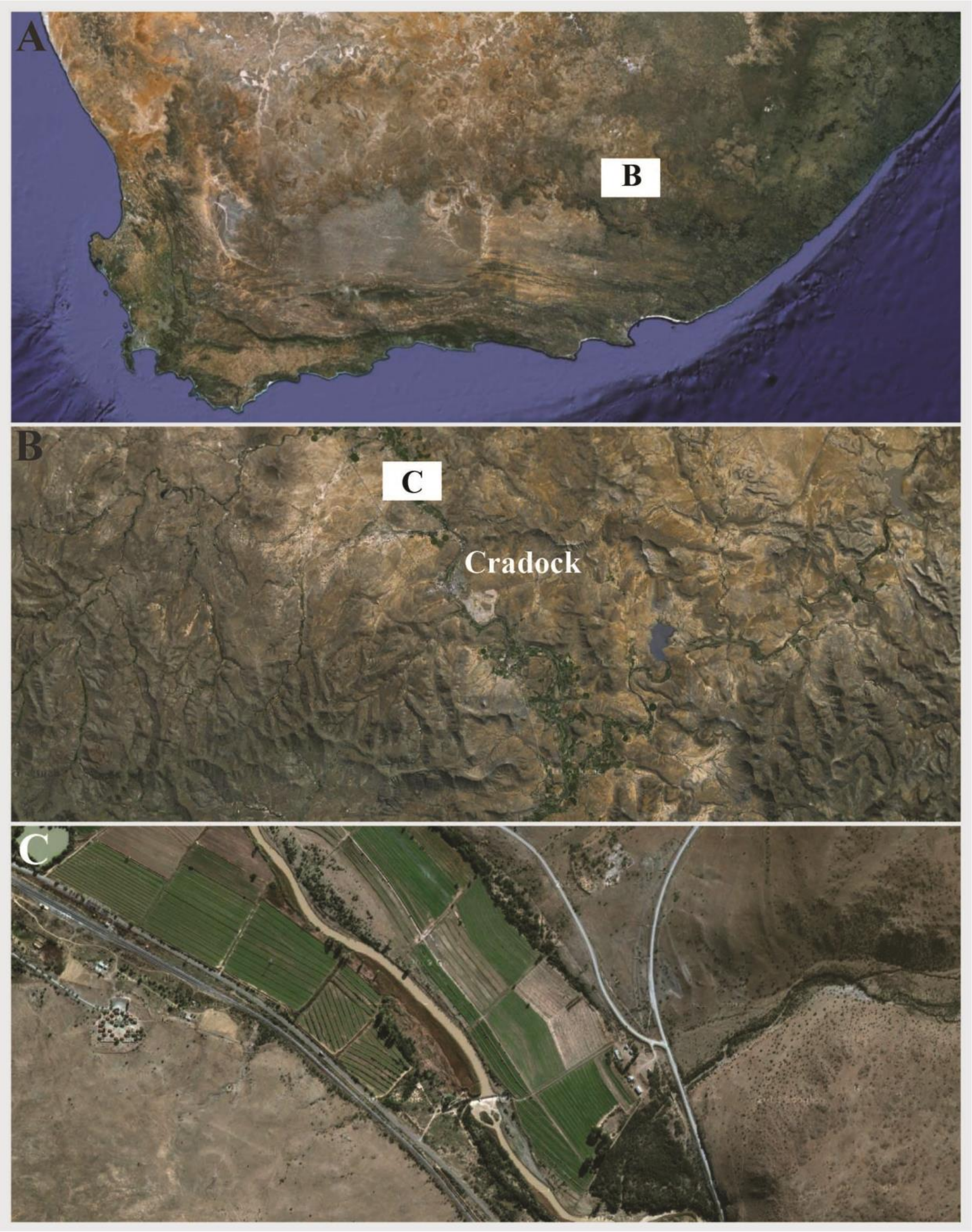

FIGURE 4 **Geography of Cradock**

Satellite images taken from Google Maps® **(A)** Cradock is situated in the Great Fish River Valley in the Eastern Cape of South Africa **(B)** Magnification on A. Shows the semi-arid mountainous Karoo landscape around Cradock. Note that agricultural activity is restricted to the proximity of the valley's rivers **(C)** Magnification on B. Shows farming activity along the Great Fish River

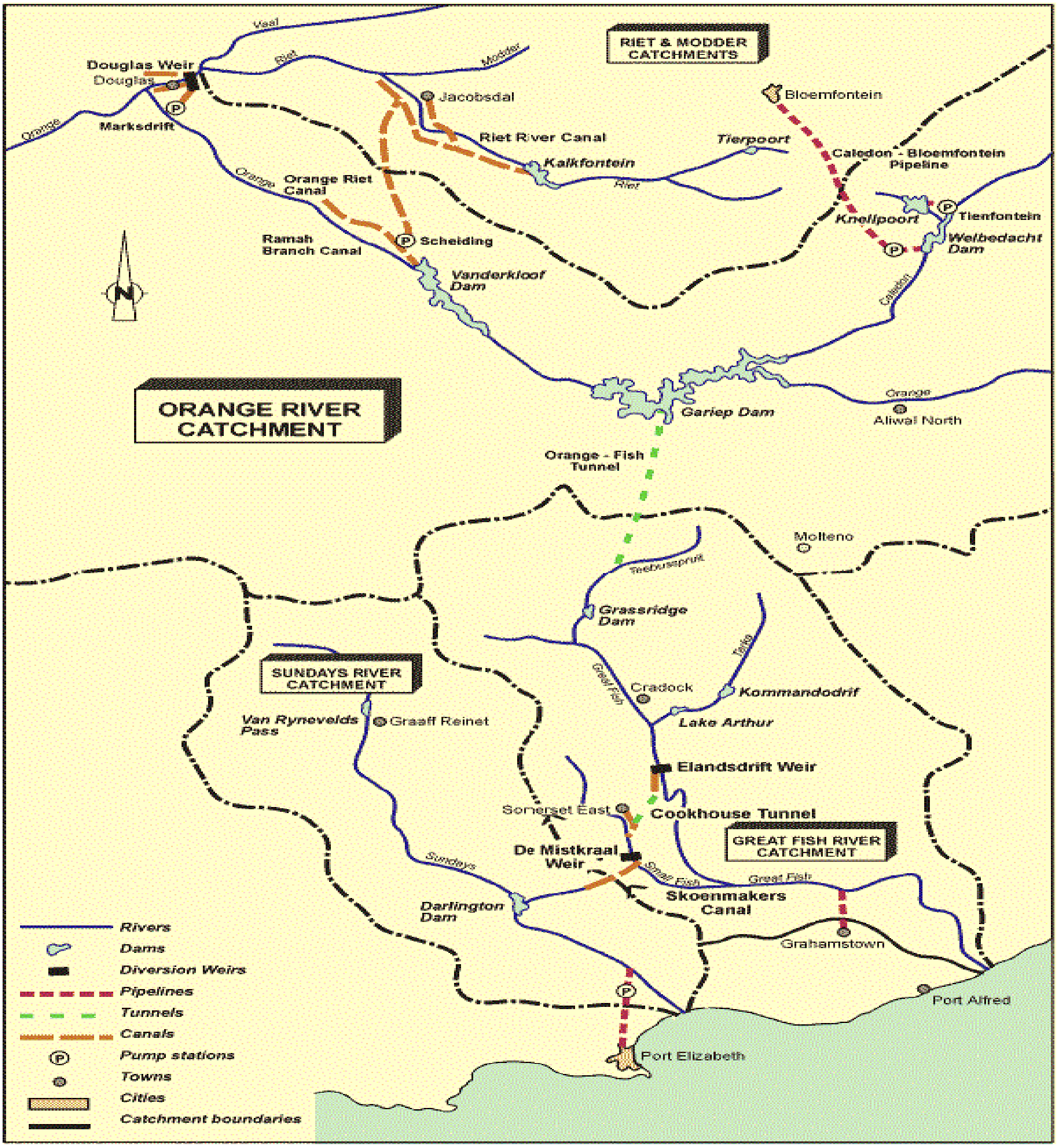

FIGURE 5 **Water bodies and irrigation schemes of the Cradock farms**

Source: Old Mutual, Cradock. Water feeding of the Cradock farms emerges from local springs and the Gariep dam that is fed by the Orange River. The tunnel connecting the Orange River scheme with the Great Fish River Scheme (green dashed line) has been operational since the 1970s

3.2 The proposed Cradock biofuel initiative – project description

Bioethanol programme – Agricultural sugar beet production trials have been conducted in the Great Fish River Valley for more than a decade. Despite promising yield results, it was perceived to be unfeasible to construct a sucrose (white sugar) production plant, as South Africa has sufficient sugar production facilities and is currently a sugar exporter (ARDA administration, 2012, personal communication). With the establishment of the South African biofuels policy (DME, 2007), what was initially investigated as a potential sugar production project in Cradock, was revised towards biofuels.

Cradock‘s highly productive irrigation farms, a high unemployment rate and connection to the railway made it a suitable site for this project. An internal bankable feasibility study of the proposed Cradock bioethanol project was conducted in 2008 (PGBI, 2008). The Environmental Impact Assessment[1] (EIA) of the proposed bioethanol plant was conducted by Africa Geo-Environmental Services in 2009 (Vivier *et al*., 2009). The project is undertaken as a joint venture of the parastatal organisation Agrarian Research and Development Agency[2] (ARDA), which was formally executing the sugar beet trials in the valley, and the Industrial Development Corporation (IDC). The Central Energy Fund, a third partner that was involved initially in the project, is no longer participating.

The plant will utilise sugar beet and, to a lesser extent, grain sorghum, as feedstock and has a projected initial production capacity of 90 million litres of ethanol per year (Vivier *et al*., 2009). This accounts for roughly a third of the 2 % biofuel contribution to national liquid fuels aim specified in the 2007 biofuels policy paper (DME, 2007). The EIA claims net-energy benefits for both types of feedstock: it states positive values of 1.31 for sugar beet and 1.22 for grain sorghum; associated carbon emissions have not been quantified. Grain sorghum will be grown locally and purchased from farmers around the country, and sugar beet will be produced locally exclusively. The average haul distance of sugar beet is expected to be about 70 km. The ethanol fuel product will be exported from Cradock via rail (Vivier *et al*., 2009). Feedstock production will be undertaken by emerging farmers, but also be performed on some of the commercial irrigation farms that are to be earmarked for sugar beet cultivation.

[1] South African environmental law requires the process of an Environmental Impact Assessment prior to the commencement of major development projects. This is prescribed in the National Environmental Management Act no 107 of 1998

[2] The Agrarian Research and Development Agency, formally known as Sugar Beet South Africa, was taken over by the Eastern Cape government and is now integrated in the Eastern Cape Agricultural Department

Black Economic Empowerment – As outlined in the 2007 South African Industrial Biofuels Strategy (DME, 2007), biofuel production plans were made with the intention to uplift rural areas and to strengthen the economic position of black South Africans. In order to produce the feedstock for the Cradock fuel ethanol plant, by early 2013, a total of 25 farms (roughly 16,000 hectares of land; this number includes irrigated land, grazing area and infrastructure) purchased from commercial farmers were reallocated to emerging farmers (so called beneficiaries) (Vivier *et al*., 2009; DRDLR, 2013a). The project aims to source 30 % of biofuel feedstock from emerging farmers, with the remainder supplied by the commercial farming community. All emerging farms are in state ownership and are allocated in the form of lease contracts. The beneficiaries have been allocated mentors from the commercial farming community and contractors to perform initial crop plantings. The maintenance of the farms and the mentorship programme are managed and coordinated by ARDA.

4 Methods

4.1 Case study approach

In these early stages of the South African biofuels programme, it is impossible to comprehensively predict its environmental and socio-economic impacts without integrating major assumptions. The proposed Cradock fuel ethanol project is not the only biofuels initiative in South Africa, but it is the most advanced in planning and will most likely be the first one to be operational (DME, 2013b). Therefore, Cradock can be viewed as the pilot project for the programme, providing an example of fuel ethanol production for other national biofuel projects. The current analysis of the environmental impacts of the proposed Cradock fuel ethanol project and the implementation barriers that derive from commercial farmer support and the associated Black Economic Empowerment (BEE) programme, are used here to determine the potential for environmentally and socially sound fuel ethanol production at this location.

A particular strength of case studies is that they are rooted in real-case scenarios (Hodkinson and Hodkinson, 2001). This allows for an assessment of the applicability of theories of environmental impacts and BEE to the reality of the Cradock case. Identification of deviations from theory in reality offers the opportunity to debate and refine the applied theory. It is acknowledged, however, that a case study serves best for providing insights for specific examples, rather than for higher-level generalisations (Flyvbjerg, 2006). Because succeeding national biofuels projects will differ in production circumstances and utilised feedstock, this study permits conclusions for the specific Cradock fuel ethanol and BEE case only. The transferability of the findings to other projects in and outside South Africa will therefore depend on case-specific attributes.

4.2 Methods summary

The EIA of the proposed Cradock plant has a strong focus on the environmental and social impacts of the factory (DME, 2007), only peripherally investigating the agricultural impacts, which traditionally determine the desirability of fuel ethanol production (Puppán, 2002; Stephenson *et al.*, 2010). This study takes a broader perspective, incorporating social and environmental aspects of agricultural activity and an interview-based evaluation of possible implementation barriers.

This study employs a mixed method approach of qualitative and quantitative data collection and analysis. The social implications that arise from ethanol fuel production, specifically the expectations and the support of the Cradock farming community and the performance of the BEE programme, are deduced from semi-structured interviews with commercial and emerging farmers, as well as relevant representatives of government, the private sector and researchers (Table 1). The specific responses of the key informants (*e.g.* ARDA representative on the project plans; state agent on the BEE program) enable qualitative analyses only. Perceptions on food security impacts are recorded from farmer interviews and contextualised with descriptive food production statistics. Impacts on habitat and biodiversity from biofuel feedstock cultivation are inferred from commercial farmer interviews and biodiversity maps of the area. The choice of method for quantifying the carbon footprint of the Cradock biofuel is a life-cycle based assessment, which provides a "cradle-to-grave" analysis of GHG emissions during the life-cycle of a product. The inputs of commercial and emerging farmers were analysed using descriptive statistics. A detailed description of the applied methodologies is given in the following sections.

4.3 Interviews

4.3.1 Interviewee selection and ethics considerations

Field work for this study was conducted during two field trips to Cradock; a one-week screening trip in December 2012 and a subsequent 3-week field trip in February 2013. Initial contacts for beneficiary and commercial farmer interviews were obtained from the Agrarian Research and Development Agency (ARDA). Potential subsequent interviewees were identified with the assistance of the initial contacts. The interviewees represented farming units along each of Cradock's access roads, covering the whole range of the farmers' geographical distributions in regards to the Cradock area. The geographical distribution of farms visited extended up to 80 km north and 120 km south of Cradock. The interviewees were contacted before personal meetings were arranged, and the purpose of the study was explained before and again during the interviews. Participation in the study was completely voluntary. Interviews with commercial farmers were tape recorded, and those with emerging farmer were recorded using written notes only. This was an adjustment taken in response to the possibility of recording potentially sensitive information of a more vulnerable interview group. No names are displayed in this document, and care was taken to prevent interviewees from being personally identified.

4.3.2 Semi-structured interviews: commercial and emerging farmers

Commercial farmers were interviewed about their agricultural practices and opinions towards the various aspects of the proposed Cradock bioethanol project. Questions on social aspects were posed to determine the support and concerns of the farmers. Questions on farming practices and the environment were used to infer possible environmental impacts from agricultural activity.

A total of 22 commercial farmers were interviewed, representing 22 farming units. The study was comprised exclusively of farmers with irrigation farms suitable for sugar beet production. Game farms and livestock-only farms were excluded from sampling. The combined irrigation area of the interviewed farmers comprised more than 6,000 hectares, out of the ~30,000 hectares found in the valley (Vivier *et al*., 2009), thus the sampled commercial farmers account for more than 20 % of the total irrigation crop production area of the region.

The interview questions were standardised, but open-ended to ascertain the full spectrum of the farmers' concerns. Themes included experience of involvement in the sugar beet trials, willingness to plant sugar beet, expectations for their own businesses and the wider area, food security issues and the BEE programme. Environmental impacts were inferred from farmer inputs on changing patterns of chemical use and irrigation, the consideration of agricultural expansion, opinions about possible impacts on biodiversity, and farming practice (*e.g*. organic, or the planting of genetically modified (GM) crops).

The vast majority of interviews were held on the farmers' properties. All interviews were face-to-face. The interviews were tape recorded, lasting between 30 and 60 minutes. Based on the individual responses, general opinions were extracted for each investigated aspect in order to construct quantitative analyses of certain issues (Table 2; based on Appendix 1, 2). In cases where the interviewees took clear positions on a subject, they were classified as either "positive" or "negative"; in the case of undecided, ambivalent or contrasting statements, the input was classified as "neutral". This served to determine which aspects of the proposed Cradock biofuels project are controversial. A more detailed demonstration of frequently raised concerns and notable comments is depicted in the results section that summarises the responses from all 44 interviewees (Table 4).

A total of 12 emerging farmers, representing 10 farming units, were interviewed to assess the performance of the BEE programme. This covered 40 % of the emerging farms (by unit) in the area. Emerging farmers were questioned on the beneficiary application process, condition of their farm and crops, supervision, relation to neighbours and their expectations of the proposed Cradock ethanol fuel project. Five beneficiary farms were visited during fieldwork, with the rest of the interviews held in the town of Cradock. Similar to the commercial farmers' interviews, general opinions were extracted for each investigated aspect (Table 3, based on Appendix 3).

4.3.3 Semi-structured interviews: key informants

Ten key informants from the governmental, commercial and research sectors were interviewed as complementary information sources (Table 1). Due to the heterogeneity of the interviewees, the questions were not standardised. The same themes were covered, but adjusted to the specific interviewees. All interviews were open-ended. The information gathered from these interviews are either used in form of citations, or summarised in the results Table 4.

TABLE 1 **Supplementary key informant interviews of government, private sector and research representatives.**

Government	Private	Research
- Representative of the administration of ARDA - Representative of the land reform section of ARDA - Representative of the Department of Agriculture (Cradock, Eastern Cape) - Representative of the Local Economic Development Department - State Agent involved in BEE	- Retailer of agricultural supplies - Retailer of agricultural goods	- Representative of the research department of ARDA - Independent researcher on sugar beet trials - Representative of the Mountain Zebra National Park

4.4 Chemical and water use data

To achieve a broader environmental assessment, complementary to the interview data, fertiliser and water use in sugar beet cultivation were compared with those of crops that are currently grown in Cradock and are likely to be replaced with sugar beet. Most frequently this would be maize or a maize / wheat double crop that is grown within one year (6 months each). As sugar beet is a 9 month crop in the Cradock area, the remaining 3 months of the year would possibly not be used for growing crops. Lucerne (also alfalfa; *Medicago sativa*), a popular animal feed crop in Cradock, would play a role in the sugar beet crop rotation.

The average chemical use of nitrogen (N), phosphate (P) and potassium (K) fertilisers for a maize / wheat double crop and lucerne cultivation in Cradock were obtained from an agricultural supplies retailer. Fertiliser used in sugar beet cultivation is based on actual data from the latest sugar beet trials and is supplemented with an independent researcher's (Table 1) and the 2009 Cradock EIA estimates. Water use by a maize / wheat double crop and lucerne was obtained as a range from the inputs of three commercial farmers. Water use of the sugar beet cultivation is based on the input from two Cradock sugar beet researchers and the 2009 Cradock EIA (Vivier *et al*., 2009).

4.5 Carbon footprint analysis

4.5.1 Scope and input values

The carbon footprint of a biofuel crop is determined by the various steps of its life-cycle (Figure 2). The cultivation module is calculated using the Roundtable on Sustainable Biofuels (RSB) tool "Sustainable Quick Check for Biofuels" (SQCB). This life-cycle assessment (LCA) tool is available online at www.rsb.org/ghgcalc/. Direct land-use change is considered in the SQCB tool, but to date indirect land-use change (iLUC) (discussed in section 2.5.2) is not included. A detailed description of the parameters used in SQCB is provided by Emmenegger *et al.* (2009).

