Strategic evaluation large scale sustainable bioenergy export from Mozambique to the Netherlands

Creative Energy
Energy Transition

Universiteit Utrecht

ECOFYS

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This report presents the results of a joint study by Ecofys and the Copernicus Institute for the former Platform Biorenewable Resources. The Copernicus Institute has carried out the modeling of land availability in this study. Ecofys coordinated the study and developed the business cases and the roadmap.

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Executive summary

The Dutch government foresees an important role for biomass. Biomass is needed a) to contribute to growing national renewable energy targets and b) to fuel the establishment of a bio-based economy. Given limited national production potentials, The Netherlands will have to rely heavily on imported biomass.

This report presents a case study on Mozambique as to provide insights on how import of biomass to the Netherlands can be realised. The report provides an evaluation of the techno-economic aspects of large-scale production of biomass in Mozambique and subsequent export to the Netherlands.

Mozambique has been selected for this case study as it is considered an example of a promising Southern African biomass production region. The government of Mozambique has articulated policies to promote the production of biofuels and the establishment of a national market. Large potential export markets, such as the EU, offer additional incentives for establishing a national Mozambican biomass and bioenergy industry. However, ensuring the development of international sustainable bioenergy supply chains are a significant challenge.

Potential land availability in Mozambique

By 2030, between 6.4 and 16.5 millions of hectares of land could be made available in Mozambique for the production of bioenergy feedstock, while taking into account sustainability aspects. If the developments in the agricultural sector continue along the current trends (Business As Usual Scenario), it will only be possible to realise the lower end of this range. However, if agricultural practices significantly improve, the higher end of the range could be achieved (Progressive Scenario).

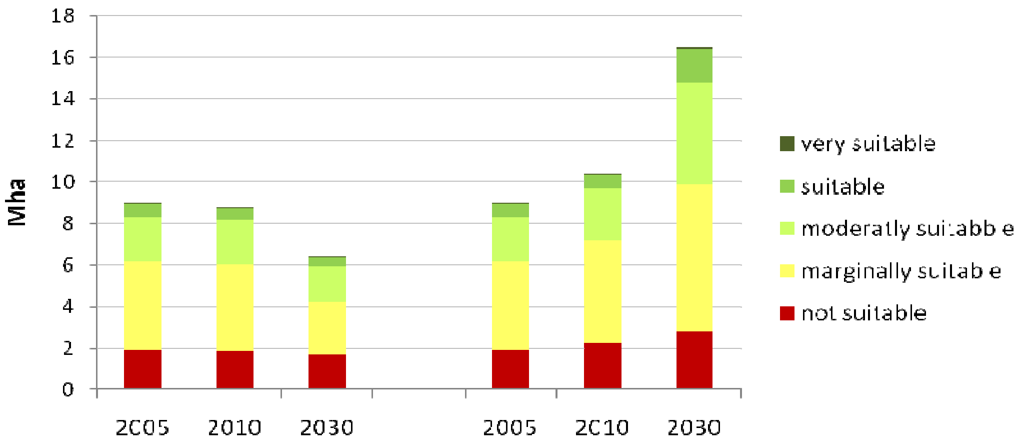

Figure 0 - 1: The development of land availability over time differentiated for suitability classes for the BAU scenario (left) and the Progressive scenario (right)

The Progressive Scenario reflects the Mozambican ambition for more advanced development. In this scenario, the additional land primarily comes available because the existing land use functions become more efficient, with higher food and feed yields per hectare. The scenario assumes commercialisation of the agricultural sector with a high rate of technological and land management practice changes. An increasing part of the farmers will need to have access to improved seeds, fertilisers, pesticides and, above all, (agricultural) knowledge.

Despite the ambitions, in an agricultural sector that is currently dominated by subsistence farming, the actual trends show only modest annual yield increases. Agricultural improvements are implemented only at a slow pace, amongst others because there is barely a market for the end-products.

The necessary agricultural improvements could be realised in conjunction with the development of a bioenergy production sector in Mozambique. And vice versa, a sustainable and economically viable bioenergy sector can only be realised if the existing agricultural sector develops in the same fast pace. *A large-scale sustainable bioenergy sector can only be established if it is developed simultaneously with a more productive and sustainable agricultural sector.*

Business cases to explore the opportunities for biomass production and export to the Netherlands: ethanol from sugar cane and wood pellets from plantation eucalyptus

There are a multitude of potential bioenergy production chains that could be considered for bioenergy production and export from Mozambique to the Netherlands. To determine the economic viability of large-scale biomass export supply-chains from Mozambique to the Netherlands, two business cases have been developed and analysed. These business cases could be developed with positive effects for social and environmental sustainability and are relevant for different end-use markets, both national and international.