Many components of cultivation and biofuel production LCAs are already known. The SQCB tool is based on a database of known parameters and is complemented with the user's entries. Initially, the tool was invented to allow small and medium-sized enterprises (especially in developing countries) to test whether their production complied with European sustainability standards (Zah *et al*., 2009). The SQCB tool standardises the biofuel LCA methodology and further allows for hypothetical data entries, which is utilised in this study to estimate the effects of alternative GM feedstock cultivation (see below, 4.5.2). The specific input values are given in the results section (Table 6). Irrigation is calculated as 800 mm sprayed on a centre pivot (using 98 kWh per million litres pumped; estimate based on DEPI, 2007). The one-time carbon release from dLUC is accounted over a period of 20 years using standardised RSB methodology (EPFL, 2011a).

The modules of transportation, biofuel production, storage, blending and handling (Figure 2) were supplemented and calculated with adjusted default values in the UK Carbon Footprint

Calculator, version 6.0 (Table 7). The reason for the utilisation of default values is that the plant is not yet operational, and the engineering plans are confidential.

The transport of feedstock is calculated assuming a range of 70 km with trucks (Vivier *et al*., 2009). The ethanol export transportation route is calculated based on a 150 km railway. For all steps that require electricity use, the emission values of South African grid electricity were calculated as 1.03 kg CO_2 equivalent (CO_2eq) per kWh (Eskom, 2012). Plant ethanol yield is calculated as 0.086 tons of ethanol per ton of sugar beet, or 109 litres (based on the internal bankable feasibility study; PGBI, 2008). The carbon footprint of hard coal in conversion operations is calculated using 0.112 kg CO_2eq per MJ (LCA default value). The fossil fuel reference was calculated using 90g CO_2eq per MJ (EPFL, 2011b). Animal feed, derived from the beet bulb, is accounted as an ethanol by-product (Vivier *et al*., 2009), and is calculated as 0.692 tons per ton of produced ethanol (LCA default value).

4.5.2 Simulated sugar beet production scenarios

Four production scenarios were simulated using the latest sugar beet trial data: i) conventional cultivation on existing cropland; ii) hypothetical GM cultivation on existing cropland iii) conventional cultivation on virgin grounds, and iv) hypothetical GM cultivation on virgin grounds. Scenario i) was also simulated with a conservative yield estimation of 95 tons per annum. This scenario emulates the description in the 2009 Cradock EIA, which is based on older sugar beet trials (Vivier *et al*., 2009).

Virgin grounds were defined as moderately degraded grass- and shrub land, which are currently unutilised agricultural grounds on the Cradock farms. Genetically modified crops are represented by a glyphosate resistant (marketed as Roundup Ready™) version of sugar beet. Glyphosate (N-phosphonomethylglycine) is a broad-spectrum herbicide that functions by inhibiting the protein biosynthesis, eventually leading to the death of the plant. Transgenic glyphosate resistant crop plants are genetically designed to be unaffected by glyphosate exposure.

Between 1997 and 2012, 16 GM crop crops were introduced into South Africa (DST, 2013). Genetically modified sugar beet is not yet approved in South Africa; however, this study incorporates hypothetical GM biofuel crop cultivation because i) other crops in the valley are already GM, and ii) although laboratory and field tests are required for the approval of a GM crop, it is likely that biofuel production from sugar beet triggers the introduction of a GM variant in the near future (ARDA administration, 2012, personal communication). Organic cultivation practices for this biofuel crop are not assessed in the present study, because weed control has been reported to be vital for the success of crop plantations in the Cradock area (ARDA research department 2013, personal communication) and yields without herbicide use are therefore considered to be highly uncertain. The differences in cultivation practices of (hypothetical) GM crops and conventional cultivation are illustrated in the results section (Table 6).

4.6 Mapping and imaging

Satellite images were obtained from Google Maps. Maps on biomes, land cover, terrestrial Critical Biodiversity Areas (CBAs) and threatened ecosystems were obtained from the South African National Biodiversity Institutes' Geographical Information System website (www.bgis.sanbi.org). This mapping information, combined with the farmers' inputs on species occurring on their farms, informs the assessment of the ecological value of the land that is potentially utilised for biofuel feedstock cultivation. Graphs were produced with Microsoft Excel®, ArcGIS™, Adobe Illustrator® and Adobe Photoshop®.

4.7 Limitations

4.7.1 Response bias and access to information

The interview data obtained for this study reflects the interviewees' responses, and not necessarily their actual opinions. For example, respondents may refrain from giving honest answers in fear of their opinions being revealed to the "wrong" persons, or that their views may be seen as socially undesirable. Because these possible response biases are well known (Furnham, 1986), many of the interview questions were broadly formulated. After a topic was introduced, the respondents were allowed to speak freely. There were no time limits set by the interviewer. However, although measures were taken to avoid response biases, their existence and influence in this study cannot be refuted with certainty.

Some of the information with regards to the engineering plans and the sugar beet trials are subjected to intellectual property of the IDC and / or ARDA. Although limited (time-restricted) access was granted to the bankable feasibility study (PGBI, 2008), some information that would increase the sophistication of the LCA and other parts of this study could not be obtained.

Although assessed peripherally with the various interviews held for this study, this dissertation does not comprise a detailed economic evaluation of the proposed Cradock fuel ethanol project. It is acknowledged that this is a limitation in regards to comprehensively understand the socio-economic desirability of the proposed project.

4.7.2 Limitations of the carbon footprint analysis

Since the Cradock bioethanol plant is not yet operational, there is no empirical validation of the GHG calculations. The same applies to the values of GHG emissions from the utilisation of GM crops, which are based on ARDA estimates. Since the data entry of sugar-beet-to-ethanol conversion processes is based on default values for the amount of electricity and heat source used, emissions from this module were calculated conservatively through the inclusion of a conservative factor of 1.4 that is applied to this particular step of the biofuel production chain. This study therefore describes the upper limit of emission estimations (and therefore the lower end of GHG savings). Spillage was not taken into account; the LCA assumes no transportation losses.

The plant will require sugar beet as main feedstock, but grain sorghum will be utilised as supplementary feedstock for ethanol production as well. According to the 2009 EIA, sugar beet will be utilised for 240 days a year, and grain sorghum for 98 days (Vivier *et al.*, 2009), although an ARDA representative described a different scenario where grain sorghum was an initial feedstock that would eventually be replaced by sugar beet (ARDA administration, 2012, personal communication). The LCA conducted in this study focuses on the sugar beet feedstock, *i.e.* the results of this assessment describe the carbon footprint of sugar beet ethanol only. This has been done for two reasons: i) sugar beet will be the main feedstock of the plant (regardless of the scenarios outlined above), and ii) uncertainties and heterogeneity of the circumstances for grain sorghum cultivation (such as the associated yields, chemical and water inputs) that will be locally grown or imported from locations around the country (Vivier *et al.*, 2009) make a reliable assessment of sorghum ethanol GHG emissions unfeasible at this stage.

5 Results

5.1 Interview data

5.1.1 Commercial farmers – perceptions on social aspects and food security

Questions on willingness to participate in the project, food security ramifications and Black Economic Empowerment (BEE) were posed to ascertain the perceptions of the commercial farming community of the social aspects of the proposed Cradock biofuel project. The commercial farmers' responses to the interview topics are summarised in Table 2.

Seven out of the 22 (32 %) interviewed commercial farmers were involved in the sugar beet trials. Their farms ranged from 40 to 1,300 hectares of irrigation area (mean: 289 ha; n = 21). The farmers have run farms between 5 and 40 years (mean: 22 years; n = 19). Most commercial farmers interviewed (n = 16; 73 %) are willing to plant sugar beet if economic benefits occur. Six farmers (27 %) stated that switching to sugar beet comprised (too) much inconvenience. Most farmers questioned (n = 18; 82 %) think of the Cradock fuel ethanol project as beneficial for either the town and / or their own business. Only three farmers remained sceptic due to uncertain economics, one believed it to be unfavourable due to a projected traffic increase and negative impacts on tourism. Food security is of least concern according to the farmers. The scale of the project was emphasised to be too small to impact on South Africa's food market ("*This valley is only a drop in the ocean of food supply*", farmer 14; Appendix 1). Returns from beet bulb during biofuel production, yield increases over the years and agricultural expansion were mentioned to offset losses of food production.

There is generally little trust in the success of the BEE programme. Only four commercial farmers were favourable of the performance of this programme (18 %), ten responses were negative (45.5 %) and eight answers were ambivalent (36.5 %).

5.1.2 Commercial farmers – impact of farming practice on biodiversity

The interview questions on farming practice and biodiversity aimed to determine the environmental impacts that are caused by agricultural activity in the Great Fish River Valley.

More than half of the questioned farmers would consider agricultural expansion on virgin grounds (n = 13; 59 %), either because it is in their current plans, or hypothetically if they had irrigation water to spare (see below: water requirements for sugar beet cultivation; 5.2.1). The vast majority did not believe there were negative impacts on biodiversity from agricultural activity and expansion (n = 17; 77 %). Only one farmer believed he had cleared ecologically valuable lands as he removed numerous *Acacia* trees for a centre-pivot, which was the "*habitat of the* [vervet] *monkey and the guinea fowl*" (farmer 21; Appendix 2). On the other hand, it was stated that wildlife had "*skyrocketed*" (farmer 20; Appendix 2) due to agricultural activity. Those farmers that had lived in the valley before the construction of the Orange-Fish-River tunnel (Figure 5) reported that animal species abundance had increased as irrigation farms had spread, which comprised the (re-)introduction of certain mammalian predators ("*We've got more species of animals now than we had when I was a kid*", farmer 17; Appendix 2). According to the farmers, mammalian predator sightings in the area included jackals (*Canis mesomelas*), African wild cat (*Felis silvestris lybica*), caracals (*Caracal caracal*), and recently introduced servals (*Leptailurus serval*) and black footed cats (*Felis nigripes*). Farmers, as well as representatives of the nearby Mountain Zebra National Park confirmed that jackal hunts are frequently undertaken in the Cradock area in order to control the population of this livestock predator. Almost all farmers have opportunistic crop raiders on their farms, such as kudu (*Tragelaphus* spec.) and other antelope species, as well as bush pig (*Potamochoerus larvatus)*, vervet monkey (*Chlorocebus pygerythrus*) and chacma baboon (*Papio ursinus*). However, few perceive crop-raiding to be an economic problem ("*It is so little, I just let them eat*", farmer 21; Appendix 2). One farmer mentioned that there were "*hardly any* Acacia *trees*" (farmer 18; appendix 2) present in the past, and another stated that the spreading of *Acacia* trees are considered a "*pest*" (farmer 11; Appendix 2).

5.1.3 Commercial farmers − utilisation of genetically modified crops

Soy beans and maize are planted as genetically modified (GM) crop variants in Cradock. A seed retailer (2013, personal communication) stated that 95 % of the maize seeds sold are transgenic. These are either glyphosate-resistant and / or express *Bacillus thuringiensis* toxin (Bt; a plant-produced insecticide). Only one of the questioned farmers did not use GM crops, as he is adopting "*organic*" farming practices (farmer 9; Appendix 2).

The Agrarian Research and Development Agency's (ARDA) research department that executed the sugar beet trials stated that GM sugar beet is "*not necessary*" for successful weed control. Contrastingly, in the administrative department of ARDA, the perception reflected those of many interviewed farmers, as it was stated that

"*the main advantage* [of GM cultivation] *is the ability to prepare the fields and you're finished (…). You just have to irrigate after that. In conventional growing you keep going in, spraying for stem borer and weed control, it's more difficult*", and further that

"*there is Roundup Ready sugar beet on the international market, but nobody will touch it, because the sugar industry doesn't want to be associated with GM. Of course, this is for fuel, it wouldn't matter at all* (…). *It does make life simpler. And the car is not going to mind it*".

The above statement indicates that the South African sugar industry has refrained from using GM sugar crops because they rely on exports, and GM food is banned in many target countries. However, almost all of the commercial farmers preferred a glyphosate-resistant sugar beet variant (n = 19; 86 %), with only three being equally satisfied with a conventional line. A main advantage was perceived to be convenience, as glyphosate-resistant crops were reported to require less intervention and fewer herbicide applications. Genetically modified crops were further stated to produce higher yields due to efficient weed control and to offer overall economic benefits. Emphasising its effectiveness, none of the farmers reported that they had personally experienced problems of glyphosate resistance formation in weeds, although the need to increase glyphosate application rates over time has been mentioned.

5.1.4 Emerging farmers – aspects of Black Economic Empowerment in Cradock

The emerging farmer interviews form part of the core of the BEE performance evaluation for this study. Table 3 depicts the inputs of the interviewed emerging farmers in response to the interview topics. The beneficiaries of the Cradock valley have diverse backgrounds, but most have farming experience with livestock or community gardens. Only some have experience with irrigation farms. With few exceptions, interviewed emerging farmers had been on their farms for no longer than three months when the interviews were held.

Social and administrative aspects – The Land Reform department of ARDA assists in the beneficiary pre-selection, but the final decision is made by the national ministry. In an interview, an ARDA Land Reform department representative stated that

"*the process of applying and getting to be a beneficiary can take anywhere between 3 months and 6 years. But once this is established, the Land Reform process will be streamlined*", and; "*If we get this right here, this could be an example for how to do things on a national level*".

In contrast, only two of the interviewed emerging farmers (17 %) were satisfied with the application process to become a beneficiary; most complained that the process took too long, therefore making planning difficult. ARDA also managed the allocation of supervisors; however, half of the interviewed beneficiaries (n = 6; 50 %) were not satisfied with their supervision. The interviewees stated that mentor meetings were infrequent and not long enough, and that their relationships to the mentors are sometimes suboptimal. Omissions in training and book keeping were also mentioned. A third of the interviewees described the relationship to their neighbours as distrustful or bad (n = 4; 33 %). Racism was mentioned.

Materialistic aspects − More than half of the beneficiaries (n = 7; 58 %) stated that their farms were received in a poor and deteriorated condition. The crops that were planted on the farms were prepared by contractors. They were described to be in fair condition by five beneficiaries (42 %), with seven beneficiaries (58 %) not satisfied with the plantings. It was pointed out that the fields were not prepared properly and that fertilisers were not applied on time, leading a beneficiary to state "*We've been set up for failure*" (beneficiary 12; Appendix 3). A state agent that was familiar with the situation claimed that "*the contractors that plant the crops don't mind if the crops are a success or not. They just want to get paid*". On some farms, allocated water rights were not fully utilised, but paid for. Four beneficiaries (33 %) declared the lack of own implements, such as tractors, to be a significant problem. The lease contracts were described as untransparent or unfair by four beneficiaries (33 %), with one stating that "*beneficiaries are chained*" (beneficiary 4; Appendix 3). The expectations about the proposed fuel ethanol project are generally positive. However, the uncertain monetary returns of sugar beet cultivation for biofuel feedstock were raised as concerns, as (unlike the commercial farmers) the emerging farmers are required by contract to produce this crop.

TABLE 2 **Summary of commercial farmers' inputs on interview topics**

Unless stated otherwise, positive responses are highlighted in green, neutral or ambivalent responses in orange, negative responses in red. Blank indicates missing data. Source: Appendix 1, 2. Abbreviations used: BEE, Black Economic Empowerment

ID	Willingness to plant sugar beet	Expectations for Cradock and business	Perception of food security impacts	Perception of BEE programme	Considering agricultural expension?[1]	Perception of biodiversity impacts	Preference for GM sugar beet
Farmer 1							
Farmer 2							
Farmer 3							
Farmer 4							
Farmer 5							
Farmer 6							
Farmer 7							
Farmer 8							
Farmer 9							
Farmer 10							
Farmer 11							
Farmer 12							
Farmer 13							
Farmer 14							
Farmer 15							
Farmer 16							
Farmer 17							
Farmer 18							
Farmer 19							
Farmer 20							
Farmer 21							
Farmer 22							

[1] red: considers agricultural expansion; green: does not consider agricultural expansion

TABLE 3 Summary of beneficiaries' (emerging farmers') inputs on interview topics

Positive responses are highlighted in green, neutral or ambivalent responses in orange, negative responses in red. Blank indicates missing data. Source: Appendix 3

ID	Application process	Condition of farm	Condition of crops	Super-vision	Relation to neighbours	Project expectations
Beneficiary 1						
Beneficiary 2						
Beneficiary 3						
Beneficiary 4						
Beneficiary 5						
Beneficiary 6						
Beneficiary 7						
Beneficiary 8-10						
Beneficiary 11						
Beneficiary 12						

5.1.5 Interview summary

Table 4 depicts frequently raised statements, pooled from all interviewees with statements categorised relating to i) administrative action, ii) BEE, iii) socio-economic issues, and iv) environmental concerns.

Administrative action − In terms of administrative action, farmers frequently raised the concern that numerous delays in the project schedule damages the support of the commercial farmer community, and that governmental action is generally too slow (n = 16). Consequently, many stated that they had lost interest in the fuel ethanol project (n = 15). Furthermore, communication and transparency between farmers and government, as well as within involved departments were believed to be poor (n = 9). This was confirmed by the Cradock Department of Agriculture, a state agent involved in the purchase of commercial farms, and a representative of ARDA, who said that "*the government officials only see what they have to see, they don't have the overview*".

Black Economic Empowerment − The BEE programme raised much controversy (see also Table 2, 3). Few of the interviewed farmers have trust that the programme works. Most frequently, it was stated that the allocated farms are in poor condition, as noted by the commercial and the emerging farmers, as well as a representative of government (n = 19). A state agent that was involved in the allocation of farms stated that

"*the process went totally wrong. The thing with irrigation farms is that you cannot leave them alone for one minute (...). The government purchased the farms, but they didn't pay electricity, water rights or the labour. Those people sat there for a couple of months without water, the crops were dying and everything*".

Almost half of the interviewed commercial farmers and some emerging farmers mentioned that the beneficiaries lack technical skills to operate an irrigation farm and have not received adequate training (n = 12). The allocation of government funds ("cash flow") has been described to be too slow and bureaucratic (n = 6). Emerging farmers stated that it is hard or impossible to make profits (n = 5). Farmers and beneficiaries acknowledged that there is a lack of trust between the two parties that hinders cooperation (n = 7). A third of the interviewed beneficiaries and one government representative stated that racism occurs (n = 5).

Socio-economic issues − With only one exception, all interviewed parties had neutral or positive expectations towards the Cradock biofuel project (n = 37). This included two retailers of agricultural goods and supplies, as well as representatives of government, agriculture and researchers. However, the economics of sugar beet cultivation were questioned frequently (n = 8). Food security on the other hand is of no major concern, and only one commercial farmer and one beneficiary considered that a shortage in food supply could occur during drought years (n = 2). An ARDA administration representative recalled that

"what happens out of your sugar beet production from the farming side, the ethanol becomes the by-product. What comes out of the factory is a high quality animal feed. The whole structure of this valley is not going to change. As far as food security goes, it is not affected at all, in fact it secures it, because it is creating that market".

The perception that food security is not limited by the availability of food, but by the economic means of some to purchase it, was shared by two farmers (farmer 11, 19; Appendix 1). They also perceived that the proposed fuel ethanol project could enhance food security through economic spin offs and employment creation.

TABLE 4 **Frequent statements (pooled from 44 interviews)**

Topic	Statement	Raised by	Total
Administrative action	- Government action is too slow	Commercial farmers (15) Government (1)	16
	- Farmers lose interest in the biofuel project due to lengthy administrative action	Commercial farmers (15)	15
	- Lack of transparency and communication	Commercial farmers (7) Governmental (2)	9
Black empowerment	- Allocated farms are in poor condition	Commercial farmers (10) Beneficiaries (8) Government (1)	19
	- Beneficiaries lack skill or training	Commercial farmers (10) Beneficiaries (2)	12
	- Lack of trust between commercial and emerging farmers	Commercial farmers (5) Beneficiaries (2)	7
	- Cash flow too slow and bureaucratic	Commercial farmers (5) Government (1)	6
	- Hard to make a profit	Beneficiaries (5)	5
	- Racism hinders cooperation between farmers and beneficiaries	Beneficiaries (4) Government (1)	5
Socio-economic issues	- The Cradock fuel ethanol project will benefit the town	Commercial farmers (21) Beneficiaries (10) Governmental (3) Commerce (2) Research (1)	37
	- Sugar beet cultivation may not be economically feasible	Commercial farmers (6) Beneficiaries (2)	8
	- Food security will be compromised	Commercial farmers (1) Beneficiaries (1)	2
Environmental concerns	- There will be impacts from traffic increase	Commercial farmers (5)	5
	- Soil quality will decrease from sugar beet cultivation	Commercial farmers (3)	3
	- Biodiversity will be affected	Commercial farmers (2)	2

Environmental concerns − From an environmental perspective, impacts from (truck) traffic increase was the biggest concern to interviewees (n = 5). Three farmers feared impacts on agricultural soil quality from heavy harvesting machinery, since it was pointed out that the harvesting dates would have to be fixed by contract in order to ensure a steady and orderly feedstock supply to the plant, regardless of temporary weather conditions. Possible biodiversity impacts from agricultural expansion were raised by only two interviewees.

5.2 Cultivation practice and yields

5.2.1 Water and fertiliser use

Water use − According to the 2009 EIA, despite the farmers' current expansion operations, sugar beet is envisaged to be planted on existing croplands, based on the notion that existing water rights will be utilised (Vivier *et al*., 2009). Thus, sugar beet will replace crops that are currently grown on the Cradock farms. Figure 6A depicts water use of sugar beet cultivation compared to selected crops grown in the Great Fish River Valley. Maize is a six months crop in Cradock and its cultivation is frequently followed by other crops such as wheat, which results in an annual double crop where each crop is grown for 6 months. According to the farmers, sugar beet cultivation would mainly replace this maize / wheat double crop, but lucerne would appear in the rotation cycle as well. Annual irrigation for these are between 1,100 and 1,400 mm (maize / wheat) and 1,800 to 2,000 mm (lucerne). The latest sugar beet trials reported annual irrigation amounts of 800 mm. A second opinion from an independent sugar beet researcher that was involved in the trials states 1,000 mm irrigation as a more realistic scenario of average sugar beet irrigation in the valley. The 2009 EIA notes 900 to 1,100 mm (Vivier *et al*., 2009). On average, replacing existing crops with sugar beet would therefore reduce water requirements (Figure 6A).

Fertiliser use − Figure 6B depicts fertiliser use of sugar beet cultivation compared to a maize / wheat double crop and lucerne. During the latest trials, 209 kg of nitrogen (N) fertiliser, 98 kg of phosphate (P) fertiliser and 99 kg of potassium (K) fertiliser were applied (ARDA, 2013, personal communication). An independent researcher suggested a higher amount of 120 kg K fertiliser as average for the valley. Combined, a maize / wheat double crop utilises marginally higher P and K values: 101 – 136 kg of P and 101 – 133 kg of K. Substantial difference is found in N fertiliser use: 209 kg per hectare of sugar beet cultivation contrasts 480 – 580 N utilised for a maize / wheat double crop. Maize as a single crop requires between 220 and 320 kg of N fertiliser, 45 to 80 kg of P and 48 to 80 kg of K, and therefore requires more N fertiliser than sugar beet, but less P and K application.

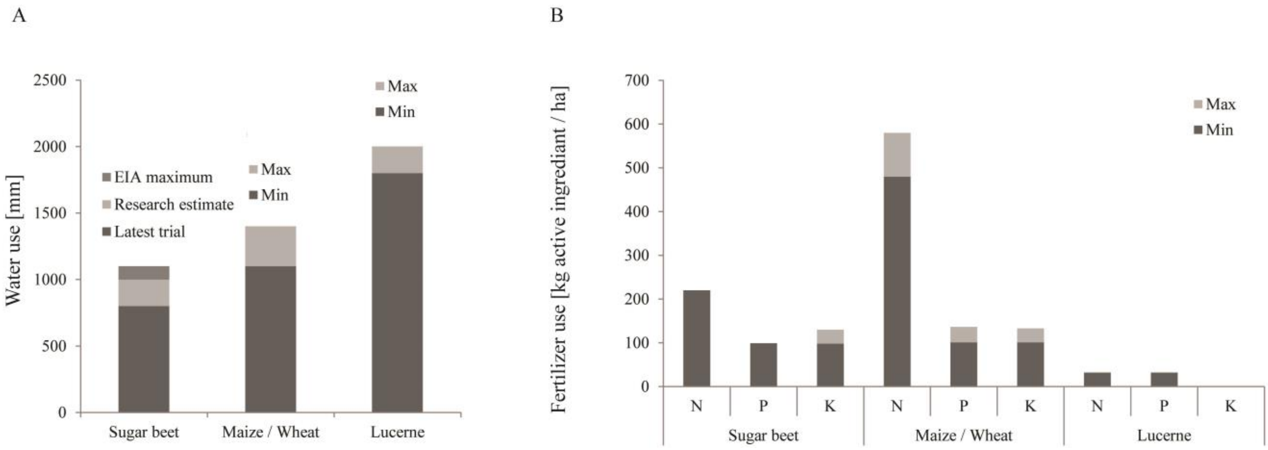

FIGURE 6 **Annual water (A) and fertiliser (B) use of sugar beet, maize / wheat double crop and lucerne cultivation per hectare.**

Abbreviations used: K, potassium; N, nitrogen; P, phosphate **(A)** Sugar beet utilises 800 to 1,100 mm irrigation; maize / wheat utilises 1,100 to 1,400 mm; lucerne utilises 1,800 to 2,000 mm per annum. Sugar beet data obtained from researchers, maize, wheat and lucerne data obtained from commercial farmer interviews **(B)** Sugar beet: N = 209 kg; P = 98 kg; K = 99 – 110kg. Maize / wheat: N = 480 – 580 kg; P = 101 – 136 kg; K = 101 – 133 kg. Lucerne: N = 32 kg; P = 32 kg; K = 0 kg. Sugar beet data obtained from researchers; maize, wheat and lucerne data obtained from agricultural supplies retailer

5.2.2 Biofuel crop and ethanol yields

The latest trials resulted in 149 tons of sugar beet wet mass per hectare after a nine months growing season. Isolated trials achieved yields of more than 200 tons per hectare. An internal feasibility study predicts 109 litres of ethanol to be gained per ton of sugar beet (PGBI, 2008). This would result in 16,241 litres of ethanol produced per hectare land for the latest trials. A more conservative estimation of 95 tons yields based on earlier trials in the 2009 EIA (Vivier *et al*., 2009) would result in 10,682 litres of ethanol per hectare and year.

5.2.3 Statistics of Eastern Cape food crop production

This section serves to determine the significance of maize and wheat production on the Cradock farms for the national food market. The following statistics are obtained from the Department of Agriculture, Forestry and Fisheries (2012) and are summarised in Table 5. Between 2006 and 2011, the national production of maize fluctuated between 7.1 million and 12.8 million tons (average: 11 million tons). Cradock-specific production statistics could not be obtained; but over the same time period, maize production in the whole of the Eastern Cape ranged from 68,000 to 92,000 tons (average: 82,000 tons), which equals an average share of 0.74 % of the national production. Wheat production is less prominent in South

Africa: between 2006 and 2011, national production ranged from 1.4 million to 2.1 million tons (average 1.9 million tons), of which the Eastern Cape contributed an annual average of 20,600 tons. This equals 1.1 % of the national production. The production of maize and wheat in the Eastern Cape is thus small compared to the national level (combined < 1.0 %), and the Cradock farms only depict a fraction of the production of the whole Eastern Cape province.

Table 5 Average annual maize and wheat crop production 2006 to 2011 in the Eastern Cape and the whole of South Africa, and the shares that the Eastern Cape production holds of the total national production.
Source: Department of Agriculture, Forestry and Fisheries (2012)**.** All amounts in 1,000 tons

Crop	Eastern Cape	South Africa	Share [% total]
Maize	82	11,010	0.74
Wheat	21	1,896	1.1

5.3 Visual impressions of the study site

Environment − The appearance of the Great Fish River Valley is characterised by the dominance of agricultural activity. In some regions, irrigation fields border the river banks, but often there is a green stripe of riparian vegetation preserved. In the presence of crop fields, agricultural activity tends to limit the extent of intact riparian zones (Figure 7A). These riparian zones are characterised by reeds and *Acacia* trees, as depicted in Figure 7B. Mammal, reptile and bird sightings were plentiful during fieldwork. Figure 7C depicts a common duiker (*Sylvica pragrimmia*), one of the many antelope species that are found on and off the farmlands. As flood irrigation fields are replaced by more water-efficient centre pivot irrigation, new land is being agriculturally developed (Figure 7D−E; Figure 9B). Unlike flood irrigation fields, centre pivots can be placed further away from the river canals. The maximum distance is determined by the presence of suitable soils and the electricity costs for water pumping.

Emerging farms − Many beneficiary farms were deteriorated and overgrown with weeds, and, from these characteristics, one could often identify these farms from their gates. In accordance with the frequent report of poor crop conditions on emerging farms, some maize fields on these were infested by weeds, and crop plants were relatively scarce (Figure 8A). Only in some cases were the fields in proper condition and indistinguishable from the commercial farmers' crops (Figure 8B).

FIGURE 7 **Visual impressions of the Great Fish River Valley (environmental aspects)**

(A) View on the Great Fish River (South of Cradock). The vegetation stripes along the river banks are limited by agricultural activity **(B)** River banks of the Great Fish River **(C)** Male common Duiker (*Sylvica pragrimmia*), one of many mammal species found on and around the farms in the Great Fish River Valley **(D)** Centre pivot irrigation that replaces the abundantly utilised flood irrigation method **(E)** Centre pivots in the valley, as seen from the mountains South of Cradock.

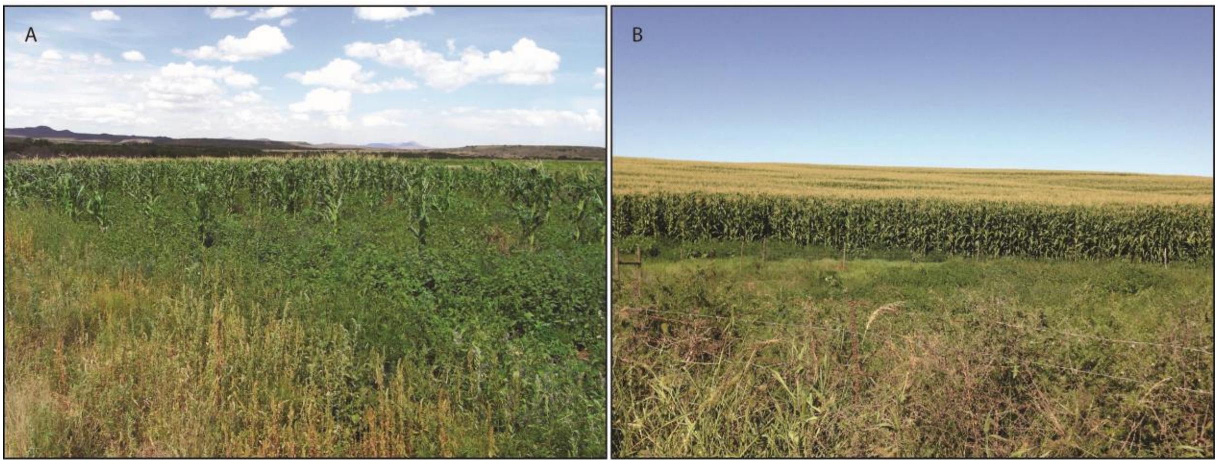

FIGURE 8 **Visual impressions of the Great Fish River Valley (emerging farms)**
(A) Example of poorly maintained maize on a beneficiary farm. Notice the scarcity of crop plants and the vast amount of weeds **(B)** Example of weed-free maize on a beneficiary farm

5.4 Impacts on habitat from agricultural activity

5.4.1 Affected biomes and their threat statuses

Since the extent of agriculture in Cradock is limited by the availability of irrigation water, and sugar beet cultivation requires marginally less water than the crops that will be replaced (Figure 6A), sugar beet cultivation on the Cradock farms is likely to drive agricultural expansion with spare water from savings. This expansion will take place on dedicated farmland, but will affect four biomes found in the Great Fish River Valley, namely Nama Karoo, Grassland, Albany Thicket and, alongside the river, Southern Karoo Riviere (Figure 9A). Figure 9B illustrates the spreading of centre pivot (CP) irrigation fields on virgin grounds; replacing the more water-intensive flood irrigation (FI) fields. This agricultural expansion that is linked to a modernisation of irrigation techniques takes place independently from sugar beet cultivation; however, more land could be converted into irrigation fields due to the lower water requirements of the biofuel feedstock crop (Figure 6A).

Figure 10A depicts the distribution of threatened biomes in South Africa. All biomes in the Inxuba Yethemba municipality, where Cradock is situated, are characterised as “least concern” (Figure 10B). The municipality stretches over 11,600 km^2, of which 96.2 % are classified as natural or near natural, and 3.8 % as transformed (“no natural habitat remaining”). Only 2 % of the municipality area is formally protected (SANBI, 2013). The Mountain Zebra National Park that is adjacent to Cradock incorporates three of the four biomes that are potentially affected by agricultural activity.

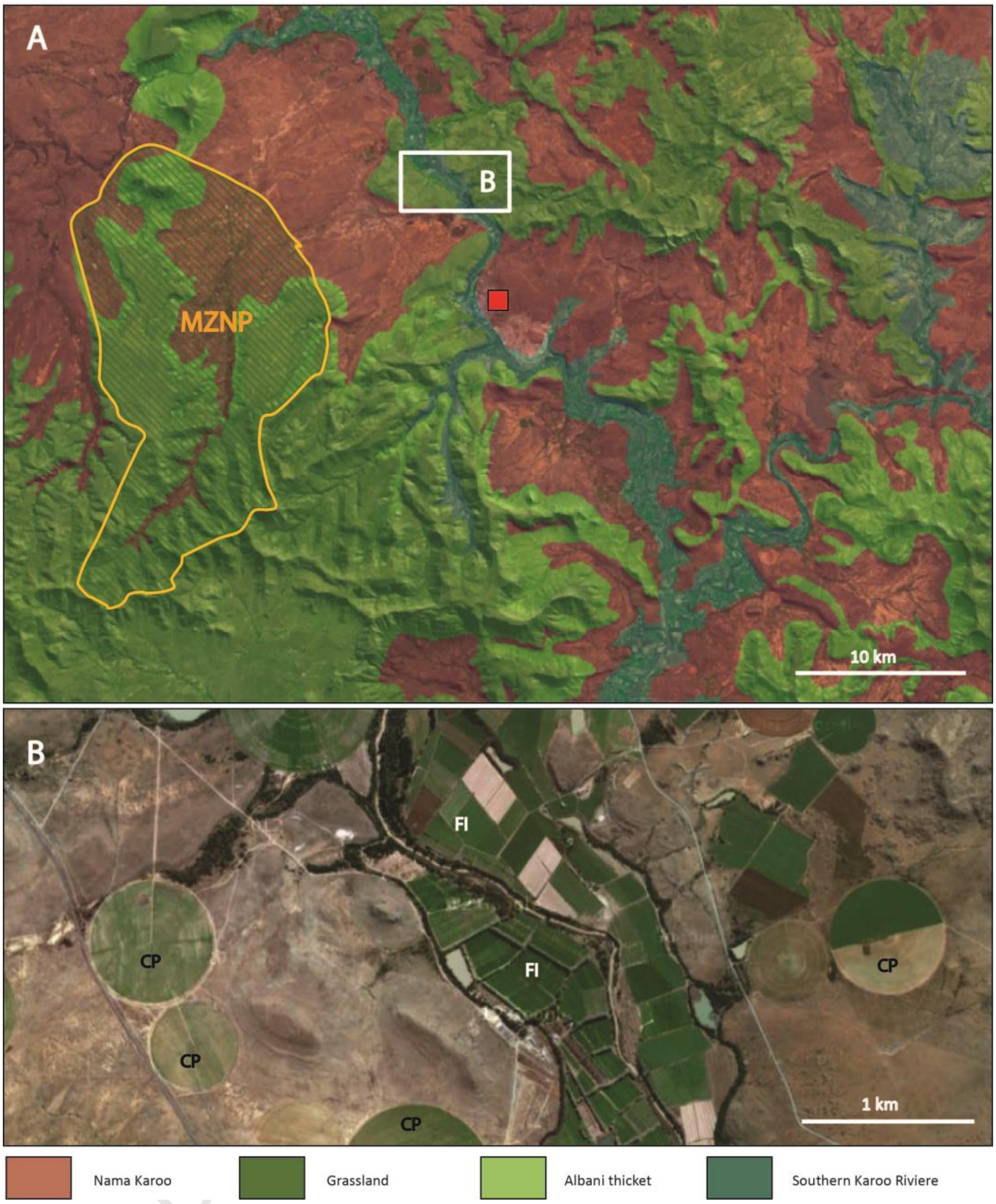

FIGURE 9 Biomes of the Great Fish River Valley (A) and agricultural expansion with centre pivots (B)

Source: South African National Biodiversity Institute (SANBI). Abbreviations used: centre pivot (CP); flood irrigation (FI); Mountain Zebra National Park (MZNP). Cradock town marked in red

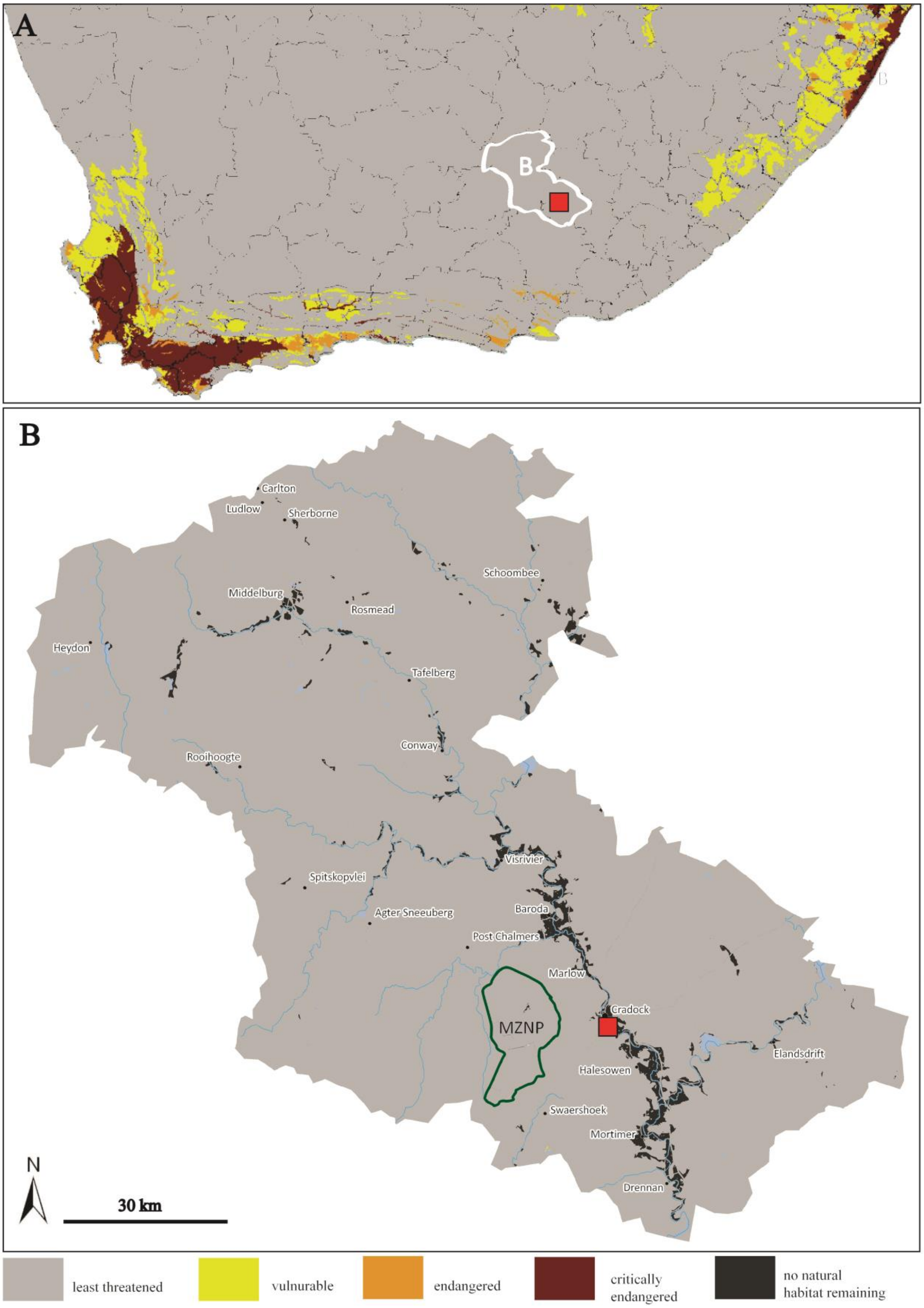

FIGURE 10 **Threat statuses of South African ecosystems (A) and magnification on the Inxuba Yethemba municipality (B)**

Source: South African National Biodiversity Institute (SANBI): National Biodiversity Assessment of 2011. Abbreviations used: Mountain Zebra National Park (MZNP). Cradock town marked in red.