For both supply chains, we have taken into account the cultivation methods, the production organisation, the logistics, the conversion and the international shipment of the bioenergy carriers.

Table 0 - 1: Selected business cases

	Sugar cane	**Eucalyptus**
Type of crop	Semi-perennial (ratooning)	Short rotation coppice
Type of management	Intensive	Semi-intensive
Harvesting	Mechanical	Semi-mechanical (chainsaws)
End product	Ethanol	Wood pellets

Eucalyptus pellets

The averaged costs for eucalyptus pellets come at 143 USD/tonne, or 104 Euro/tonne[1], at the port of Rotterdam. Pellets are currently being traded for a price around 120 Euro/tonne in the port of Rotterdam (APX/ENDEX).

The feedstock production costs (48%) and the transport costs (21%) contribute largest to the total cost of the pellets in this business case. The conversion plant investment costs only contribute 14%. This is partly due to the fact that these investment costs are less sensitive to the inflation rates, as occurring in relatively early years (6 and 7) of the project. This business case shows a relatively long pay-back time (10.3 years) because the inflow of cash only starts after the first harvest, seven years after the first investments. If the plantation and the pellet production are separately considered, they both have shorter payback times. Until 2030, the project has an IRR of 15%, and a net present value of 4.3 MUSD.

The most important parameter to achieve shorter payback times and higher IRR is the price of the pellet product on the European market. With a pellet price of 150 Euro/tonne, the payback time is reduced to less than 3 years after the first harvest (9 years after project start). Also, yields per hectare are projected to increase over the next decade which also results in better project performance.

Sugar cane ethanol

The estimated production and delivery costs for sugar cane ethanol are about 430 USD/m^3. Major contributors to these costs are the plant investment, harvesting and land clearing. A major source of income is excess electricity that can be co-produced from the bagasse residue. The value of the ethanol is currently around 690 USD/m^3, so that the project would have an IRR of almost 21%. Note that ethanol from Mozambique imported to the EU does not face import tariffs and therefore has a competitive advantage of 100-200 Euro/m^3 (depending on the imported form) in comparison with ethanol from Brazil. The cash flow results show a positive cash flow from 2014 onwards (with project start in 2011). The cumulative cash flow turns positive 7 years after project start. This is regarded as attractive for this kind of projects.

Several future developments could make the business case even more attractive. For example, additional ethanol can be produced from the lignocellulosic part of the plant. This part now ends up unused in the bagasse or remains in the trash currently left on the field. Technological learning might lead to only limited cost improvements, as the technology is mature and the existing global mill capacity is already very large. Note that the conditions for investing in ethanol projects are currently attractive in Mozambique, where corporate taxes on bioenergy projects are receiving significant discounts. These discounts will be gradually phased out over the next decade. Potential cost reductions that could be achieved by future improvements will be partially compensated by the tax induced cost increases.

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[1] At an exchange rate of 1 EUR = 1.4 USD

Roadmap: developments for realising a large-scale sustainable biomass supply

The two case studies have shown that the two large-scale biomass production routes that could be realised in Mozambique and subsequent export of bioethanol and biomass pellets to the Netherlands are feasible. By creating the right institutional and infrastructural systems, the development of such routes can be managed and accelerated, while ensuring a certain level of sustainability of the bioenergy carriers and optimising the benefits for Mozambique.

Crucial elements for this development are:

- Identification of preferred developing zones:
  - Zoning helps infrastructure planning;
  - Leads to regional specialisation;
- Attractive legal and financial environment for project developers:
  - Facilitate procedures;
  - Maintain network of financiers;
  - Organise trade missions;
- Creating of essential infrastructure:
  - Main roads and harbour;
- Safeguarding sustainability:
  - Environmental Impact Assessments;
  - Match international sustainability requirements;
- Rural development:
  - Project developer responsible for improving agricultural practice in region;
- Robust selection of feasible projects:
  - Focus on most valuable projects;
- Assistance to project developers:
  - Access to finance;
  - Guidance in procedures;
  - Project advise;
- Increase agricultural yields:
  - Access to product market;
  - Access to machinery and inputs;
  - Improve know-how;
  - Access to credit.

For further elaboration on these elements a roadmap of actions is described in Chapter 5 of this report. Several resulting actions match the path that has already been set-out by the Mozambican government in their Liquid Biofuel Strategy. Some resulting actions will be costly and need to be financed in a way that the benefits for Mozambique outbalance the costs in the long run, and that the costs and risks in the short run remain acceptable.

This roadmap is intended to create the conditions and setting within which the desired developments are stimulated, so that a viable bioenergy sector can be developed while at the same time improving the existing agricultural sector, so that the agricultural land in Mozambique can be utilised most effectively.