5.4.2 Affected terrestrial Critical Biodiversity Areas

Figure 11 depicts the presence of agricultural activity and terrestrial Critical Biodiverstiy Areas (CBAs) in the Cradock area. Some of the Cradock surroundings that have been described as habitat of "natural" and "near natural" state were declared CBA type I ("natural") and II ("near natural") in the Eastern Cape Biodiversity Conservation Plan (ECBCP, 2007; Figure 11). Critical biodiversity areas type I are hardly affected by agriculture in the Great Fish River Valley, but agricultural activity overlays with a type II corridor in the South of Cradock (Figure 11).

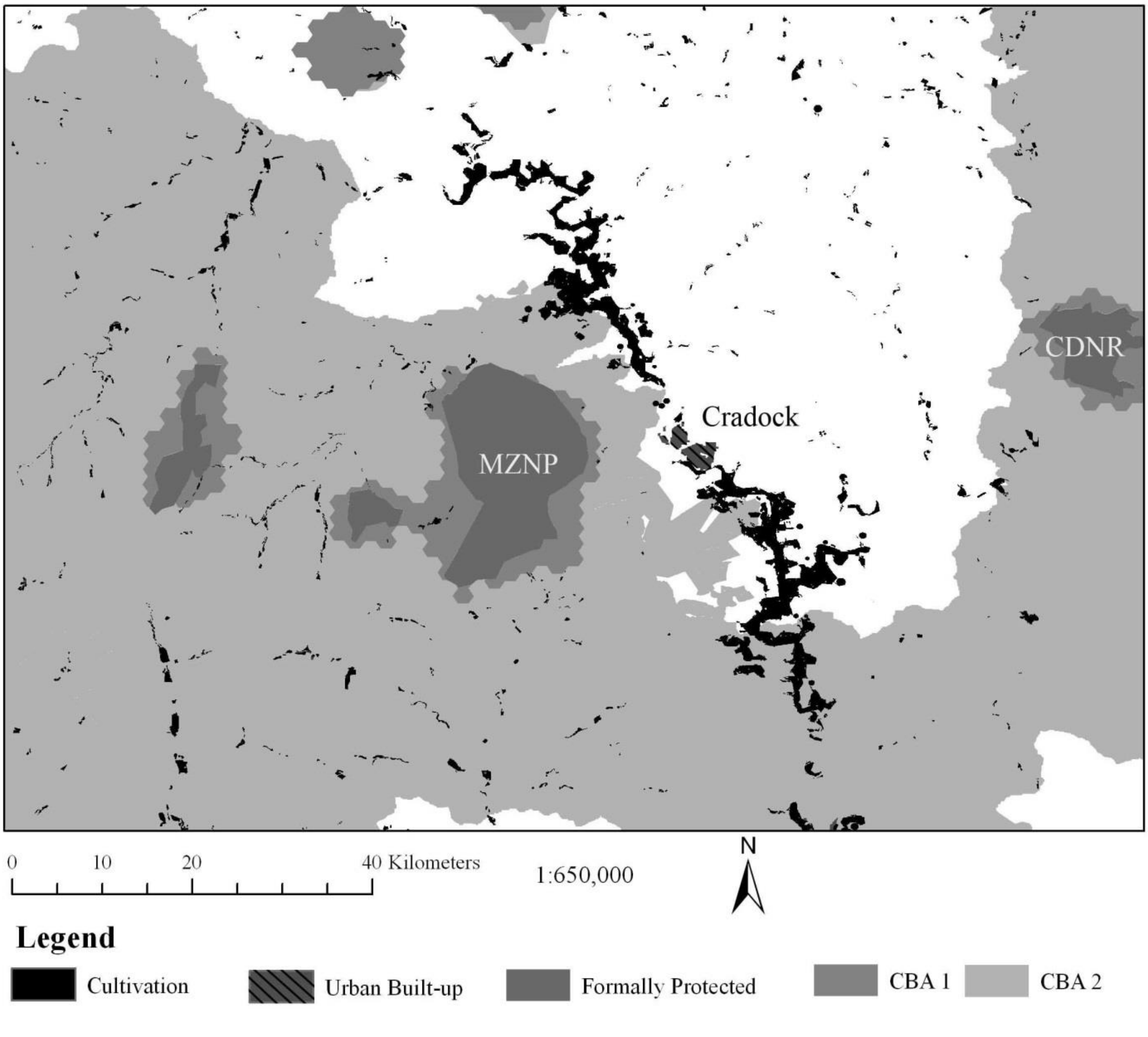

FIGURE 11 **The effects of agricultural activity on terrestrial Critical Biodiversity Areas (CBAs) type I and II**

Source: South African National Biodiversity Institute (SANBI). Abbreviations used: CDNR, Commando Drift Nature Reserve; MZNO, Mountain Zebra National Park

Note that agricultural activity (black) already overlays with CBA II (light grey), especially in the South of Cradock, where the CBA II depicts a corridor between the MZNP and the CDNR

5.5 Carbon footprint analysis

The carbon footprint analysis performed for this study forms part of the assessment of environmental impacts from sugar beet cultivation in Cradock. As mentioned in the methods section 4.5.2, four scenarios of sugar beet cultivation that are based on the latest trials were investigated in relation to their carbon footprint in the present study: conventional and glyphosate resistant cultivation, both on existing cropland and moderately degraded grass / shrub land (which describes the vegetation type on the currently unutilised farm land). Since glyphosate-resistant sugar beet is not yet approved in South Africa, the GM scenarios are based on ARDA estimates and are therefore hypothetical. Additionally, it was simulated how the conservative 95 tons yield scenario (on existing cropland) described in the 2009 EIA compares to the 149 tons scenario of the latest trials (note that this simulation assumes the same input values for 149 tons and 95 tons yields in terms of irrigation and chemical use). The inputs for the cultivation module of the carbon footprint analysis are depicted in Table 6. Both conventional and GM crops would require an insecticide (in this case: cypermethrin), but reduced application of herbicides in GM cultivation (and therefore less tractor runs) results in a projected reduction of annual diesel use from 116 litres to 65 litres per hectare. A possible reduction of tillage practice for GM crops is suggested by Givens *et al*. (2009) and Kniss (2010), which may affect carbon emissions from dLUC.

Figure 12A displays the carbon footprint of the simulated scenarios during the cultivation period. When cultivated on existing cropland, Cradock sugar beet produced by conventional farming (non GM) causes 36.4 kg CO_2 equivalent (CO_2eq) emissions per ton sugar beet produced; a GM version with reduced pesticide, diesel and tillage requirements causes 33.9 kg CO_2eq emissions per ton sugar beet. When cultivated on virgin grounds, dLUC (averaged for an accounting period of 20 years) causes additional emissions: conventional and glyphosate-resistant (GM) sugar beet cultivation cause 49.7 and 45.4 kg CO_2eq emissions per kg sugar beet (Figure 11A). The Cradock EIA scenario leads to emissions of 47.6 kg CO_2eq per ton sugar beet (existing cropland, no dLUC, non-GM).

TABLE 6 **Life-cycle assessments: input for the cultivation module of the RSB tool.**

		Conventional Farming	Glyphosate[1]	Sources
CONTEXT	Country	South Africa	"	
	Main product	Sugar beet	"	
	Ecozone	Subtropical mountain system	"	FAO "Global Ecological Zones" map
	Annual rainfall	350 mm	"	Department of Environmental Affairs and Tourism (SA) "Annual precipitation" map
	Winter-type precipitation distribution	No	"	
	USDA soil order	Alfisol	"	Office of Agriculture (US) "Distribution of soil orders" map
	Mean slope	2.5 %	"	ARDA
	Annual yield	149 tons	"	ARDA
	Seeds	6 kg	"	RSB
	Crop residue / co-products	Not used	"	
LAND USE	Former land use	Cropland / grassland (managed; moderately degraded)	"	
	Former vegetation	Annual crops / shrub land	"	
	Former cultivation practice	Long term cultivated; medium input; full tillage	"	
	Fires for clearing	No	"	
	Soil type	Mineral: Arenosol ("hutton")	"	ARDA
	Tillage	Full	Reduced	Givens *et al.* (2009)
	Tillage method	Spring plow		ARDA
	Anti-erosion practice	Contour farming	"	ARDA
	Annual irrigation	8,000 m^3 (centre pivot) 98 kWh / ML	"	ARDA DEPI (2007)
	Conventional drainage	No	"	ARDA
INPUT	N fertiliser	209 kg	"	ARDA
	P fertiliser	98 kg	"	ARDA
	K fertiliser	99 kg	"	ARDA
	Organic fertiliser	None	"	ARDA
	Liquid manure	None	"	ARDA
	Pesticides	300 ml Cypermethrin Herbicide I[2] Herbicide II[2]	300 ml Cypermethrin 4 l glyphosate (2,160 g)	ARDA; independent researcher
	Annual diesel use	117 liters	65 liters	ARDA

[1] glyphosate-resistant sugar beet cultivation not empirically tested – input based on ARDA estimates

[2] herbicide mix subject to intellectual property of ARDA

The input values for the succeeding steps of the biofuel life-cycle are depicted in Table 7. The cultivation of sugar beet accounts for roughly a fifth of the total emissions caused in bioethanol production, the remainder being held by transport, conversion, blending and handling (Figure 12B). Cradock fuel ethanol from conventional cultivation causes 1,638 kg CO_2eq emissions per ton without dLUC and 1,748 kg CO_2eq emissions per ton in inclusion of dLUC. That equals 61.2 and 65.3 g CO_2eq per MJ produced. The GM cultivation performs marginally better with 1,603 and 1,713 kg CO_2eq emissions per ton fuel ethanol, which equals 59.9 and 64.0 g CO_2eq per MJ (Figure 12B). The EIA scenario results in 1,730 kg CO_2eq emissions per ton fuel ethanol (equals 64.6 g CO_2eq per MJ).

TABLE 7 Life-cycle assessment: input for succeeding modules of the UK Carbon Calculator tool

Module	Input	Sources
Transport of sugar beets	- truck, 70 km - emission values: 0.94 MJ (diesel) / t km	Vivier *et al*., 2009 UK Carbon Calculator default
Production	- plant yield: 0.086 tons ethanol per ton sugar beet - electricity used: 1075 MJ / ton output - electricity emission values: 1.03 kg CO_2eq per kWh - beet bulb co-products: 0.692 ton / ton produced - conservative factor: 1.4 - hard coal use: 8355.64 MJ / t	PGBI, 2008 Eskom, 2012 UK Carbon Calculator default
Transport of liquid fuel	- railway, 150 km - emission values: 0.21 MJ (electric) / t km - electricity emission values: 1.03 kg CO_2eq per kWh	Vivier *et al*., 2009 UK Carbon Calculator default
Depot	- electricity used: 22.5 MJ / ton - electricity emission values: 1.03 kg CO_2eq per kWh	Eskom, 2012 UK Carbon Calculator default
Transport to end use	- truck (liquids), 150 km - emission values: 1.01 MJ (diesel) / t km	UK Carbon Calculator default
Fuel handling	- electricity used: 91.1 MJ / ton - electricity emission values: 1.03 kg CO_2eq per kWh	Eskom, 2012 UK Carbon Calculator default

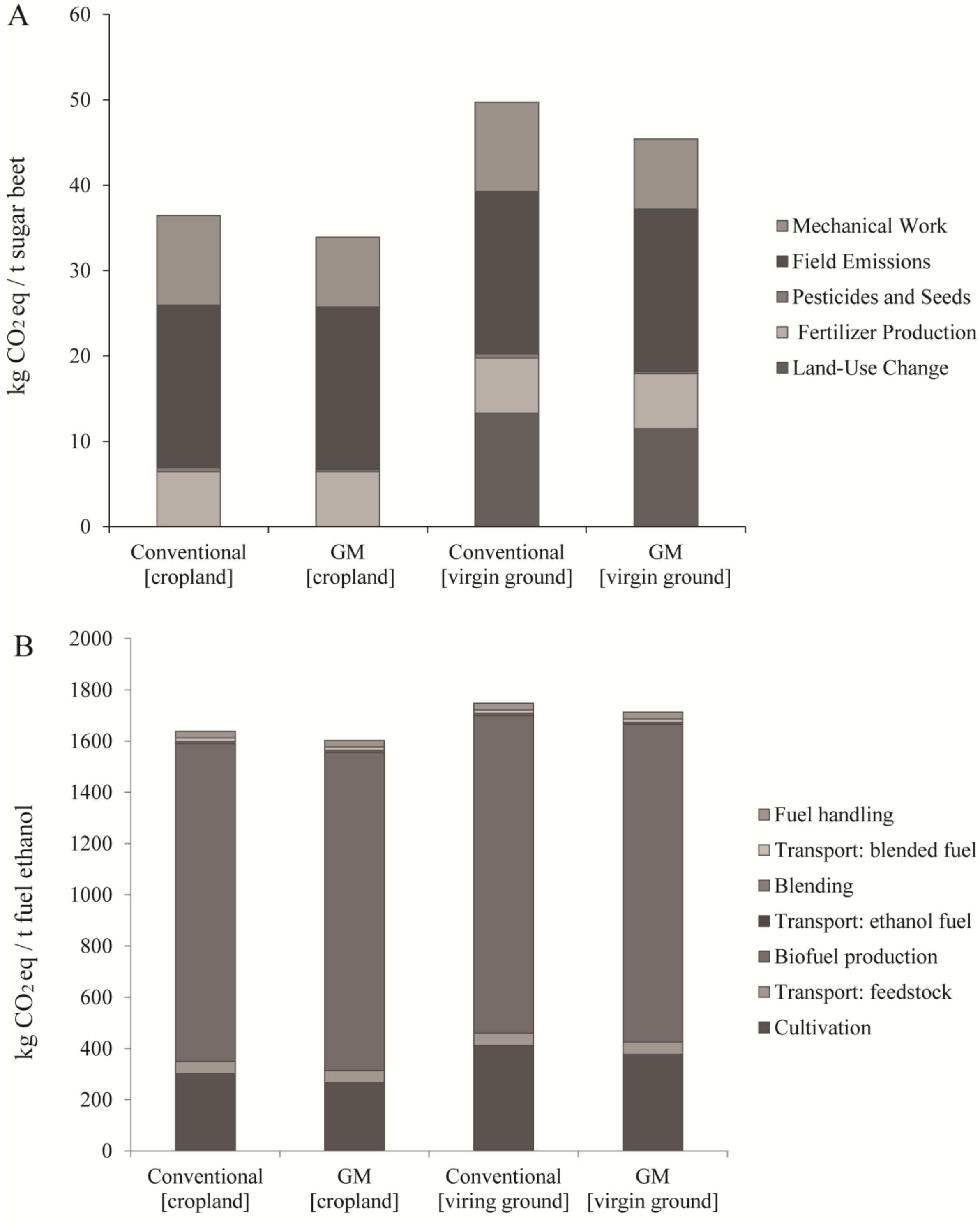

FIGURE 12 **Carbon footprint of Cradock fuel ethanol caused by cultivation (A) and for the whole production chain (B)**

Abbreviations used: dLUC, direct land-use change. (A) Conventional without dLUC: 36.4; GM without dLUC: 33.9; conventional with dLUC 49.7; GM with dLUC: 45.4. (B) Conventional without dLUC: 1,638; GM without dLUC: 1,603; conventional with dLUC: 1,748; GM with dLUC: 1,713. Land-use change is calculated as sugar beet cultivation on moderately degraded shrub and grass land; genetic modification depicts glyphosate resistance

5.6 Results summary

5.6.1 Social implementation barriers: commercial farmer perceptions and Black Economic Empowerment programme

Table 2 visually depicts where commercial farmers perceive the main controversies of the proposed Cradock fuel ethanol project to lie. It is clear that most are willing to participate in the proposed biofuel project, although some have stated that a drawn-out administrative process and numerous delays caused disinterest (Table 4). The successful implementation of the BEE programme is doubted by many commercial farmers. The emerging farmer interviews (Table 3) and the key informant interviews reveal that the beneficiaries struggle to make a living on their farms. The interviewees claim malpractice in the form of administrative delays, non-transparent action, and general shortcomings in the execution of plans.

5.6.2 Environmental impacts and food security

Environmental concerns were generally minimal in the interview responses. From the latest trials, annual ethanol production per hectare was inferred to exceed 16,000 litres. Since more than half of the interviewed farmers consider agricultural expansion (Table 2), habitat transformation is likely to occur. Marginally smaller water requirements (Figure 6A) and the farmers' expansion plans make it likely that biofuel crops will be grown partially on virgin grounds. Nitrogen fertiliser application will be reduced if maize or a maize / wheat double crop is replaced with sugar beet cultivation (Figure 6B). The affected biomes are classified as "least concern"; however, disturbance of a corridor classified a CBA type II could occur in the South of Cradock (Figure 10, 11). The farmers' reports suggest that agricultural activity has complex effects on biodiversity in the valley, and there is little evidence that marginal expansion could lead to a biodiversity decline. Contrastingly, farmers reported that biodiversity increased with farming activity. In terms of food security, the Cradock farms produce only a fraction (< 1 %) of the national maize and wheat production (Table 5). Almost all interviewees perceive food security to be unaffected by bioethanol feedstock production, and believed it may even be enhanced due to economic upliftment. The carbon footprint of the produced fuel from sugar beet is lower by about one-third than its fossil reference. Hypothetical GM sugar beet cultivation could perform marginally better in GHG emissions than the conventional grown equivalent. If degraded grassland is used for agricultural expansion, dLUC has little effects on the carbon footprint of the final product (Figure 12B).

6 Discussion

Following the objectives laid out in the Introduction, the conceptual layout depicted in chapters 2−4, and the results of the research described in chapter 5, in this sixth chapter, these results are interpreted and contextualised in the current biofuels debate. First, social desirability and implementation barriers that were identified from interviews are discussed in section 6.1. This section includes a *status quo* report of the biofuels-related Black Economic Empowerment (BEE) programme on the Cradock farms. The following section 6.2 discusses the issue of food security and its significance in regards to the proposed Cradock fuel ethanol project. The environmental concerns regarding biodiversity impacts, land transformation and the carbon footprint are discussed in sections 6.3 and 6.4. The succeeding section 6.5 debates the implications of conventional and hypothetical GM biofuel feedstock cultivation in the Cradock area. The last section of this chapter (6.6) provides a synthesis based on of the findings of the present dissertation.

6.1 Social desirability and implementation barriers

Socially undesirable effects from biofuel production, such as land grabs and exploitation of vulnerable groups, have been reported from some developing countries (Cotula *et al.*, 2008, 2009), including numerous examples on the African continent (Friis and Reenberg, 2010). Contrastingly, as a consequence of its unique history, South Africa has the opportunity to link the emergence of this new industry to rural development and black empowerment (DME, 2007). In order to achieve these two aims, the proposed Cradock fuel ethanol project requires the support of the local farming community and a successful implementation of the BEE programme on the farms of beneficiaries. Whereas most commercial farmers of the Cradock area are in principle willing to participate in the project, shortcomings in the implementation of the BEE programme threaten the social integrity of the project.

6.1.1 Expectations towards the project and the farmers' willingness to participate

Throughout the conducted interviews, the respondents' opinions about the Cradock fuel ethanol project were mostly positive (Table 4). From government to the private and agricultural sectors, people responded with enthusiasm and high expectations. It is noteworthy that all stated benefits were of an economic and not environmental nature. None of the interviewees highlighted possible climatic advantages of bioethanol to motivate the building of the plant. This reflects the priorities of the interviewees, but is also linked to the structure of the interview sample: from an agriculturalist's and stakeholder's point of view, the project is essentially economically motivated.

From the 22 interviewed commercial farmers, only one was opposed to the proposed bioethanol plant, as he perceived tree nut cultivation to be a better economic foundation for the valley. However, since it was announced years ago, commercial farmers stated there has been a general loss of interest (Table 4). Consequently, the project barely influences the farmers' lives at present, and they remarked that their expansion and production plans would be made independently of a possible biofuels programme. This lack of support is attributed to the lengthy administrative process and the numerous delays that the Cradock biofuel project had undergone.

Economic upliftment and employment creation in the area, enhanced by a spin-off effect that attracts new businesses to Cradock, was most frequently named as the biggest benefit from the proposed project. The research department of ARDA envisaged that

"*this project has great opportunities to create jobs, looking at about 20,000 jobs upstream and downstream. This town is going to grow, more schools, more hospitals, and so on. This is a mushroom effect*",

and another representative of ARDA affirmed this view:

"*it'll create spin-off jobs. The factory itself doesn't have a huge number - 168 jobs - but there is a lot in agriculture. These will be new and old but secured jobs*" (ARDA administration representative).

It is undisputed that the biofuel project factory will result in employment creation, but it will likely be limited by mechanisation. The bankable feasibility study (PGBI, 2008) stated that mechanised harvesting results in ZAR 37,52 per ton sugar beet harvested (3,83 US $), whereas manual harvesting costs ZAR 53,04 per ton sugar beet (5,42 US $), which is a strong economic incentive to mechanise. Since biofuels generally require subsidies to be able to compete with conventional fuel prices (Demirbas, 2009), and many interviewed farmers have started to now replace manual workforce due to recent minimum wage laws in South Africa, it is almost certain that sugar beet harvesting will be mechanised where possible. The project itself could therefore fall short of previous job creation estimates, specifically for unskilled labour. The employment potentials from the envisaged spin-off effects remain to be seen.

At this stage, despite the plans to source feedstock from emerging farmers, achieving sufficient biofuel feedstock cultivation relies on cooperation with commercial farmers. Most interviewed commercial farmers are willing to plant sugar beet if there are sufficient economic benefits to make the substitution worthwhile (Table 2). However, doubts about the economic feasibility have been raised by both commercial and emerging farmers (Table 4). In order to make farmers' efforts and investments for sugar beet cultivation worthwhile, the price for sugar beet must be higher than the combined value of an annual double crop, such as maize and wheat. Nevertheless, some farmers stated that they would be willing to trade off profit for the market stability that the biofuel project would offer.

6.1.2 The role of government in success of the project

The commercial farmer community believed government to be hindering progress and attributed disinterest in the project to the many delays that the programme had experienced. The South African agrarian journal "Farmers Weekly" (2013: 26) quotes Graham Jewitt, the chairperson of Water Resources Management:

"*biofuel and bio-energy policy is so unclear that it's acting as a barrier to investment. The number of inconsistent policies between the departments and between national and provincial government is causing confusion*".

This reflects not only many farmers' perceptions, but is also consistent with statements from the Cradock Department of Agriculture and the ARDA administration representative interviewed for the present study. On the other hand, the ARDA stated that the project is indeed progressing and that it has worked on getting the final regulations for water rights and mandatory biofuel blending ratios in place to secure the creation of a biofuels market:

"*at present we are standing at three outstanding regulations (…). We are heading towards 2 billion Rand* [of project costs], *and you can understand that the investors want all the deductions in row first*" (ARDA administration representative).

Despite apparent progress in the administrative domain, it is evident that organisation and communication hurdles between the involved governmental departments create substantial implementation barriers. Without compromising careful planning and the consideration of sustainability criteria prior to the commencement of the project, structural changes towards a transparent, coordinated and streamlined administrative domain may therefore prove a vital step necessary for the successful implementation of the proposed Cradock fuel ethanol initiative.

6.1.3 Current status of Black Economic Empowerment in Cradock

After almost two decades post Apartheid in South Africa, land reallocation has a substantial history; however, it has faced many drawbacks. Reports of successful projects are relatively few, whereas numerous failures have been reported (O'Laughlin *et al*., 2013). The present assessment of the Cradock agrarian BEE project reveals a myriad of shortcomings. From the interviews, it became apparent that neither commercial nor emerging farmers are fully satisfied with the BEE project that is currently taking place in Cradock (Table 2, 3). Several beneficiary farms were visited during the fieldwork for this study. Some of the farms were managed by multiple emerging farmers, which the beneficiaries reported to occasionally lead to social tension. Many commercial farmers were sceptical about the farming skills of the beneficiaries, and the emerging farmers were concerned about a lack of training (Table 4).

Farm and crop condition – Most involved parties recognised that the conditions of the allocated farms were generally poor. The notion held by some farmers that one could easily identify an emerging farm by driving by the gate could be confirmed during fieldwork. The main reason for the deterioration of farms seemed to be the delays between purchasing and allocating the farms. The state agent interviewed for this study perceived that during this period of non-utilisation "*ARDA did not have the manpower to maintain these farms*". Additionally, because some farms were not utilised for up to three years, besides their physical degradation, the Cradock area lost substantial revenues through the non-production of crops, and previous farmworkers have lost their employment (state agent, 2013, personal communication). Beneficiaries reported that they struggled with their farms, which were received vandalised and overgrown with weeds, as well as their crops being in suboptimal conditions. It is almost certain that, at least for the majority of emerging farm units, they will not be profitable in their first year(s).

Farm allocation and beneficiary selection – Some farms that were allocated to beneficiaries turned out to be unsuitable for the individual. A beneficiary that already had a livestock farm was allocated a farm with insufficient grazing area. As a result, he had to manage two farms, as he could not move his livestock to the new irrigation farm. In other cases, vast grazing areas were underutilised.

Commercial farmers perceived the process of beneficiary selection to be enigmatic and untransparent: apparently, there was no age restriction, as the oldest emerging farmer in Cradock was in his seventies when he received his farm. Some commercial farmers who suggested candidates as potential beneficiaries claimed that their voices were ignored, and that the selection process was directed by the emerging farmers' social connections, rather than an even-handed process. These claims could not be empirically tested, but the emergence of these rumours may have been avoided with a more transparent selection process.

Farming implements – The lack of own implements was reported to be a potential pitfall: some emerging farmers did not own a car, on one farm there was no flowing water for household use, and one was lacking basic infrastructure, including a farm house. None of the beneficiaries had their own tractors when interviews were held, these being supplied by the mentors of the farms. Beneficiaries reported that the tractors were only supplied when the mentors have them available, which is often too late for a timeous harvest.

Administration – Emerging farmers reported that the application process to become a beneficiary was often too long. Processing and notification deadlines pledged were not adhered to, and life planning was made difficult for the applicants. Frequent reports have also been made about a bureaucratic and delayed cash flow: in the case of unforeseen events, such as caterpillar infestation, pesticides could not be applied in time because the money to buy implements has to be first approved in a lengthy administrative process.

Synthesis – The Cradock agrarian BEE programme faces similar problems to other land reform projects, such as delayed cash flow (Mogari and Lotze, 2006), as well as insecure funding of the programme management, uncertain economics and shortages of operating skills (Fauconnier and Mathur-Helm, 2008). The problems that the implementation of the BEE programme faces do not make it undesirable *per se*. However, feedstock supplies for the proposed plant could face interruptions if the emerging farms are not to deliver the required amounts. Two months after fieldwork for this thesis was conducted, the Department of Rural Development and Land Reform published a note on their website titled "Minister Nkwinti lambasts the lazy" (DRDLR, 2013b) which made the following statement:

"*the Minister of Rural Development and Land Reform, Gugile Nkwinti, lambasted all those who are lazy in farming. He said some just stay next to their houses and fail even to do work on their gardens. The minister said others keep talking and accuse government of doing* *nothing for them. He said some had been provided with tractors to till their land, but that has not inspired them (…). Minister Nkwinti urged them to always provide sugar beet to the bio fuel factory that is to be built in Cradock so that the factory and subsequently they remain productive.*" (DRDLR, 2013b).

The results of the present study can neither confirm nor deny the accusation of "laziness", however, given the myriad of materialistic and formation problems that the beneficiaries face, this accusation seems to ignore the preconditions on these farms. Omissions in training and supervision as highlighted by the beneficiaries may not easily be overcome by the provision of implements, such as tractors. It is apparent that administrative delays, insecure cash flow, farm deterioration, lack of training and supervision and occasional careless crop plantings by contractors limit and damage the success of the Cradock agrarian land reform programme. It is therefore evident that much effort is needed to ensure the sustainable implementation of the BEE programme on the Cradock farms.

Despite the many difficulties that the Cradock BEE programme faces in its beginning, and the likelihood that not all emerging farmers will be of sustained success, there is potential of achieving the aim of rural development and black empowerment with the Cradock biofuels programme. This is beneficial in terms of its social performance and desirability, and differs from previously mentioned social drawbacks in other (developing) countries. However, it is suggested to employ approaches for future beneficiary selections that incorporate the recommendations of the commercial farming community, and to test alternative mentorship models that result in a seamless transition of ownership, as phases of non-production were a prominent cause of farmland degradation. For example, the previous farm owner and the emerging farmer(s) could simultaneously stay and work on the farm for a restricted time (but at least one growing season). In this transitional phase, farming and management skills could be taught to the beneficiaries, and a seamless change of ownership might avoid interruptions in production and deterioration.

6.2 Food security impacts

6.2.1 Food security in Cradock

The previous sections discussed the social implementation barriers of the Cradock fuel ethanol project that mainly derive from delayed administrative action and suboptimal management of the agrarian BEE programme. Although food security represents a major issue that opponents of biofuels emphasise around the globe (Ewing and Msangi, 2009; Pimentel *et* *al*., 2009; Tilman *et al*., 2009), neither agricultural nor governmental representatives in the Cradock area listed it as a concern. Only one interviewed commercial farmer and one emerging farmer perceived that there could be a shortage of animal feed production in drought years if crop substitutions are made (Table 4).

There is a combination of reasons for farmers to declare food security issues to be no major concern. The majority of Cradock farms produce primarily animal feed that goes directly into their own livestock, which implies that the essential product of the valley's farms is livestock products (ARDA administration, 2012, personal communication). Surplus production is exported (SA, 2012). Due to the crop rotation that sugar beet requires, no more than a third of the valley's (animal) food production fields could be earmarked for sugar beet cultivation at a time. This restrains the production of this biofuel feedstock; however, some more land could be utilised for grain sorghum production, which is the proposed supplementary feedstock for the plant (Vivier *et al*., 2009).

The anticipated animal feed co-production from beet bulb that accrues from sugar beet ethanol production, which lies in the magnitude of several tons per hectare per year, will at least partially offset a shortage of food production on the fields. It has further been stated that yields have steadily increased and nearly doubled over the past decade (farmer 7, 10; Appendix 1). Combined with the reports that some livestock farmers have trouble selling their meat for an adequate price (farmer 22; Appendix 1), which is a sign of food market saturation, Cradock's food security is unlikely to be compromised with biofuel feedstock production. This is in accordance with the results of Besharati (2012), stating that the main reason for food insecurity in the Cradock area is not the availability of food, but the economic means to buy it. Besharati (2012) found income to be the biggest determinant of food security in Cradock, demonstrating the apparent paradox that Cradock biofuel production potentially enhances food security in the Great Fish River Valley through economic upliftment.

6.2.2 Food security impacts outside Cradock

It is noteworthy that South Africa is a net food exporter (SA, 2012), yet food insecurity exists, and the Eastern Cape is more affected than any other province in South Africa (Labadarios *et al*., 2011).

Farmers highlighted that the agricultural production of the Cradock valley is small compared to the national level, and that the scale of the project is therefore too small to make a significant impact on food supply outside the valley. Indeed, the latest agricultural statistics published by the Department of Agriculture, Forestry and Fisheries (2012) reveal that the combined production of the Eastern Cape is less than 0.75 % of South Africa's maize, and less than 1.1 % of the national wheat production (Table 5). Recalling that only up to one third of the current production in the Great Fish River Valley could be replaced by sugar beet because of its required 3-year rotational system, and the fact that additional offsets from animal feed co-production, it can be concluded that the losses in (animal) food production from sugar beet cultivation in Cradock will be negligible on a national level.

There is hence no evidence that fuel ethanol production in Cradock notably impacts on food security on a regional, national or international domain. In contrast, food security in the Cradock area could be enhanced through the creation of employment (Besharati, 2012; present study). It is also noteworthy that, among South America and the Caribbean, sub-Saharan Africa has the largest amounts of unutilised arable land (Escobar *et al*., 2009), leaving the potential to expand the food-producing sector in Southern Africa, although this could lead to considerable environmental impacts caused by land clearing and habitat destruction.

6.2.3 The exclusion of maize for bioethanol production

A supplementary feedstock (besides sugar beet) is necessary to ensure sustained Cradock fuel ethanol production throughout its operational phase. The current South African biofuels strategy excludes maize as a biofuel feedstock for food security reasons (DME, 2007). Farmers and governmental representatives interviewed for this study contested its reasoning (farmer 19, ARDA administrative representative, ARDA research department; appendix 1). The research department of ARDA stated that

"*it makes no economic sense and no sense in terms of food security. It is just jeopardising the potential of bioethanol*".

The reasoning that (staple) food crops should not be utilised for biofuels is valid if feedstock is obtained from the open market. For crops that are grown locally, earmarked for biofuel production, in theory, there is no difference with regards to the utilised feedstock (besides providing for marginal differences of animal feed by-products). The production of maize is well established in the Great Fish River Valley, and, compared to the current vision of using grain sorghum, transportation costs (both monetary and from a greenhouse gas [GHG] perspective) could be reduced by the incorporation of locally grown crops. Taking an average annual yield of 12,5 tons of maize per hectare in the valley, the ethanol yield per hectare from maize is above 5,000 litres (when producing 411 litres of ethanol per ton; PGBI, 2008), which is more than most other countries produce, though lower than for sugar beet (see 6.3.2). Grain sorghum, even if grown locally, is not yet established on the Cradock farms. Its potential in terms of ethanol yields per hectare remains to be seen. The 2009 EIA advises use of a genetic strain that is most suitable for biofuel production (Vivier *et al*., 2009). Although not mentioned explicitly, this would most likely be a sweet sorghum variant. Because of its relatively low water requirements, sorghum cultivation is suitable for arid regions (Almodares and Hadi, 2009); however, the Cradock farms perform under irrigation and sorghum may be better grown in regions that have lesser access to irrigation water. It is therefore encouraged to make the choice of the Cradock biofuel feedstock by environmental and economic reasoning, and to reinvestigate the potential of locally grown maize in comparison to the current plans of utilising sorghum.

6.3 Environmental aspects of biofuel production in Cradock: cultivation practice and biodiversity

In this section, environmental impacts from sugar beet cultivation are discussed with relevance to the proposed Cradock fuel ethanol project. This is done in terms of chemical and water requirements (6.3.1), and agricultural land-use footprint (6.3.2 and 6.3.3), which, globally, are the most frequently raised criticisms of first-generation biofuels (*e.g.* Blottnitz and Curran, 2007; Wilcove and Kohl, 2010; Börjesson and Tufvesson, 2011, Fletcher Jr. *et al*., 2011).

6.3.1 Water and chemical use in sugar beet cultivation

Water − The presence of arable land is not the limiting factor of agricultural activity in the valley; it is the availability of water, which is controlled in the form of allocated water rights. While the 2009 EIA states that the water use of sugar beet is of the magnitude of other crops grown in the valley (Vivier *et al*., 2009), incorporating newer data obtained from the more recent trials for this study shows that sugar beet is grown with 800 to 1,000 mm of irrigation water, which is marginally less than a maize / wheat double crop that it would replace in the valley and substantially less than what lucerne requires (Figure 6A). Spared water can be used either on existing land to increase yields, or for the cultivation of virgin grounds. Regardless of sugar beet plantings, agricultural expansion is currently taking place in Cradock, as much of the flood irrigated land is being replaced with more water-efficient centre pivot farming.

However, in a maximum-case scenario where a full third of Cradock farmland is dedicated for sugar beet cultivation (the rest being cultivated with other crops for rotation), the area for agricultural activity could notably expand with the existing water rights. Marginally accelerated land conversion and habitat destruction, which are main factors for biodiversity declines on a global scale (Fahrig, 1997) could therefore be attributed to biofuel production in Cradock. The actual expansion that can be attributed to the water savings from sugar beet cultivation will, however, be lower, since only thirteen out of the 22 interviewed commercial farmers (59 %) stated that they would consider agricultural expansion and the plant itself will require water that was formally allocated for agricultural use (equals the water rights of 96 hectares; Vivier *et al*., 2009).The collective water rights of the valley are generally fully utilised, regardless of the crops that are grown (with the only exception of non-utilised water rights on some emerging farms, which is unintentional and attributed to faulty planning or execution of plans, see also 6.1.3). Therefore, a scenario where sugar beet cultivation would lower the valley's irrigation water consumption is unrealistic.

Fertiliser − The application of nitrogen (N) fertilisers will be substantially reduced with sugar beet cultivation. The biofuel feedstock crop requires between 260 and 360 kg less N fertiliser than a maize / wheat double crop (Figure 6B). The fertiliser needs for lucerne are much lower than for maize / wheat and sugar beet. Although perennial lucerne plays a role in the crop rotational circle, it is the annual crops (mainly maize) which are primarily being replaced by sugar beet. Lowering the application of N fertiliser is beneficial because it underlies the nitric oxide field emissions, which are potent GHGs (Veldkamp and Keller, 1997; Erisman *et al*., 2010). From a climatic perspective, phosphate (P) and potassium (K) fertilisers are less important, and there will not be substantial changes if a maize / wheat double crop is replaced (Figure 6B). In case of replacing a maize crop only, P and K fertiliser use increases; however, due to the substantial N requirements of maize, this fertiliser would still be reduced in application.

6.3.2 Cradock ethanol yields in international comparison

Figure 13 depicts selected ethanol yield examples from France, Brazil and the United States (Brown, 2006).With more than 16,000 litres of ethanol per hectare with the sugar beet yields of the latest trials (see 5.2.2), in international comparison, sugar beet ethanol from Cradock reveals a significantly better performance than other countries. Even using the more conservative assumption of 95 tons per hectare as calculated by Vivier *et al*. (2009), ethanol yields perform with more than 10,000 litres. France also gains ethanol from sugar beet, but the yields are lower due to the climatic conditions that restrict the growing season to 6 months. Brazilian ethanol from sugar cane, Indian ethanol from sweet sorghum and the U.S. corn ethanol deliver substantially lesser yields (Brown, 2006; Figure 13). The ethanol yields per hectare have implications for the land-use footprint of a produced biofuel: at least in theory, higher yields mean that less land is required to produce the product (Borlaug, 2007). From a conservation perspective, this is desirable in terms of habitat preservation, although, in the absence of conservation policies, higher yields not necessarily imply reduced land-use (Rudel *et al*., 2009). Moreover, little can be drawn from this in terms of economic viability. The costs of first generation biofuels mainly derive from feedstock cultivation, and sugarcane in Brazil currently provides for the only fuel ethanol that can compete with the present gasoline market price (Demirbas, 2009). Corn ethanol in the United States is still more expansive than fossil fuel, and European bioethanol is even more costly (Demirbas, 2009). Although a detailed assessment of the production costs of Cradock fuel ethanol are not covered in the present study, despite the projected world-leading ethanol yields in South Africa (Figure 13), it is well possible that South African fuel ethanol will require substantial subsidies to compete with the current fossil fuel prices.

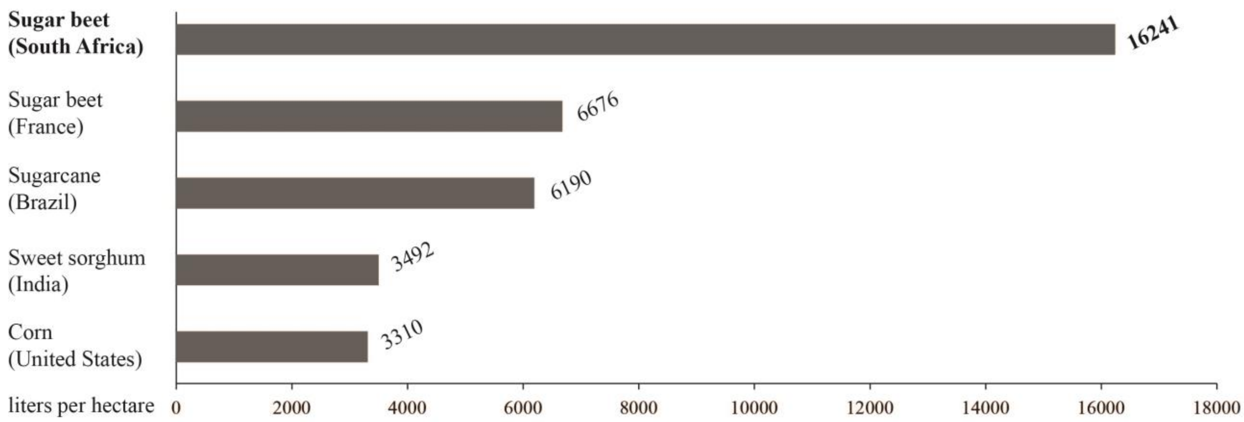

FIGURE 13 Annual ethanol yield of selected crops and countries in litres per hectare
South African data based on a 149 tons yield (latest sugar beet trials) and an extraction value of 109 litres ethanol per ton crop (PGBI, 2008). Data of other crops and countries taken from Brown (2006)

6.3.3 Biodiversity impacts from sugar beet cultivation

Possible impacts on biodiversity from biofuel feedstock production are frequently raised in the global biofuels controversy (Wilcove and Kohl, 2010, Fletcher Jr. *et al*., 2011). Although the land-use footprint of Cradock fuel ethanol is projected to be small in international comparison due to the high sugar beet yields (Figure 13), the ecological importance of the

Great Fish River Valley plays a considerable role in determining the environmental desirability of fuel ethanol production in this region.