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1 Introduction

The Dutch perspective

Because of climate change, increasing energy demand and security of supply, the urge to implement non fossil energy technologies is increasing. Biomass is by many expected to play an important role in meeting future energy demands and in establishing a bio-based economy. The Netherlands has to rely on imported biomass and bioenergy, as the domestic biomass and bioenergy supply is both low and expensive (de Wit et al. 2010; van der Hilst et al. 2010; PGG 2006; Projectgroep 'Duurzame productie van Biomassa' 2006). An important precondition for such imports is that the biomass is produced sustainably and that both producing and importing country benefit.

The question arises how large-scale import of biomass is best realised when the Dutch government aims for biomass to contribute to realising national targets for renewable energy and to achieving a more bio-based economy. This report contributes to this question by presenting a case study on Mozambique. We evaluate the feasibility and socio-economic desirability of large-scale production of biomass in Mozambique and export to the Netherlands.

The Mozambican perspective

Global bioenergy potential studies have indicated large techno-economic bioenergy production potentials in the Southern African Development Community (SADC) regions of sub Saharan Africa (Hoogwijk et al. 2005; Smeets et al. 2007; Hoogwijk et al. 2009). Mozambique is considered a promising region for biomass production within Southern Africa because of:

- The availability of land (Smeets et al. 2004; Namburete 2006);
- Relatively favourable environmental conditions for agricultural production (INE 2003; Batidzirai et al. 2006); and
- The relatively low current agricultural productivity which offers potential for improvement.

Decreased dependence on oil imports, enhanced energy security and socio-economic sustainable development, especially in rural areas, are the main incentives for the Mozambican government to focus on the development of a bioenergy industry. Mozambique's domestic oil consumption of 16 thousand bbl/day (110 TJ/day, 2009 estimates) is fully supplied by import (mainly form South Africa) which puts a large burden on the import balance (15% of GDP). The government of Mozambique has articulated a political and strategic framework for biofuels (Conselho de Ministros da república de Moçambique 2009). Blending targets and financial incentive systems will be applied to promote the production of biofuels and the establishment of a national market. Large potential export markets, such as the EU, also offer incentives for establishing a biomass and bioenergy industry.

Besides the opportunities, however, there are also concerns about the sustainability of bioenergy. Large scale production of biomass for energy purposes (albeit for domestic consumption or export) might lead, for example, to large-scale conversion of land and might in that case have impacts on biodiversity and carbon stocks. Concerns also exist about the availability of land and competition with other provisioning services, such as food production.

Bioenergy therefore provides both threats and opportunities for sustainable development. The direction and the extent of these impacts depend on the design of the bioenergy supply chains and on the physical and socio-economic characteristics of the region of production. Developing feasible and desirable bioenergy supply chains is a significant challenge. This report contributes to this challenge and presents elements that can help shape such a transition.

The sustainability perspective

Different societal actors have developed criteria and standards for sustainable bioenergy production. The European Renewable Energy Directive (EC, 2009) contains binding sustainability criteria for biofuels. Companies that supply biofuels to the EU have to prove that they meet the sustainability criteria in order for their biofuels to count towards national targets. The sustainability criteria consist of GHG-criteria and criteria related to land use (biodiversity, carbon stock and peatland).

In Mozambique, the need for formulation of sustainability criteria in order to manage social and environmental impacts as well as the need for certifier service companies is expressed in the action plan of the strategic framework for biofuels (Ministry of Energy Mozambique 2010). The subgroup for the sustainability criteria drafted sustainability criteria for biofuels in Mozambique. The input from the stakeholder consultation in 2010 was included in a new version of the sustainability criteria. These sustainability criteria focus on legalities, social acceptability, energy security, economic and financial viability, agricultural productivity and environmental protection and will not entirely overlap with criteria formulated in Europe. In order to able export to Europe, supply chains need to comply with the European sustainability criteria.

Although some studies are available about the techno economic bioenergy potential in Mozambique, no research results are available about the sustainable bioenergy production potential. In addition, experience on how to deploy these potentials and knowledge about the required conditions in terms of investments, policies and stakeholder alignment is lacking. Therefore research on large scale deployment of sustainable bioenergy in Mozambique is required, taking into account current and future availability of land, spatial distribution of potential environmental and socio-economic impacts, a broad range of bioenergy chains, Mozambican and European views on sustainability, (inter-) national policy and stakeholder perspectives.

For this study several visits to Mozambique were organised for data collection and consultations. In June 2010, cooperation was set up with CEPAGRI, the Mozambican agricultural investment promotion department of the Ministry of Agriculture. The results of our analyses were presented at a workshop in Maputo in February and in Rotterdam in March 2011 (for a summary of the workshop see Appendix C and Appendix D respectively). Based on the input and suggestions of the participants of the workshops, we have formulated our final recommendations.