Biomes of the Great Fish River valley − There are four major biomes found in the Great Fish River Valley, namely Nama Karoo, grassland, Albany thicket and Southern Karoo Riviere (Figure 9). All these biomes are affected by agricultural activity. Although host to a great number of wildlife, the occurring biomes are characterised as “least threatened” (Figure 10B). Overall formal protection in the municipality is low (2 %), but the nearby Mountain Zebra National Park covers three of the four biomes (Figure 9). The only biome that is not covered is the Southern Karoo Riviere along the Great Fish River, which has been developed largely by agriculture in the valley (Figure 9).

Agricultural development – The Cradock farms are located in proximity to the valley’s rivers, with irrigation land stretching up to several hundred meters towards the mountains bordering the valley. In many cases, and contrary to the South African legislation for the protection of riparian zones, fields are adjacent to the rivers. According to farmer interviews conducted in this study, this is due to the historic establishment of flood irrigation fields close to the river, and prior to newer environmental regulations (Appendix 2). The riparian zones of the Great Fish River are, where they remain, characterised by reeds and *Acacia* trees, whilst the extent of these riparian zones varies highly, depending on water flow, local soil quality and agricultural development. The preservation of riparian habitat is desirable for a number of ecosystem services, including flood buffering, stabilisation of the water course, forming habitat and decreased salt runoff (Simon and Collison, 2002; Brauman *et al*., 2007). Stringent law enforcement, especially in the case of agricultural expansion on virgin grounds, should be undertaken to maintain these ecosystem services.

Critical biodiversity areas − Some of the Cradock surroundings have been described as habitats of “natural” and “near natural” state, and therefore are declared a critical biodiversity area (CBA) type I and II in the Eastern Cape Biodiversity Conservation Plan (ECBCP, 2007; Figure 11). Development and agricultural activity is discouraged on these lands (ECBCP, 2007). However, the plans are poorly developed and the boundaries of the CBAs are not well defined, as they seem to partially ignore the presence of infrastructure, local geology and existing agricultural activity. Nevertheless, it is apparent that agricultural activity affects a CBA Type II in the south of Cradock that serves as a corridor between the Mountain Zebra National Park and the Commando Drift Nature Reserve (Figure 11). It is recommended that further development is prevented along this corridor, which is more relevant for linear agricultural development along the river than for expansion in an east or west direction (see

Figure 11). Recapturing Mathews and Tan's (2009) opinion that the effects of land-use change are best controlled through formal protection measures (see section 2.5.2), both riparian habitat and ecological corridors in Cradock should not be further developed.

Wildlife abundance – There is high wildlife abundance in the Great Fish River Valley. This study does not provide for a comprehensive biodiversity assessment, but during the fieldwork for this study, sightings of antelopes, such as kudu (*Tragelaphus* spec.), springbok (*Antidorcas marsupialis*) and duiker (*Sylvica pragrimmia*), and small mammals, such as mongooses (Herpestidae), meercats (*Suricata suricatta)*, ground squirrels (Sciuridae) and vervet monkeys (*Chlorocebus pygerythrus*) were frequent. Monitor lizards (*Varanus* spec.), tortoises (Testudinidae), green tree snakes (*Dispholidus typus*) and a variety of birds were sighted. From sightings and reports of the farmers, it is apparent that the Cradock valley is host to several International Union for Conservation of Nature (IUCN) red-listed species. The black footed cat (*Felis nigripes*), a newly introduced mammalian predator found in the Cradock area, is red-listed ("vulnerable") by the IUCN. One farmer reported to have counted 160 blue cranes (*Anthropoides paradiseus*) on his farm, classified "vulnerable". Some species (mainly bush pigs, baboons, vervet monkeys and kudu) have become so abundant that they have turned into opportunistic crop raiders, although few of the interviewed commercial farmers perceived the opportunistic feeding to cause significant economic impacts.

In the global debate, most reports of biodiversity impacts from biofuels, or more generally agricultural activity and expansion, depict land clearing and deforestation, often in tropical or sub-tropical regions (*e.g.* Koh and Wilcove, 2008). Agricultural activity has led to the removal of trees in Cradock (Masubelele, 2012); however, the mechanisms of agricultural impacts on biodiversity in Cradock are notably different. Although agricultural activity is known to pose a threat to biodiversity through habitat transformation and fragmentation, in the Cradock case, this effect seems partially offset. The older generation of farmers that lived in the valley before irrigation farms became abundant, affirmed that with the spreading of irrigation, wildlife abundance increased in the valley (farmer 8, 20, 17, 19; appendix 2), including those species red-listed by the IUCN. A possible explanation is that the crops on Cradock irrigation farms attract small mammals that serve as prey for (newly) introduced predators. In addition, Cradock farms may have resulted in an enhanced heterogeneity into the semi-arid Karoo landscape that seems to partially offset, or even override, the effects of biodiversity decline through habitat transformation. Irrigation farms are commonly perceived to be in conflict with wildlife preservation due to their substantial water demands (Lemly *et al*., 2000); however, in Cradock, agricultural activity led to the construction of the Orange-

Fish-River tunnel (Figure 5), which effectively provides additional water flow for the valley (see below). Therefore, and contrary to the common hypothesis of biodiversity declining in response to agricultural expansion, farmer reports suggest that wildlife abundance was increased with agricultural activity in the Great Fish River Valley. Intermediate ecological disturbance has been reported to peak wildlife abundance (Blair, 2004), and species richness alone is therefore not an indicator of sound wildlife management practice. However, unlike suggested in the literature, agricultural activity, and more specific future biofuel feedstock cultivation, may not result in biodiversity declines in the valley, and some species, including the "vulnerable" ones, may even profit from this development. Nevertheless, compared to their original state, changes in species compositions are in all likelihood inevitable.

It is important to note that the biomes in the Great Fish River Valley are altered from their historical state (Masubelele, 2012), partially due to the additional water flow from the Gariep dam (Figure 5). Besides having caused vegetation changes alongside the river, the enablement of irrigation activity may have artificially "greened" the valley. Grassy vegetation became more abundant, and farmers reported removing spreading indigenous *Acacia* trees manually every year as they became a "*weed*" (Farmer 11; appendix 2). The river banks are now inhabited by reeds and grasses (Masubelele, 2012). Figure 14 illustrates these changes with historical photographs from 1902 and 2009. The pictures depict changes in water flow and (riparian) vegetation of the Great Fish River.

Biodiversity impact summary – Acknowledging that the biomes of the valley are categorised as "least concern", that three out of four are moreover covered by the adjacent Mountain Zebra National Park, and that much of the valley is already transformed by agricultural activity and the provision of new water supplies from the Orange River scheme, it is concluded that the negative effects of biofuel feedstock cultivation on biodiversity, even if planted on virgin grounds, would be small. Some species, including IUCN classified "vulnerable" organisms, may even profit from agricultural activity due to additional food sources, enhanced and altered habitat heterogeneity, and artificial water supplies. This links to the debate over the desirability of "novel ecosystems" that can potentially provide for ecosystem services equal to or improved over their purely indigenous equivalents, although they are altered from their original state (Seastedt *et al*., 2008; Marris, 2009). The absence of large predators and the frequently performed jackal hunts in Cradock are certainly undesirable from a conservationist's perspective; however, contrary to assumptions made in the global

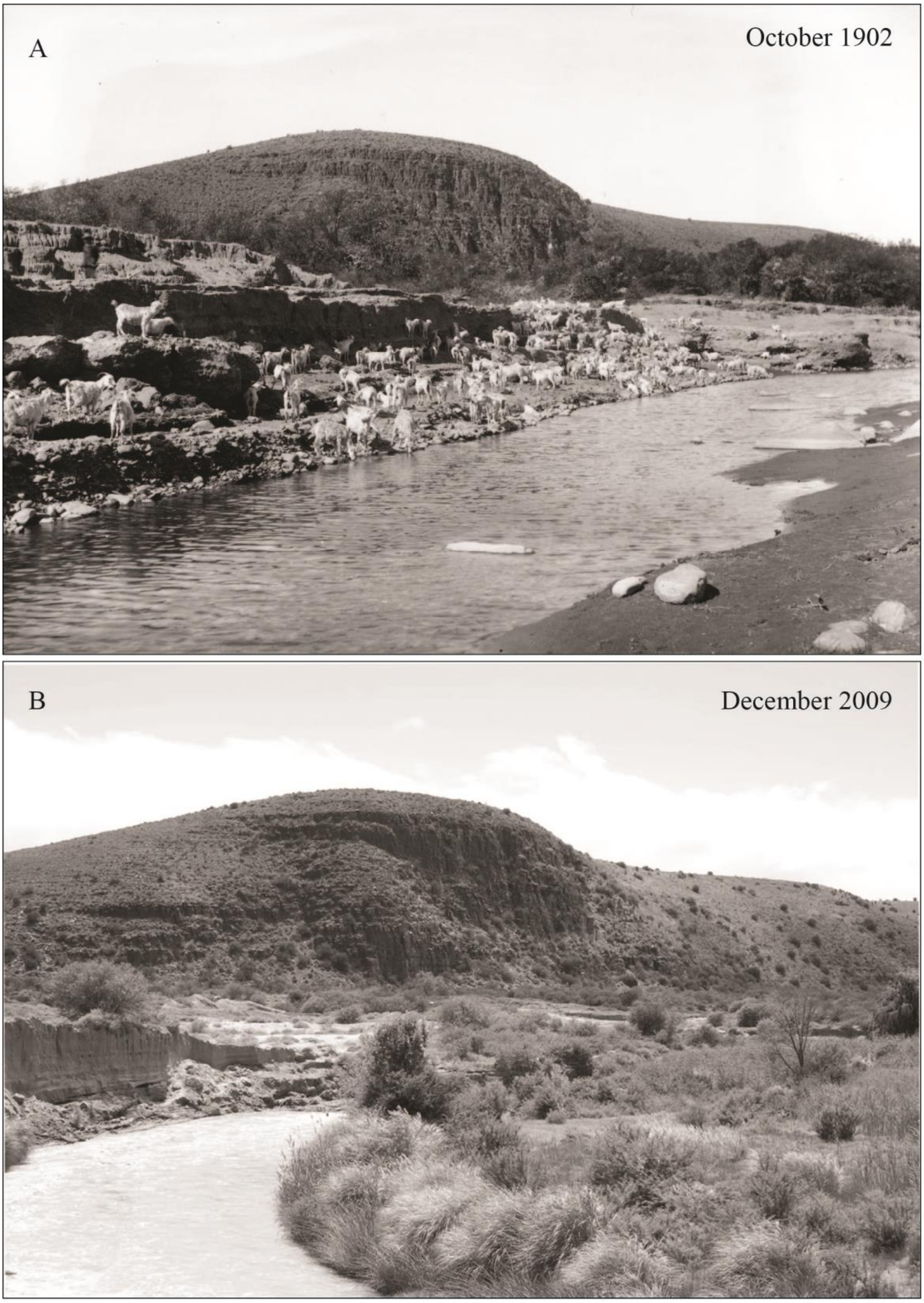

FIGURE 14 Historical photographs of the Great Fish River Valley from 1902 (A) and 2009 (B)
From Masubelele (2012). Location: S 32.19225, E 25.65514. Altitude: 860 meters**.** Note the changes of riparian vegetation.

biofuels debate, biodiversity declines from the *staus quo* are not to be expected from biofuel production in the valley. The farmer reports suggest that there is no trivial relationship between agricultural activity and biodiversity abundance at the Cradock study site. This is certainly surprising, although it affirms previous findings that agricultural impacts are region-specific (McLaughlin and Mineau, 1995). Being beyond the scope of the current assessment, an in-depth study on the effects of irrigation fields, culling of livestock predators and the (re-) introduction of (vulnerable) species (such as the black-footed cat) could shed more light on the ecological impacts of biofuel production and agriculture in general in Cradock and elsewhere.

6.4 Environmental aspects of biofuel production in Cradock: carbon footprint

6.4.1 Carbon footprint of simulated scenarios

In addition to possible land-conversion and biodiversity impacts, the carbon footprint of a biofuel forms a vital component of its environmental desirability. In order to mitigate climate change, the carbon footprint must be lower than that of a fossil equivalent. This is given in all simulated scenarios of Cradock fuel ethanol production (Table 8). The present carbon footprint analysis on conventional and hypothetical GM feedstock cultivation for the Cradock plant suggests that glyphosate-resistant cultivation would differ in three aspects from conventional farming practice (Table 5): i) herbicide use: in both cases, an insecticide (here: 300 ml cypermethrin) is used during cultivation, but the amount of annually applied herbicides is changed from 5.4 kg (mix of two herbicides, subject to intellectual property of ARDA) per hectare to 2.2 kg per hectare (glyphosate); ii) diesel use: due to the reduced herbicide inputs in GM cultivation, a glyphosate-resistant crop is projected to require less tractor runs, hence there would be a reduction of annual diesel use from 117 litres to 65 litres; and iii) tillage practice: recent studies found that tillage practice can be reduced with glyphosate-resistant crops (Givens *et al*., 2009; Kniss, 2010).

Carbon footprint according to the simulations − According to the carbon footprint analyses performed in this study, conventionally grown sugar beet emits 9.1 to 9.3 % more GHGs than the GM variant during the cultivation phase. Land-use change adds about 1 / 3rd to the emissions during cultivation for a 20 year period (Figure 12A).

Because cultivation accounts only for roughly 1 / 5th of the total emissions in the present assessment (Figure 12B), these differences become marginalised in light of the full production chain. The results for the final product's carbon footprint from the various scenarios simulated for this study are summarised in Table 8. In conjunction with the remaining steps of the biofuel lifecycle (Table 7), conventionally grown sugar beet results in GHG emission reductions of 32.0 % (on cropland) and 27.4 % (on virgin grounds) when compared to a gasoline reference with a carbon footprint of 90 grams CO_2 equivalent (CO_2eq) per MJ (EPFL, 2011b). The hypothetical GM variants now only perform marginally better, with savings of 33.4 % (on cropland) and 28.9 % (on virgin grounds).

TABLE 8 Summary: carbon footprint of Cradock fuel ethanol from sugar beet

Cultivation practice	Carbon footprint: final product [g CO_2eq / MJ]	GHG savings: fossil fuel reference[1] [%]	GHG savings: conventional cultivation reference [%]
Conventional on cropland	61.2	32.0	0
Conventional on virgin grounds	65.3	27.4	- 4.4
Genetically modified on cropland	59.9	33.4	+ 1.4
Genetically modified on virgin grounds	64.0	28.9	- 3,1
Conservative yield est.[2] on cropland	64.6	28.2	- 6,2

[1] 90 g CO_2eq / MJ (EPFL, 2011b)

[2] 98 tons / hectare (Vivier *et al*., 2009)

Genetically modified crop cultivation could hence offer GHG savings in the magnitude of 35 kg CO_2eq per ton ethanol, or ~ 1.5 % for the final product. Direct land-use change increases the carbon footprint by ~ 4.4 % over a period of 20 years (Table 8). Taking the more conservative 95 tons yield estimations from the EIA (Vivier *et al*., 2009), the GHG emissions during cultivation (on cropland) would be 30.8 % higher during cultivation (compared to the 149 ton yields), but even with the lesser yields, there would be GHG reductions for the final fuel of 28.2 % (compared to 32.0 % with 149 tons yield). These results are in the magnitude of other studies on fuel ethanol from sugar beet, such as Foteinis *et al*. (2011) who calculated GHG reductions of 32.6 % from ethanol production in Greece.

6.4.2. The Cradock case: contributions of cultivation and conversion modules

Cultivation and direct land-use change – The high sugar beet yields would place this project as one of the top producers of ethanol per hectare in the world (Figure 13). Consequently, the GHG emissions from cultivation are projected to be low, even when virgin grounds are cultivated. The share of land-conversion related emissions is relatively small compared to other studies (Fargione *et al*., 2008; Searchinger *et al*., 2008). This is mainly due to the low carbon stock of the dry grass and shrubby vegetation of the Karoo *veld* and that the land is partially degraded through livestock grazing. This study assumes agricultural expansion to take place on this "moderately degraded grass / shrub land" (LCA input variable). However, if trees were removed for expansion, dLUC emissions would possibly have a much greater impact on the current calculations. Because food security is unlikely to be affected elsewhere in or outside the country (see above; 6.2.2), downstream iLUC processes can be ignored in the present carbon footprint analysis.

Conversion operations – Using hard coal as a heating fuel during ethanol production has been criticised in the literature (Wang *et al*., 2007; Börjesson, 2009) and reduces the beneficial GHG emissions during Cradock feedstock cultivation substantially. In fact, the emission footprint of conversion operations overrides the other modules by far (Figure 12B). Assessing alternative heating sources, such as natural gas, or, most-preferably from a GHG perspective, wood chips, for the plant is therefore encouraged. Another factor that limits GHG savings is the relatively high carbon footprint of South Africa's grid electricity, which is about twice as high as a European equivalent because it is based mainly on coal power generation (Eskom, 2012; EEA, 2009). Nevertheless, all simulated scenarios lead to a reduction of GHG emissions, ranging from 27.4 to 33.4 % (Table 8). The carbon footprint of biofuel production has the potential to be reduced by the incorporation of alternative energies such as wind and solar to generate South Africa's grid electricity, which will positively affect the carbon footprint of the Cradock biofuel production steps where electricity is used.

6.5 Conventional versus glyphosate-resistant cultivation

Two major changes were identified to have impacted on Cradock agricultural practice over the last decades. First, the adoption of centre pivot irrigation that is currently replacing the more water intense flood irrigation fields allows for agricultural expansion due to more efficient water use. The second is the planting of GM crops, which are currently available as Bt-producing and glyphosate-resistant soy and maize. The vast majority (95 %) of the maize planted in Cradock is glyphosate-resistant (agricultural supplies retailer, 2013, personal communication).

Flood irrigation, and to a lesser extent sprinkle irrigation, bring in vast amounts of weed seeds on the Cradock fields. At this stage, because weed control was a crucial factor in the setup of the trials (ARDA research department, 2013, personal communication) organic sugar beet cultivation in Cradock is unlikely to be established in the near future. According to the commercial farmers interviewed for this study, glyphosate has simplified farming substantially for the farmers. They referred to this herbicide as "*incredibly effective*", "*revolutionary*" and a "*miracle*" (farmer 1, 2, 13; Appendix 2). It is therefore not surprising that almost all of the interviewed commercial farmers showed strong preference for a glyphosate-resistant sugar beet crop (Table 2). As shown in the preceding section, the GM variant would decrease the use of chemicals and diesel, therefore lowering GHG emissions and increasing net-energy benefits. These benefits could, however, become marginalised as some farmers reported that glyphosate application rates increase over time. This is a known phenomenon, and a recent study has suggested that due to glyphosate resistance formation in weeds, this herbicide's application rates need to be increased to maintain its potency (Benbrook, 2012).

The desirability of GM crops for fuel ethanol production depends on numerous factors. From their experiences, farmers and the ARDA administration representative confirmed economic benefits, and highlighted that crop management becomes more convenient as GM cultivation requires less interventions, therefore enhancing crop management efficiency. The present assessment thus affirms previous studies on glyphosate-resistant crops that have been reported to offer economic benefits and reduced herbicide inputs (Gianessi, 2005). Specifically to the sugar beet crop, the introduction of a GM variant in Wyoming was reported to increase sugar yields, reduce tillage, and increase economic returns (Kniss, 2010). Similar conclusions were drawn from a GM sugar beet study in Europe (Nichterlein *et al.*, 2012). Unlike Gianessi (2005), Kniss (2010) and Nichterlein (2012), Heinemann *et al*. (2013) did not find benefits of yield and herbicide use from the adoption of GM crops. The different outcome of this study could be attributed to its experimental setup. Heinemann *et al*. (2013) compared cultivation practice and yield development across nations, whereas the other studies conducted comparisons within a region.