Reading guide

In Chapter 2 we provide a general overview of the socio-economic and physical context of Mozambique is given. We also outline the legislative context of bioenergy production within Mozambique.

In Chapter 3 we describe current land use and methods to assess future land use and land availability for biofuels. We have employed a scenario approach to explore future developments in land use. In addition, we applied sustainability constraints to narrow down the potential land availability to areas that could be employed sustainable for bioenergy production.

In Chapter 4 we evaluate two business cases of selected bioenergy supply-chains: ethanol from sugar cane and pellets from plantation Eucalyptus, both produced in Mozambique and exported to the EU. We analyse the economic viability of these supply-chains, taking into account the cultivation methods, the production organisation, the logistics, the conversion and the international shipment of the bioenergy carriers.

Finally, in Chapter 5 we discuss the implications of the insights brought about in all previous sections, and, taking into account the feedback from Mozambican and Dutch stakeholders, will outline a roadmap for strategies to be developed and actions to be taken by involved stakeholders.

2 Country description of Mozambique

In this section the physical characteristics of Mozambique, its current land use and its socio-economic situation are described. This provides a valuable understanding on the context in which bioenergy developments in Mozambique are implemented.

2.1 Physical context

Mozambique is located on the eastern coast of southern Africa bordered by the Indian Ocean in the east, Tanzania in the north, Malawi and Zambia in the North-West, Zimbabwe in the west and South Africa and Swaziland in the South South-West. Mozambique has 10 provinces and 192 administrative districts (see Figure 1 for a map of Mozambique). It is a vast country of 801 590 km^2 of which 2% is interior waters. It has five main rivers of which the Zambezi River is the largest one and there are three large lakes, all situated in the north. The coastal belt and the area below the Save River have a low altitude. The middle plateau situated in the central and northern inlands ranges in 200-1000m in elevation. The high plateau and the mountainous areas close to the north western borders have average elevations of 1000m. The climate varies from tropical and subtropical in the northern and central parts of Mozambique to dry semi arid climate in the south. There are two main seasons: the warm and rainy season from October to March and the dry and somewhat cooler season from April to September. Rainfall patterns vary strongly within the country: along the coast average precipitation is 800 to 1000 mm/y, close to Beira and Quilimane it exceeds 1200mm a year. The average rainfall decreases inland to 400 mm/y near to border with South Africa and Zimbabwe. In the north and central part of Mozambique precipitation levels range from 1000 to over 2000 mm/y on average (FAO 2005). The Mozambican climate and geography is spatially highly heterogeneous. Mozambique suffers relatively frequently from natural disasters like severe floods (2000-2001) and (periodically) droughts. A large part of the country (39.6% of the country's surface, mostly situated in north western and central part) is affected by fire every year (Taquidir, 1996 quoted by IFFN 2001).

Figure 1: Topographic map of Mozambique

Slash and burn practices are the main cause of forest fires. The lack of forest management and the low level of accessibility hamper effective fire control (IFFN 2001).

2.2 Socio economic context

Mozambique has a population of 22.9 million people. The population density is low (28.7 people/km^2 on average) and varies strongly between regions (FAO 2008). The majority of the population (63.5%) lives in rural areas (FAO 2008). At independence in 1975, Mozambique was one of the world's poorest countries. Although strong economic growth has been achieved last decade (8% on average), about 54% of the population remains in poverty today (Fox et al 2005, Mather et al 2005).Although adequate food is available in Mozambique from domestic production and imports, inadequate access to food is clearly an issue (FAO et al. 2010). Life expectancy is very low but has significantly increased over last decade to almost 48 years (UNDP 2008a).The illiteracy of adults (>15years) is 52.2% (2003 estimates) with large gender inequity (CIA 2009). There is a large spatial variation in illiteracy rates among the population: rates range from 15% in Maputo province to 68% in Cabo Delgado (Mario et al. 2005). Unemployment rates in urban areas (31%) are higher than in rural areas (13%). However, people employed in the rural areas are mostly self-employed or family workers without pay and obtain so little income that other employment would be preferred (Econergy 2008).

2.3 Agricultural sector

This section gives an overview of the agricultural sector in Mozambique. More detailed considerations for scenario building are provided in chapter 3.

About 80% of the population depend on agriculture for their livelihood (FAO *et al.* 2010). However, this sector contributes only 25% of the Gross Domestic Product. This reflects the low agricultural production and the low international trade of agricultural products (agricultural products are 16% of the exports) (Econergy, 2008)

The agricultural sector is characterized by a large number of small scale producers (<10 ha) with mainly rain fed subsistence farming based on manual cultivation techniques and little use of purchased inputs (improved seeds, fertilizers, pesticides) (Bias et al 2003). Even in the rural areas, farming families are net importers of maize, rice and cassava, in varying amounts depending on the region (FAO 2010).

Most important cash crops are cotton, sugar cane and tobacco (INE 2003) and in addition tea, beans, sunflower, cashew and sesame. Because of the dependence of self sufficiency, price elasticity of cash crop supply is very low (Nielson *et al* 2009). Sugar cane, tobacco, tea and cotton are mainly cultivated by plantation production systems. 16% of the farmers participate in tobacco and cotton out-grower schemes (World Bank 2006).

Animal product consumption and livestock numbers and are very low in Mozambique. During the civil war, there was a significant reduction of livestock number. Since 1993, livestock numbers increased with an average rate of 10% (FAO et al. 2010) but diseases and the lack of control of these diseases form a threat for the developments the sector. Tsetse, tick borne diseases and foot-and mouth disease form the most important threats for cattle. Most occurring diseases for pigs are the African Swine fever (ASF) and Porcine Cysticercosis. Chicken production at a household level is endangered by the Newcastle disease as there is still a resistance to vaccination among individual farmers (FAO 2005; FAO *et al.* 2010). There is large spatial variation in the distribution of livestock. Cattle is mainly concentrated in the south, due to the prevalence of tsetse in central and northern parts of Mozambique (above Rio save) (Timberlake *et al.* 1986; INE 2003; Maposse *et al.* 2003). Small ruminants (Goats and sheep) and pigs are mainly kept in central and northern parts of Mozambique. The cattle and ruminant production systems are categorized as (agro)-pastoral in arid and semi arid regions and extensive mixed systems in semi arid and sub-humid regions (Otte *et al.* 2002)(INE 2003; FAO 2005).

Forest products that can be distinguished are industrial round wood, fuel wood, and non-wood forest products (NWFP). Timber production is assumed to be a driving force for industrial development in rural areas (Fath 2001). Local communities are the most important exploiter of timber and non-timber forest products (NTFPs) are characterized by a low level of investment and financial return and a lack of technology (Nhancale et al 2009). The contribution of the forest sector to the GDP is estimated to be 1.8% and the sector employs 5.7% of the total economic active population (Nhancale et al. 2009). The majority of the industrial round wood production is currently exported of which 80% is shipped to China. Wood products in total contribute 2.6% to the total export value. It is estimated that 50-70% of the total round wood production is clandestine and that 95% of the fuel wood is illegally harvested (Nhancale et al. 2009).

2.4 Infrastructure

Although large scale rehabilitation of destroyed infrastructure has been achieved, infrastructure remains very limited in Mozambique. Infrastructure is mainly East-West directed as historically Mozambique has played an important role as a transit country for South African, Swazi, Malawian and Zimbabwean import and export through Mozambican ports (Meeuws 2004). The infrastructure inherited form the past has a strong regional dimension and little has been invested in linking the different regions of the country (Meeuws 2004).

Road

The majority of roads are not paved and the conditions of trucks are generally poor. Therefore, road transport is generally time consuming and expensive. The lack of infrastructure and access to markets is an important restrictive factor for economic growth, especially in the rural areas. The variations in cost for road transport are relatively large. Road transport is relatively cheaper to and from Maputo than around Beira.

Despite of the poor road infrastructure transportation of goods is most often done by truck. Commercial wood producers apply a maximum radius of 100 km from the saw mill. As transport costs are relatively high, longer transport distances are economically not feasible (personal communication C.M. Rungo, Ifloma). For large scale sugar cane plantations a maximum transport radius of 60 km is applied (personal communication R. Hurley, Principle Energy). The low density of sugar cane makes transport over longer distances unattractive.

Rail

The railway network is not extensive and the lines are not interconnected. Costs for railway transport depend on type of cargo and track and distance and are relatively high. Five main railroads are available for transporting Cargo. There is a railway that links the Zimbabwean border with Beira and comes through Tete. This railway is being extensively upgraded to accommodate the export of coal through Beira from the Vale and Riversdale mines that are being established at Tete (information R. Petre 2009). Stocks of locomotives and wagons have decreased significantly during the nineties. The costs for reloading from truck to train makes the use of railroad only economically feasible for long distances when adequate road infrastructure is lacking

Ocean freight

There are six ports in Mozambique. Maputo, Beira and Nacala serve the international trade while Pemba and Quelimane serve mainly domestic cargos.