Although this study finds minor GHG benefits from the planting of GM sugar beet, it is not advisable to base the assessment of GM or non-GM cultivation impact on the carbon footprint of a product alone. The ecological impacts of GM crops, especially for glyphosate resistance, have been debated rigorously in scientific and public domains. Snell *et al*. (2012) reviewed 24 long-term studies and concluded that there is no evidence for health risks from GM crops. Contrastingly, a recent study from Séralini *et al*. (2012) found that rats are more likely to develop cancer when fed with glyphosate treated crops. This study has to be seen with caution, because it had evoked many responses from the scientific community pointing out methodological flaws in the experiment setup and biased data interpretations (*e.g.* Berry, 2013; de Souca and Ouda, 2013; Langridge, 2013). However, the media had broadcasted the paper's conclusions, often ignoring the many concerns that have been raised regarding its validity (Arjó *et al*., 2013).

Laboratory studies on glyphosate eco-toxicity suggest that the presence of glyphosate in fresh water impacts on aquatic organisms. For example, Mensah *et al*. (2011) found 96 hours LC^{1}_{50} on freshwater shrimp neonates to be as low as 2.5 mg per litre. Common glyphosate application concentrations are 20−30 mg per litre; however, when diluted as runoff, *in situ* concentrations are often much lower, and glyphosate can perform better than other herbicides (Shipitalo and Owens, 2011). Since the literature is inconsistent on the eco-toxicology of glyphosate, care has to be taken when choosing a line for sugar beet cultivation in Cradock, although, since maize is already glyphosate-resistant, total application rates of this herbicide would not substantially change with the establishment of GM sugar beet.

It should also be noted that, since the distribution of GM seeds is already well established by the local seed retailers in the valley, commercial farmers may not be in need of further assistance with the purchase of the seeds. Although numerous reports throughout the world point to the social and economic risks of introducing GM crops to emerging and / or established farmers, including debt, and onerous contractual requirements (Herring, 2005), this has been refuted consistently by the Cradock farming community (Appendix 2). However, for the emerging farmers, further training and assistance in purchasing GM seeds, application of pesticides and resistance management will become necessary under such as scenario. The present study offers evidence that GHG emissions could be reduced with GM biofuel feedstock cultivation, but wider impacts of glyphosate, and its ecological and social desirability in comparison to conventional cultivation should be carefully evaluated before an application for the approval of GM sugar beet in South Africa is made.

[1] Dose lethal to 50 % of a target organism in an experimental setup lasting 96 hours

6.6 Synthesis

This last section of the present discussion chapter provides a synthesis based on its findings. The anticipated GHG emissions from Cradock bioethanol are evaluated in terms of Börjesson's (2009) criteria for environmentally sound biofuel production (6.6.1). Subsection 6.6.2 displays the anticipated social and environmental components of the project and deduces their implications for South Africa's biofuels policy. Finally, the implications of this study for the global biofuels debate are depicted in 6.6.3.

6.6.1 Börjesson's (2009) greenhouse gas criteria: is Cradock fuel ethanol a "good" fuel?

In his 2009 paper, Börjesson presented four criteria to determine whether a biofuel is "good" in terms of GHG emissions. From the results of this study, Cradock fuel ethanol complies with 3 out of the 4 criteria.

Criterion I: "ethanol plants should use biomass and not fossil fuels" – According to the current plans, this criterion is not fulfilled. The choice of coal as an external heat source may be economically sound, but raises the carbon footprint of the produced fuel. From the LCA performed in this study, conversion operations take up to 80 % of the production chain's emissions (Figure 12B). Nevertheless, GHG emissions were found to be reduced in each simulated scenario.

Criterion II: "cultivation of annual feedstock crops should be avoided on land rich in carbon – This criterion is met. Since the availability of irrigation water is restricted, the Cradock biofuel feedstock is mainly planted on existing cropland. Expansion onto new farmland (Karoo *veld*) leads to dLUC emissions, but even with their inclusion, GHG emissions will be reduced. If land clearance of forest patches would occur, significant dLUC effects could make biofuel production in Cradock unfavourable from a GHG perspective. However, there is currently no evidence that this would happen on a large scale in the Cradock area.

Criterion III: by-products should be utilised efficiently – This criterion is met. Beet bulb co-production offsets losses of (animal) food crop production.

Criterion IV: nitrous oxide emissions should be kept to a minimum – This criterion is met. The overall application of N fertiliser could decrease if sugar beet replaces a maize or a maize / wheat double crop.

From a GHG perspective, Cradock fuel ethanol may prove beneficial. However, because of the plant using coal as an external heat source, overall emission reductions may fall short of the project's potentials.

6.6.2 Anticipated environmental impacts and social implementation barriers of the proposed Cradock fuel ethanol project

In contrast to numerous studies on biofuel production around the globe, impacts on habitat and biodiversity from Cradock fuel ethanol production were found to be low. This project has the potential to achieve world leading ethanol production per hectare (Figure 13), which implies that the agricultural impacts through land-conversion are minimised. Greenhouse gas emissions will be reduced from Cradock fuel ethanol production, although not substantially. Genetically modified crops may enhance GHG savings and net-energy benefits, and are likely to be the economically preferred option. The utilisation of GM biofuel food crops should, however, be assessed in terms of economic, social and environmental desirability, under a careful consideration of downstream environmental impacts from glyphosate eco-toxicity, which is not covered with the scope of the present study. The argument that the biofuel project could enhance food security in Cradock by the creation of employment opportunities (Besharati, 2012; present study) adds to the desirability of the proposed plant. It is acknowledged that cumulative impacts from succeeding biofuel projects could draw a different picture. It is for this reason that the 2007 biofuels strategy paper states that a situational review has to be conducted after the initial biofuels target of 2 % has been reached (DME, 2007), a recommendation that is supported by this thesis.

Numerous delays of the commencement of the project have damaged the support of the Cradock farming community and have likely led to additional costs for the project. As Cockerill and Martin (2008: 10) argue, due to economic and environmental pressures, "we don't have the luxury of time" in searching for renewable energy sources, and the fact that hesitant administrative action is amongst the biggest pitfalls for the proposed Cradock plant, streamlining of the administrative process becomes crucial. The situation on the beneficiary farms that face numerous problems with the implementation of an agrarian BEE programme in Cradock similarly requires much attention. With the elimination of those social drawbacks, the proposed Cradock fuel ethanol project could provide for a positive example of sustainable development and black empowerment from biofuel production.

6.6.3 Generalisations in the biofuels debate and the role of biofuel production case studies

The results of this study suggest that many of the concerns dominant in the global biofuels debate, specifically “land grabs”, biodiversity impacts, higher GHG emissions and compromised food security, do not apply to the specific Cradock case. Notwithstanding, there seems to be a tendency in the global biofuels debate to generalise and oversimplify the complex matters that underlie biofuel production. For example, biofuels have been suspected to lead to increasing food prices, but higher fossil fuel prices could contribute to a rise of food prices as well (IFPRI, 2008), and economic upliftment in the production area is often ignored. Nevertheless, a tendency towards mono-causal explanation of biofuel production underlying higher food prices prevails. Simplifications can be observed in the biodiversity debate as well: the relationship between agricultural activity and local biodiversity can be, in some cases, non-trivial (as shown by the present assessment), and evidence from this study suggests that mono-causality (such as habitat conversion through expanding agriculture) is insufficient in its explanatory power when applied to the Cradock case. This dissertation thus highlights the importance of case study research to contribute to the theoretical framework of environmental and socio-economic impacts from biofuel production, and appeals for a re-opening of the biofuels debate with an enhanced focus on case-specific and context-relevant impacts.

7 Conclusions and Recommendations

7.1 General conclusions

This dissertation set out to determine the relevance and magnitude of the concerns that are raised about biofuels for fuel ethanol production in Cradock, South Africa. Based on the evidence assembled and discussed, it is concluded that many of the concerns raised in the global biofuels debate are inapplicable to the Cradock fuel ethanol project, or are less significant than suggested in the literature. From this case study, it is clear that the desirability of fuel ethanol production can be context-specific, perhaps more so than currently acknowledged in academic and political debate.

Regardless of future biofuel production in Cradock, agricultural activity will continue and agricultural expansion is likely to occur. It is for this reason that some environmental impacts must be attributed to agricultural activity in general and not to the specific case of biofuel feedstock production. At this stage, ecological restoration of land is unlikely to happen, since almost all of Cradock's economy is based on agriculture. The agricultural footprint that can be attributed solely to fuel ethanol production in Cradock will therefore be low. With a projected production of up to 16,000 litres ethanol per hectare from sugar beet (based on latest trials), yields are substantially higher than in other countries. Ethanol feedstock production takes place on existing farm land, or on biomes classified as "least concern". The use of climate-critical nitrogen fertiliser is likely to decrease with biofuel feedstock production.

There is little evidence of ethanol production in Cradock jeopardising food security and thus triggering indirect land transformation outside the Cradock valley. However, despite the high yields, GHG emission savings are found to be relatively low (27 to 33 %, depending on direct land-use change and cultivation practice). This is mainly due to the high carbon footprints of the coal and grid electricity that will be utilised during sugar-to-ethanol conversion operations. As simulated in this study, glyphosate resistant sugar beet (Roundup Ready™) cultivation could perform marginally better than conventionally grown equivalents (~ 9 % less emissions during cultivation; ~1.5 % more greenhouse gas savings for the final fuel ethanol) due to lower inputs of herbicides, less tractor runs and a possible reduction of tillage practice in the feedstock cultivation phase. Glyphosate is already widely used on the Cradock farms, and, should GM sugar beet be approved in South Africa, this would not result in a substantial increase of this herbicide in the valley. On the other hand, conventional sugar beet would decrease the utilisation of glyphosate (but increase the use of conventional herbicides).

It is concluded that the conglomerate of agricultural impacts is projected to not exceed those of the *status quo*. Initial emission reductions and net-energy benefits will be small, however, technological and agricultural innovations and modernisations may improve the ecological footprint of the Cradock biofuel. Most notably, the incorporation of clean technologies to produce South Africa's grid electricity will positively impact on the carbon footprint of the produced biofuel. Challenges arise from a sustainable implementation of the Cradock BEE programme. The 2009 EIA recognises that economic development is crucially needed in the Cradock area, as unemployment rates are high (Vivier *et al.*, 2009). Economic upliftment and possible enhancement of food security favour the social desirability of this project. However, a streamlined administrative process for monetary allocations, training and supervision will be necessary to ensure the success of the emerging farms. Future agrarian land reform projects could profit from the minimisation of delays between purchasing and allocating the lands, which is one prominent reason for the deterioration of the farms entrusted to land reform beneficiaries in Cradock.

7.2 Prospects for future research

This dissertation has evaluated social and environmental aspects of fuel ethanol production in Cradock, South Africa. Future research on economic feasibility can provide new insights into the desirability of fuel ethanol production from an economic point of view. The fact that biofuel production in the country promotes domestic job creation and possibly a more favourable trade balance through reduced fossil fuel imports should be incorporated in such a study. The simulation of fuel tax incentives and carbon taxes could provide new insights into optimal political measures for the promotion of renewable energies.

Cumulative impacts and means to mitigate both the agricultural and the industrial footprint offer areas for future studies. Further investigation is encouraged of the social and environmental impacts of GM crops and the potential for economically and environmentally sound biofuel production beyond the marginal climatic advantages evident from this study. Because the present study provides evidence that the effects of agricultural practice on biodiversity are non-trivial, in-depth studies on the effects of irrigation fields, culling of livestock predators and the (re-) introduction of species could shed more light on the ecological impacts of biofuel production in Cradock and elsewhere.

7.3 Policy recommendations

The findings of this dissertation have implications for South Africa's biofuel and land reform programmes. In this final section, policy recommendations are presented based on these findings.

7.3.1 Cradock fuel ethanol project

The negligible negative environmental and social impacts of the proposed Cradock fuel ethanol project justifies its commencement. Many of the concerns that are discussed in the global biofuels debate are limited in their applicability to the project: biodiversity impacts are small, GHG emissions are neither strongly reduced nor aggravated, and food security is unlikely to be jeopardised in or outside the valley.

The utilisation of Roundup Ready™ crops is preferred by the majority of farmers in the Cradock farming community. This study concludes that it offers marginal climatic benefits and is likely to be the economically preferred option. In light of a contradictory scientific debate as to its social and eco-toxicological effects, it is recommended to thoroughly investigate the environmental consequences of GM biofuel feedstock. Should this evaluation be in favour of GM crops, and a glyphosate-resistant sugar beet version be approved in South Africa, this strain may provide benefits as feedstock for the Cradock fuel ethanol plant.

The utilisation of maize as a biofuel feedstock has been refuted in the current biofuels strategy because of food security reasons (DME, 2007), and currently, grain sorghum is envisaged to be a supplementary feedstock for fuel ethanol production in Cradock. However, maize cultivation is well established in Cradock, and it is therefore proposed to re-investigate the use of maize as a supplementary feedstock in the Cradock fuel ethanol project.

As shown by the carbon footprint analysis in this study, the high carbon footprint of coal used as heat source jeopardises much of the potential for GHG reductions at the proposed Cradock plant. It is therefore encouraged to investigate low-carbon fuel alternatives as an external heat source for the plant.

7.3.2 Performing agriculture under consideration of biodiversity impacts

Many of the environmental impacts of biofuel production are attributed to its cultivation phase. It is recommended to keep agricultural activity on low-carbon grounds and to formally protect forests, riparian areas, and other lands of ecological value from agricultural expansion. In Cradock, development of the river banks and on ecological corridors should be avoided. The preservation of riparian habitat is desirable for a number of ecosystem services. This may be the most effective measure to avoid biodiversity impacts from biofuel production and to mitigate the ecological impacts of direct and indirect land transformation.

7.3.3 Cradock agrarian Land Reform

The BEE program in Cradock faces similar problems to other land reform projects in the country (see also Mogari and Lotze, 2006; Fauconnier and Mathur-Helm, 2008). It was apparent that a drawn-out process led to many farms being unutilised for up to several years, with monetary losses from non-production and new implementation barriers due to the deterioration of farm land. It is possible that conditions will improve over time, but future agrarian land reform projects should consider alternative management models to facilitate a streamlined process. Most notably, irrigation farms should be managed continuously. It could be beneficial to assign beneficiaries to their farms whilst having the original owner for a fixed time (but at least for one season) remaining on the farm to enable a seamless transition of ownership.

The beneficiary selection process was criticised by both emerging and commercial farmers, albeit for different reasons. A streamlined and transparent process for future beneficiary selection may avoid the emergence of discomfort and distrust amongst all involved parties.

7.3.4 Getting a biofuels industry started

Both the agrarian land reform and the biofuels policy process should be streamlined. The various delays in the implementation of these projects eventually lead to higher costs and inconveniences for all affected parties, dis-incentivising participation. The commencement of the industry will also offer experience and development that is needed to facilitate international competitiveness on the biofuel market. However, streamlining should not compromise thorough environmental, social and economic investigations and stringent planning prior to the commencement of the project.

7.3.5 Biofuel industry expansion under the consideration of cumulative impacts

The Cradock project accounts for roughly a third of South Africa’s biofuel target of 2 % (DME, 2007), which is a small contribution to the country’s fuel consumption. Due to the heterogeneity of future biofuel projects, care has to be taken when assessing cumulative impacts. Most notably, the scale of the project has been identified to be too small to have a significant impact on food production; however, it is acknowledged that cumulative impacts from many biofuels projects throughout the country can be of great significance. The biofuel industry in South Africa is an emerging one, which implies a step-by-step implementation of various projects to achieve subsequent goals set by the government. Inherent in such a step-by-step implementation, however, lies a danger in not noticing their cumulative impacts. A separate mechanism has to be put in place to track these.

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Appendix

This section depicts the interviews with the commercial farmers (Appendix 1, 2) and beneficiaries (Appendix 3) in table form. They underlie tables 2−4 of the Results chapter of the present dissertation.

Appendix 1 Commercial farmer interview table (socio-economics)

ID	Involvement in beet trials	Willingness to plant sugar beet	Expectations for Cradock and business	Impacts on food security	Opinion on black empowerment	Potential pitfalls / additional comments
Farmer 1	- yes	- possible under right economic conditions	- positive: project is generally beneficial	- positive: none or little impacts expected	- negative: no trust in ability of emerging farmers - initial omissions in farmer involvement - fair compensation for land purchase	- lack of experience of emerging farmers. - project process taking too long - lack of communication between government and farmers - expectations for own business: mildly beneficial through improved market stability
Farmer 2	- yes	- not planned	- positive: job creation, promoting investment in the area	- positive: no impacts expected	- negative: no trust that program works - lack of farmer involvement	- black empowerment strategy may fail - sugar beet cultivation may not be economically feasible
Farmer 3	- yes	- possibly if beet pulp can be purchased to offset animal feed loss	- positive: job creation	- neutral: depending on animal feed co-production	- negative: land purchased for black empowerment is deteriorating - lack of skills - lack of supervision - own recommendations for emerging farmers not considered	- selection of emerging farmers suspected to be politically driven - special harvesters needed for sugar beet - farmers lose interest because of project delays - farmers change plans to other farming methods - lack of trust in governmental administration
Farmer 4	- no	- not planned	- negative: impacts on tourism, impacts through increased traffic	- positive: no impacts expected	- emerging farmers lack experience and knowledge	- sugar beet not economically feasible - machinery not suitable for high yield sugar beet - political action uncoordinated - impacts on tourism - sees more potential in 2nd and 3rd generation biofuels - Cradock farmers should focus on tree nuts
Farmer 5	- yes	- possible under right economic conditions	- positive: project is generally beneficial	- positive: no impacts expected because of beet bulb byproduct - South Africa is a food exporter	- negative: Land Reform harms the valley's production	- project process taking too long - governmental administration too complex - project support lost momentum
Farmer 6	- no	- possible under right economic conditions	- positive: project is generally beneficial,	- positive: no impacts expected	- negative: "*it doesn't work at the moment*"	- infrastructure is a problem at the moment, roads are not upgraded yet, there may be enhanced stock theft

ID	Involvement in beet trials	Willingness to plant sugar beet	Expectations for Cradock and business	Impacts on food security	Opinion on black empowerment	Potential pitfalls / additional comments
			promotion of investment in the area, sugar beet as an "identity crop"		- communication problems - farm land deteriorated - is in favor for BE to happen, but: - process takes too long, too bureaucratic - beneficiaries not supported enough - biggest problem: they should have bought the farms with implements	with tar roads - increased traffic may be problematic - older generation less keen on the project - sugar beet has to be viable (has to outcompete double crop maize and wheat) - crop rotation no problems, market stability beneficial
Farmer 7	- no	- possible under right economic conditions	- positive: investment in town and infrastructure, ethanol project starts a mushroom effect	- positive: no impacts expected	- negative: process of appointing beneficiaries not transparent - black empowerment harms production - beneficiaries "*not eager to learn*" - would welcome black farmers in the farmers' association - wishes more initiative of beneficiaries to make contacts - some purchased farms were not productive	- soil depletion may occur from sugar beet cultivation - rotation bears risks that have to be economically offset - labour factor is a problem, tries to reduce employment (minimum wage and land claim) - herbicides don't work well - food security: maize should be grown elsewhere, maize contribution from Cradock is "*tiny*" - irrigation should be used for high-value crops
Farmer 8	- yes	- possible under right economic conditions	- positive: project is generally beneficial	- neutral: there will be impacts, but food production from Cradock is small in national comparison	- negative: no trust because of experience in the Transkei - money allocation disorganised, payments too late - lack of skills - lack of trust between commercial and emerging farmers	- little trust in BEE programme - government takes too long - minimum wages and land claim limit labour potential, there may be less jobs in the future - Cradock very suitable for sugar beet, rotation is good for the soil
Farmer 9	- no	- possible under right economic conditions	- positive: project is generally beneficial	- positive: no impacts expected	- huge monetary losses through underutilisation of purchased land - agriculture is difficult is survive with, beneficiaries have "*no chance*" - theory is good, practice is bad - farms are "*ruined*"	- fears impacts from traffic - crop rotation is a problem, because of possible premature harvest - process seems to have been prolonged artificially to benefit few (people from ARDA), corruption - unprocessed sugar beet not the best animal feed - government plans not transparent - going "*organic*", trying to get away from synthetic