Table 2: Suitable ports for large-scale biomass export

Port and cargo type	Capacity (t)	Depth (m)
Beira		
General cargo	1 700 000	9
Containers	950 000	12
Nacala		
General cargo	1 000 000	10
Containers	600 000	14
Quelimane		
General cargo	650 000	13.5
Containers	–	–
Pemba		
General cargo	640 000	7.5
Containers	–	–

Source: Savcor-WWF 2010

2.5 Bioenergy initiatives in Mozambique

Schut et al (2010) provide a detailed overview of recent developments in bioenergy projects in Mozambique. Figure 2 shows a spatial distribution of projects that have been formally submitted to, and the large-scale projects approved by the Government of Mozambique by the end of 2010. Figure 3 also shows the geographical spread of other implemented biofuel projects and expressions of interest identified in Mozambique, distinguishing between projects producing bioethanol, biodiesel and pure plant oil PPO.

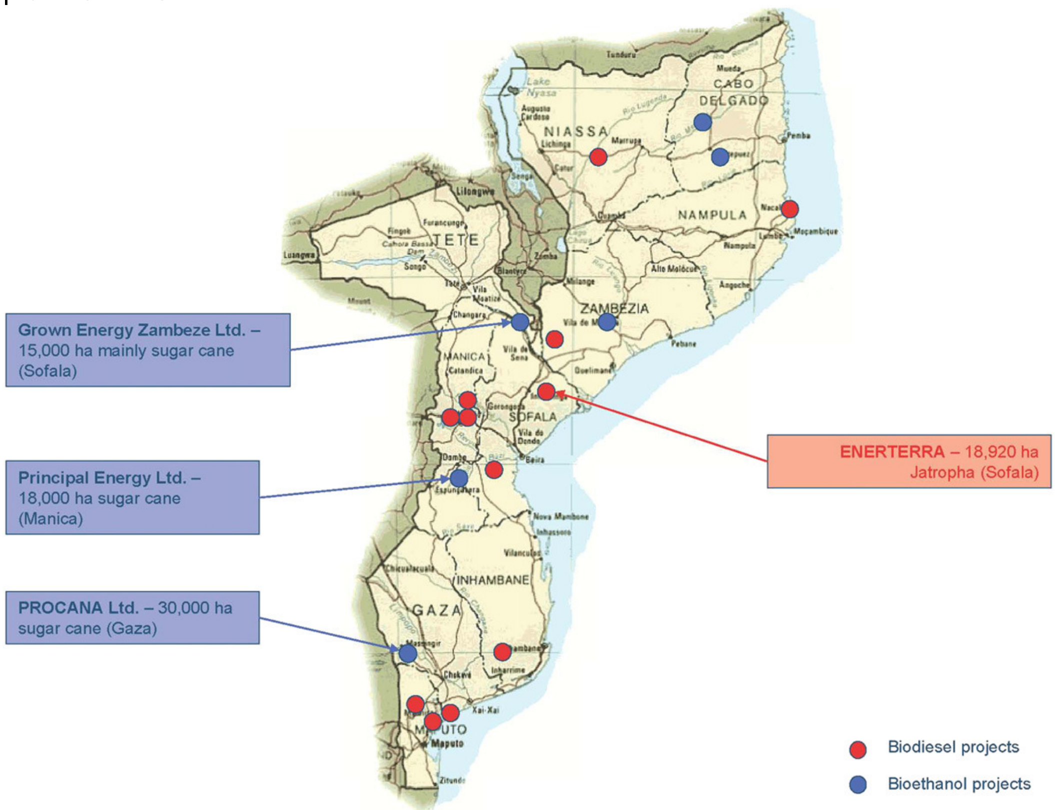

Figure 2: Biofuel projects that formally submitted investment proposals to the Government and the four large-scale projects that have been officially approved at national level[2]. Source: Schut *et al.* 2010

The core business of nearly all biodiesel projects is growing Jatropha seeds to extract oil, while the bioethanol projects mainly focus on sugar cane as a feedstock, with some interest in sweet sorghum and cassava.

[2] In December 2009, the government voided the contract of Procana because the company failed to comply with its contractual obligations (Schut *et al.* 2010). Also some smaller jatropha projects (<10 kha) have been approved.