ID	Involvement in beet trials	Willingness to plant sugar beet	Expectations for Cradock and business	Impacts on food security	Opinion on black empowerment	Potential pitfalls / additional comments
					- lack of experience - neutral: it can be turned around, but it takes effort	fertilisers - has to be mechanised
Farmer 10	- no	- possible under right economic conditions	- neutral: " wait and see" approach	-positive: no impacts expected, in the last 5 years, maize production in the valley has nearly doubled	- neutral: program does not work at the moment - as a mentor: "*with the right guidance it can work*" - trust must be build up - supervisors must be chosen by the beneficiaries - administration of program is structurally correct - politicians lack knowledge - program will work in time - there was lot of money lost already due to incorrect supervision - "*beneficiaries know quite little of what is going on* [from the government side]" - program to bureaucratic - "*Things will be better in time*"	- many employees hard to manage: cultivation has to be mechanised - minimum wages will increase unemployment - cash flow too bureaucratic in black empowerment program - single person was managing 11 farms
Farmer 11	- yes	- possible under right economic conditions	- positive: project is generally beneficial	- positive: no impacts due to by-product (3 to 4 tons per hectare) - spinoffs will enhance food security	- neutral: private programme works with former workers, but only because he intervenes frequently - as soon as he withdraws it collapses - example: water was not paid by government, crop was not planted in time - "*There has to be other ways and means to manage this thing*" - empowering own staff: problems with management skills, empowering business men: lack of experience - example: barley was planted, water rights not paid, crop	- sugar beet has hardly any residues due to heat (leaves crumble) - government not streamlined at BEE, not flexible enough for urgent needs on a farm (such as caterpillars on crops) - sugar beet has to be at least 20 % more profitable than current crops they replace - crop rotation not a big issue "*I believe in the project, but then government has to get their act together*" - benefits from spinoffs will be huge

ID	Involvement in beet trials	Willingness to plant sugar beet	Expectations for Cradock and business	Impacts on food security	Opinion on black empowerment	Potential pitfalls / additional comments
					failed - programme will take at least 5 years to be financially viable	
Farmer 12	- no	- possible under right economic conditions	- positive: project is generally beneficial - "everyone would benefit from it"	- positive: no impacts expected	- neutral: no specific opinion, not involved	- newly introduced crop rotation not a problem
Farmer 13	- no	- possible under right economic conditions	- positive: beet bulb interesting for dairy farmers, easy to grow for emerging farmers, also on smaller scales	- positive: no impacts expected, but: if putting maize in the factory, prices will go up and may destabilise the country - no impacts from sugar beet - no impacts because of scale	- positive: "*I'd like to see a lot of emerging farmers producing this sugar beet*" - wants to see BEE to be a success - there seems to be more effort to make the program a success than in past BEE programs "*It was frustrating to see good ground not being utilised*" - "*It has to work*"	- farm employees that worked on the purchased farms are now all jobless, they should have stayed on the farm - asks: why has the project not being done yet ("*What are you waiting for*?"), suspects economic hurdles - farmers lose confidence that the plant does not come - perceives it a waste of tax money - as a dairy farmer more interested in the bulb for dairy cattle - sugar beet is an easy crop to grow
Farmer 14	- no	- possible under right economic conditions	- positive: beneficial because of job creation	- positive: no impacts expected because of co-products and scale	- negative: "*people don't want to learn*" - programme does not work - beneficiaries do not trust the advice of the white farmers	- project took too long, lost interest in it - good for crop rotation - "*This valley is only a drop in the ocean of food supply*"
Farmer 15	- no	- possible under right economic conditions	- positive: project is generally beneficial	- positive: no impacts expected	- neutral: plans currently not economically based - process took too long - is in favour of black empowerment - administrative structure is right, but implementation failed - beneficiaries should have been put on farms right away after buying them	- project takes too long - people wonder what happened to the money for ARDA - economics not clear - sugar beet would compete with maize and lucerne
Farmer 16	- yes	- possible under right economic conditions	- neutral	- negative: there might be impacts during drought years	- negative: ARDA suspected to enrich themselves - nothing happening on farms - neighbouring BEE farms are deteriorated - harms the production	- if beets get too big you cannot harvest them - only grows if the money is right (must be significantly more) - wants to get away from manual labour - market stability slight advantage, but comparison to maize still involves fluctuation

ID	Involvement in beet trials	Willingness to plant sugar beet	Expectations for Cradock and business	Impacts on food security	Opinion on black empowerment	Potential pitfalls / additional comments
					- supports the program nevertheless - feels powerless to do something about corruption - beneficiary selection not transparent - losing millions by not planting properly	
Farmer 17	- no	- not planned	- positive: project is generally beneficial, job creation, investment in the area creates spin-offs	- positive: no impacts expected, because there is "*plenty of food*", although it does not reach the people - maize production per hectare increases steadily	- positive: supervision makes the difference - but: money is handed out to people that fail taking care of it	- machinery damages soil profile - "*if you have to harvest, you got to do it*" (also when it rains) - process took too long - minimum wages are not too big of a problem, will lose lower-education-end jobs though - economics of the project - doubts carbon reductions and net energy benefits of bioethanol - economic benefits would have to be huge and planting without too much inconvenience - would rather buy the beet bulb - asks: mainly jobs for the highly qualified?
Farmer 18	- no	- possible under right economic conditions	- positive: project is generally beneficial, job creation	- positive: no impacts expected because of scale and crop rotation	- much of the land not utilised - farming community offered help - positive: "*I have faith that the program works*" - "*We all need to chip in and make sure that it works*"	- process needs to be streamlined - would have to replace maize/barley - market stability good
Farmer 19	- no	- not planned	- positive: project is generally beneficial	- positive: no food supply shortage, because "*there is room for sugar beet*" - can contribute greatly to food security because of job creation	- negative: "*It's chaos at the moment*" - much land not utilised - price of lucerne is "*sky high*" because shortage of production - programme threatens food security - money flow interrupted - selection of beneficiaries not transparent - without proper supervision, they will fail	- government takes too long - "*I would love to see maize included*" because it grows well in the valley - jobs are lost due to minimum wage sugar beet cultivation - sugar beet too demanding on the land, rotation won't work with his program) - would consider growing sorghum - market stability with fixed prices would be beneficial - sorghum is easier for the valley

ID	Involvement in beet trials	Willingness to plant sugar beet	Expectations for Cradock and business	Impacts on food security	Opinion on black empowerment	Potential pitfalls / additional comments
					- lack of business and farming skills - lack of support - they will not be able to make enough profit	
Farmer 20	- no	- not planned	- neutral: job creation not certain	- positive: no impacts expected because of animal feed co-production	- farm that he saw: "*nothing is happening*" - farm association: was worried that the process took too long - neutral: some will succeed with training, but "*90 % are not going to get anywhere*", unless they get help	- process takes too long - not much job creation because of mechanisation - employment on farms may decrease - with minimum wages: told his staff that they have to work harder to keep them - concerned about traffic and road condition - concerned of pollution from factory - "*if you have to harvest during rain it is a mess*" - traffic is a concern - soil quality may decrease because of the big machines, especially during rain - concerns: what crop residues are there? How palatable is the leaves? - cultivation: rotation inconvenient - would be a taker for beet bulb
Farmer 21	- no	- not planned	- positive: project is generally beneficial	- positive: no impacts on food security because of scale - not every farmer will plant sugar beet	- positive: with correct supervision, the program can work - he is not the mentor, although it was his farm - proposed to ARDA, but was not appointed - sold one farm to the government - the price was fair - the logistics and bureaucracy "*pathetic*", took 21 months to sell it - after being sold, it took 8 months to put a beneficiary on farm - has no relation to the beneficiary, except one telephone call - they grew nothing in 8	- fears too much traffic - "*I can't see the roads lasting*" - Government is too slow - dealing with government is "*an absolute nightmare*" - cultivation: depends on economics - new rotation would be a problem / inconvenient - "*I haven't been a great supporter of sugar beet*" - "*The logistics don't make much sense to me*" - economics would have to be substantially more - market stability is beneficial - doubts that sugar beet will be best in terms of economics

ID	Involvement in beet trials	Willingness to plant sugar beet	Expectations for Cradock and business	Impacts on food security	Opinion on black empowerment	Potential pitfalls / additional comments
					months, but crops look good at the moment	
Farmer 22	- no	- possible under right economic conditions	- positive: project is generally beneficial	- positive: no major impacts on food security - people already have problems to sell their meat products for adequate prices	- positive: mentoring one beneficiary (was asked by beneficiary) - "*He will make it*" - "*They have a lot to learn*" - with good mentors, they can make a success out of it - crops were planted too late, but this will be sorted out in the next years - some farms are in bad condition, farm conditions heterogeneous - money flow is too slow - still believes that it works	- Government takes too long - farmers lost interest - needs his crops for the animals, would maybe have to cut down animals, except he can get the bulb back - more market is good for farmers

Appendix 2 Commercial farmer interview table (environment)

ID	Consider agricultural expansion?	Biodiversity or environmental impacts	Utilisation of GM crops
Farmer 1	- yes (use water for additional land)	- none	- uses Roundup ready crops - sugar beet must be Roundup ready
Farmer 2	- no (use water for other crops)	- none	- uses Roundup ready crops - sugar beet must be Roundup ready
Farmer 3	- no (limit reached)	- none (expansion would be on grazing land)	- uses Roundup ready crops - would prefer Roundup ready sugar beet
Farmer 4	- no involvement intended (no input)	- fertility of soils, including earthworms and microbes may be affected by sugar beet - doubts carbon emissions will be reduced by this fuel	- uses Roundup ready crops - sugar beet must be Roundup ready to compete
Farmer 5	- no (limit reached) - but: many farmers may expand	- none	- uses Roundup ready crops - would prefer Roundup ready sugar beet
Farmer 6	- yes - could expand to 350 hectares - on *veld* (grazing area) - expansion towards the mountain, no expansion beyond 6 km at the moment	- slight impact on habitat and biodiversity, but semi-desert with less biodiversity than *e.g.* coastal areas	- uses Roundup ready crops - Bt not necessary under centre pivots - Bt found not effective when tried - a lot of Bt farmers do not properly plant rescues, pull back now - Roundup work very good, has never had problems with resistance, but neighbour had - fears problems with soil because European countries abandon it - other chemicals (herbicides) are "*much worse*" than Roundup and dangerous - Roundup seems "*the way to go*" - would prefer a Roundup ready version for sugar beet ("*definitely*") or using a registered herbicide that works - "*if you don't control weeds, your neighbour will get them too*"
Farmer 7	- maybe (risks to develop more land), but possible - expansion would be on bushes and grass land	- none - Fish river would naturally be empty most of the year, water flow is artificial	- uses Roundup ready crops - does not see any problems with GM crops - resistances against Roundup start to begin, controls with additional herbicides would prefer Roundup ready sugar beet
Farmer 8	- yes (~ 100 hectares more) - on *veld* (with centre pivots)	- no impacts - farming increased bird life and wild life in general - 160 blue cranes on the farm, breeding ground on farm	- utilises Bt, but no Roundup - weeds are controllable with conventional chemicals - Roundup sugar beet can help, because long period of cultivation makes problems with weeds
Farmer 9	- no (already overdeveloped with irrigation)	- no input	- used GM crops in the beginning

ID	Consider agricultural expansion?	Biodiversity or environmental impacts	Utilisation of GM crops
			- not using them anymore, because yields are lower with GM - fears resistances - would not mind if sugar beet is GM or conventional
Farmer 10	- no (all good soils are in production) - expansion going on regardless of sugar beet cultivation	- habitat loss occurs, but: - no impacts on biodiversity because the valley is narrow - some species settled here that were not there 10 years ago - when he was a child, there was no kudus or bushbok, now there is hundreds (they were not even near the river) - he has no big problems with crop raiders - neighbors do have problems	- uses Roundup ready crops roundup pushed maize production a lot ("*Makes most of the difference*") for yield increase, 2nd is pivots - utilises maize and soya roundup - uses a little bit of Bt (very efficient), but less problems with pests, probably because others around use Bt - would prefer Roundup ready sugar beet - if it is not Roundup ready, economic benefits must be even higher because of inconvenience - if conventional herbicides also work, than it can be viable as well - never had a problem with resistances
Farmer 11	- yes (expansion happens from modernisation of water use) - expansion limited by pump electricity costs	- none ("*For us, thorn trees are a weed*") - *Acacia* increased with irrigation and water flow	- uses Roundup and Bt - "*I don't want to use anything else*" - "*You cut out so many sprays*" - "*The biggest advantage I have ever seen*" - no problems with resistances - would prefer Roundup ready sugar beet "*It would reduce your spraying more than half*"
Farmer 12	- yes (on *veld*)	- no impacts - the landscape got much more lively, trees got higher and reeds showed up with orange river tunnel	- uses Roundup and Bt maize - is a big help - Bt works good (no insecticides sprayed any more); without Bt one havs to spray at least 2 times - no problems with resistances - would prefer Roundup ready sugar beet - Roundup increases yields
Farmer 13	- yes (open up new ground)	- no impacts "*at all*"	- uses Bt and Roundup - "*You have to have a Roundup ready version*" - "*Roundup is incredibly effective*" - no problems with resistances
Farmer 14	- yes (on 20 hectares), on *veld*	- no impacts "*at all*" (but: he gives 10 % of crops to wildlife) - no monetary problems with crop raiding	- uses Roundup and Bt maize - "*The green people want to take it away, but I like it*" - "*They say it makes problems, but they can't prove it*" - "*It is the best way to farm*" - BT uses less pesticides than conventional - Roundup very efficient, no problems with resistances

ID	Consider agricultural expansion?	Biodiversity or environmental impacts	Utilisation of GM crops
			"*Roundup isn't bad for the ground*" - diesel use is pretty the same, same amount of runs - "*Roundup makes everything easy for us*" - would prefer Roundup ready sugar beet
Farmer 15	- no (limit reached), but arrangement with neighbours would be possible (use their land) - expansion happens regardless of sugar beet - going to close to the river: land can get flooded - expansion in direction of the mountains	- river has been developed for a long time - development takes place in Karroo veld - impacts are there, but "*small*" - some grassland, mainly shrub land - no endangered species affected in the valley - Western Cape dry land irrigation much more of a problem for *renosterveld* and *fynbos*	- uses Roundup and Bt - no problems with resistances - works very well - production not big difference - input costs not big difference - saves a lot of time - non-GM hard to manage - would prefer Roundup ready sugar beet
Farmer 16	- yes - no future for flood irrigation - bought the farm next to him for expansion - no ground available in his area, so expansion on existing land	- no input	- uses Roundup and Bt - does not spray on Bt-maize - Roundup works well - never problems with resistances - no change in diesel use - yields are similar - no input on preference
Farmer 17	- yes (*veld*), grassland, bushland, Along the river	- no impacts on threatened biodiversity expected - irrigation assists biodiversity more than it damages, "*We got more species of animals now than we had when I was a kid*" - crop raiding has no significant impact, but Kudus increased dramatically - predators increased, got African wild cat, jackels, caracals (= lynx), servals (new), black footed cat (vulnerable) - some are threatening livestock - shoots jackals (as do all his neighbours)	- tries to reduce chemical use (does not use pesticides and herbicides) - does not use GM crops - would prefer Roundup to other herbicides on sugar beet
Farmer 18	- yes (on virgin *veld*), sandy soils, Karoo bushes, bit of succulent, shrub land - development is towards the mountain, every patch on the river is developed - normally one cannot develop within 15 meters of the irrigation canals or the river (law made 20 years ago), but to that time it was already developed closer. There is no reinforcement of the law	- this section was overgrazed for many years, irrigating is "*doing it a favour*" - sights a lot of kudu and springbok, duikers - kudu raids crops, makes an economic impact, fence them out. If kudus get too many, they are culled and sold - jackal and caracal threatens livestock - river reeds are "*impossible to control*" - difference to when she was young: in the past, they were hardly any thorn trees, and no reeds	- uses roundup - works "*very well*" - economic benefits, yields are better - spray less chemicals - diesel use is reduced - no problems with resistances
Farmer 19	- no (not at the moment) - expansion limited by electricity costs to 1 km away from river canals	- rainfall too low for "real" grassland - more rainfall in the mountains - Kudus are crop raiders, does make an economic impact - lynx (*rooicat*) and jackals make problems - farming assists biodiversity	- uses Roundup - works "*great*" - no problems with resistances due to rotation - would prefer Roundup ready crops in general

ID	Consider agricultural expansion?	Biodiversity or environmental impacts	Utilisation of GM crops
Farmer 20	- yes (with and without sugar beet), by replacing flood with pivot irrigation - Karoo *veld*	- "*ecological value is always there*" but not too high for this land - fantastic soils for irrigation - jackal and lynx problems for livestock - bush pigs are a problem, they have to stop them from breeding - leaves one hectare for Kudus - in the old days: there were no kudus, the water monitors came in, birds moved in, species of fish moved in, predators came back, bushpigs arrived, warthogs are arriving, fish eagles were never here (now they are) - "*All kinds of wildlife has skyrocketed*"	- uses Roundup - works "*very well*" - damage to the soil remains to be seen - uses pesticides a lot (for stalk borer etc.) - Roundup: has to spray less - less spraying: less diesel use (about 20 % less) - less pressing on the soil - less poison
Farmer 21	- no (limit reached)	- had problems with crop raiders, but: "*it is so little I just let them eat*" - expansion causes habitat loss - expansion is mainly taken place on the big *Acacia* trees (where he expanded: kudus, duiker, guinea fowls disappeared) - shrub land, forest land and grassland	- uses Roundup and Bt - Roundup works "*excellent*" - "*Best thing ever*" - does not spray pesticides on Bt - uses 3.2 litres Roundup / ha - uses a mix of 4 pesticides for non-Roundup - would prefer Roundup sugar beet; "*Hell yes*" - diesel use stays the same (2 sprays) on maize
Farmer 22	- yes (pivots on shrub lands, no big trees), soils are suboptimal, but can be fertilised with organic manure	- no impacts - Karoo bushes are replaced with irrigation land, neutral to biodiversity - vervet monkeys feed on maize, increase each year - jackals eat about 5 % of lambs	- uses Roundup and Bt - Roundup works "*very good*" - no resistances - Bt crops are not sprayed with pesticides - makes life easier - economic benefits as well, yields are higher - would prefer Roundup ready sugar beet - diesel use is reduced by about half

Appendix 3 Beneficiary interview table

ID	Application process	Condition of farm	Condition of crops	Supervision	Relation to neighbors	Expectations for ethanol project	Comments
Beneficiary 1	- several delays, drawn-out process	- poor	- good	- ineffective	- racism occurs	- generally beneficial	- lack of machinery
Beneficiary 2	- generally fine	- good, but minor problems with implements	- good	- ineffective	- good	- generally beneficial	- hard to make profits - biggest problem: no own tractors
Beneficiary 3	- generally fine	- poor	- poor	- not optimal	- mixed	- neutral, depending on economics	- farm was vandalised - no profits in first year - farms were overpriced - economics of sugar beet questionable - farms were vandalised
Beneficiary 4	- too bureaucratic	- poor	- good	- satisfying	- good; "*We are all farmers now*"	- questionable economics ("*Even the blacks may pull out of this thing*") - generally beneficial due to job creation, spin offs	- beneficiaries can sell directly to community, which can enhance food security in the area - government acts too slow - farms were overpriced - many beneficiaries are old - lack of communication with previous farmers
Beneficiary 5	- drawn-out process	- poor	- good	- ineffective	- racism occurs - little trust between commercial and emerging farmers	- generally beneficial	- farm has no house - lack of machinery - no training in book keeping - too many farms per mentor - farms were overpriced - hard to make profits
Beneficiary 6	- drawn-out for years	- poor	- good	- ineffective	- good	- worried about food security - not keen to grow sugar beet	- mentors are imposed - "*beneficiaries are chained*" - governmental inefficiency creates distrust and hatred towards beneficiaries
Beneficiary 7	- drawn-out for years	- poor	- poor	- ineffective "We are not trained for this"	- does not know them - racism occurs	- generally beneficial	- lack of trust between commercial and emerging farmers - more than one beneficiary per farm makes management difficult - farm house has no flowing water - farm not suitable for livestock - cash flow too slow - water rights not fully utilized - farm was vandalised
Beneficiary 8 **Beneficiary 9** **Beneficiary 10**	- no input	- good	- poor	- satisfying	- good	- generally beneficial	- no own machinery - no own car - house needs renovations - crops were planted too late
Beneficiary 11	- drawn-out for years	- poor	- mixed	- satisfying	- does not know them	- generally beneficial	- has never seen the contracts - water rights not fully utilized

ID	Application process	Condition of farm	Condition of crops	Supervisio n	Relation to neighbors	Expectations for ethanol project	Comments
Beneficiary 12	- drawn-out for years	- poor	- poor	- ineffective	- bad, racism occurs	- beneficial if benefits are shared	- hard to make a profit - no livestock - house needs renovations - cropland not prepared properly - crops not properly fertilized - "*We've been set up for failure*" - beneficiaries' situations heterogeneous - irrigation canals need maintenance - "*Impossible to make profits*" - administration not transparent, fears corruption - implements (tractors) not received in time