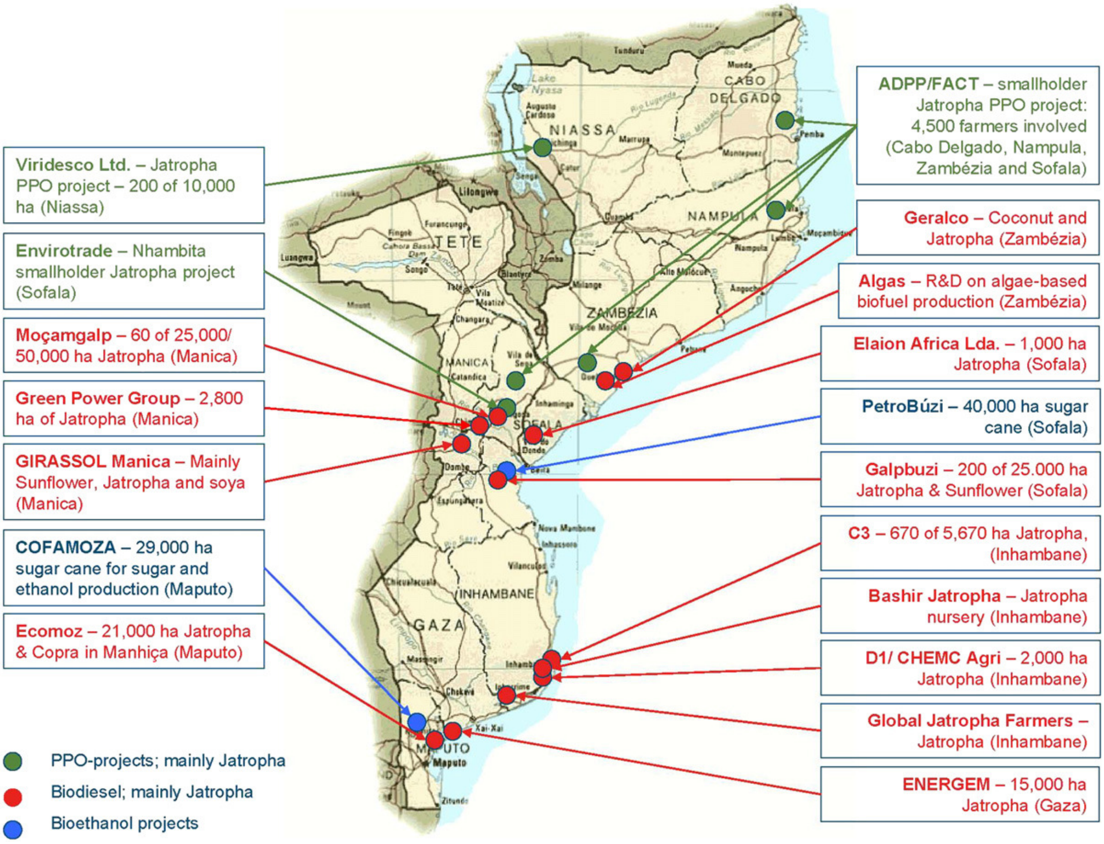

Figure 3: Geographical spread of other implemented biofuel projects and expressions of interest until January 2010. Source: Schut *et al.* 2010

From 2008-2010, 25 large biofuel projects submitted investment proposals to the Centre for the Promotion of Agriculture (CEPAGRI) representing about 300 kha[3]. The bulk of the requests was submitted in 2008 (13 projects, 191 kha). At present, less than a quarter of the projects submitted for analysis to CEPAGRI has formally been approved for biofuel projects (approximately 33 kha for sugar cane ethanol and 33 kha for jatropha biodiesel). We estimate, however, based on field visits, interviews and literature that less than 15% of the approved area has already been planted until now (maximum 10,000 ha).

2.6 Policy context

The government (collaboration between Ministry of Energy, Agriculture and Environment) has developed a liquid biofuel strategy (Conselho de Ministros da república de Moçambique, 2009). In this energy strategy four biofuel crops are selected: **Sugar cane** and **sweet sorghum** for bioethanol production and **coconut** and **jatropha** for biodiesel. In addition, a land zoning assessment was undertaken to indicate which land is available for agricultural projects including cultivation of biofuel crops. This zoning was based on the exclusion of land currently is use for dense and

[3] Proposals that CEPAGRI recieves are for projects of more than 1,000 hectares. Proposals for projects of less than 1,000 hectares are analysed at the Province level (see also section 2.6).

open forest, production forest, forestry plantations, mangroves, protected areas, currently cultivated areas (annual and perennial), land in use of communities and land without land cover like bare land, dunes, river beds etc)[4].

All Agricultural investment projects (including bioenergy projects) require approval to obtain a DUAT (Direito de Uso e Aproveitamento de Terra, land use right). The following rules are applied:

- Projects <1000 ha: the opinion of the district and province authorities is sufficient to obtain a DUAT
- Projects between 1.000 and 10.000: CEPAGRI, a department of the ministry of Agriculture and the Investment Promotion Centre (CPI) part of the ministry of Planning and Development emit their opinions of the projects and the ministry of Planning and Development decides on the approval of the investment project and the ministry of agriculture decides on the attribution of the DUAT
- Projects >10.000 ha: CEPAGRI and CPI emit their opinions and the Council of Ministers decide on the approval of the Project (investment project and DUAT)

At this time, projects can only be approved when the crop of choice is in line with the biofuel strategy (only sugar cane and sweet sorghum for ethanol and jatropha and coconut for biodiesel).

2.7 Drafted sustainability criteria Mozambique

In Table 3*:* the sustainability criteria for biofuels in Mozambique are listed. This is version 0 which was drafted in March 2010 and discussed with stakeholders in May 2010.

Table 3. Sustainability criteria for biofuels in Mozambique based on Draft Version 1 of the Mozambican Biofuel Sustainability Framework October 2010 – Regional Workshops.

Principle		Criteria	
1	**Legalities**		Biofuel operations shall respect all applicable laws, procedures, regulations and rights.
		1.1	All biofuel operations obliged to comply with Project Application1 and Land Acquisition Procedures2 (Circular No. 009/DNTF/07) shall show compliance with the biofuel sustainability criteria as presented in this framework.
		1.2	Biofuel operations shall respect Mozambican policies, strategies, laws and all customary and informal rights.
		1.3	Biofuel operations shall respect existing laws and customary rights related to the use of, and access to land, water and other

[4] The zoning exercise was performed by DNTF (Direçao nacional de Terras e florestas) of the Ministry of Agriculture and IIAM (Instituto de Investigação Agrária de Moçambique). A lot of parties have articulated their critique on the method and assumptions used for this zoning exercise. Most important point of critique is that the scale level of 1:1000000 and the accuracy of the GIS maps used is not sufficient to indicate whether land is available or not. A new zoning exercise is being undertaken to increase the resolution of the map (1:250 000) and to try to cross check data from different sources.

			natural resources
		1.4	Biofuel operations shall not violate human and labour rights
2	**Social responsibility**		Biofuel operations shall contribute to local development
		2.1	Community consultation shall be based on free, prior, and informed consent, through a consensus-driven and well-documented process
		2.2	Biofuel operations shall contribute to local socioeconomic development
		2.3	Biofuel operations shall respect social and cultural rights and practices
		2.4	Biofuel operations shall minimize risks for public health
3	**Energy security**		Biofuel operations shall contribute to energy security
		3.1	Biofuel operations shall contribute to the diversification of the Mozambican energy matrix.
		3.2	Biofuel operations shall contribute to energy transition.
4	**Macro-economic benefits, and economic and financial viability**		Biofuel operations shall result in macro-economic benefits, and be economically and financially viable.
		4.1	Biofuel operations shall create benefits at the macro-economic level.
		4.2	Biofuel operations shall be economically and financially viable
5	**Food security**		Biofuel operations shall not compromise local food security.
		5.1	Biofuel operations shall not compromise local food security by maintaining the availability of, and access to staple food as compared to before the biofuel operations was established.
6	**Agricultural productivity**		Biofuel operations shall contribute to improved agricultural productivity
		6.1	Biofuel operations shall continuously improve agricultural and industrial productivity and the effective use of resources.
		6.2	Biofuel operations shall facilitate technology transfer and knowledge sharing to enhance agricultural productivity.
7	**Environmental protection**		Biofuel operations shall reduce the risk of environmental degradation
		7.1	Biofuel operations shall contribute to the continuous reduction of GHG-emissions as compared to fossil fuels4.
		7.2	Biofuel operations shall avoid negative impacts on biodiversity, ecosystem functions and services, and maintain the conservation values existing on the land.
		7.3	Biofuel operations shall minimize negative impacts on water availability and quality
		7.4	Biofuel operations shall minimize negative impacts on water availability and quality
		7.5	Biofuel operations shall carry out an Environmental Impact Assessment (EIA) if required by Mozambican law.

The sustainability framework has been designed to be integrated in the governments Project application and land acquisition process (Circular No 009/DNTF/07). Small producers shall not be concerned by the sustainability framework (Schut et al, forthcoming, personal communication CEPAGRI).

2.8 Relation sustainability criteria Mozambique and EU

As the EU has set mandatory blending targets for biofuels, Europe provides a market for biofuels (Arndt et al. 2010). In order to develop a sustainable and viable large scale bioenergy sector, it is recommended to comply with both Mozambican and

European sustainability criteria (EC 2009). For export to the Netherlands it is important to comply with the mandatory sustainability criteria in the EU Renewable Energy Directive. Whereas the sustainability criteria of Mozambique are mainly focused on the promotion of positive socio-economic impacts, the European sustainability criteria are primary focused on GHG emission reduction and prevention of negative environmental impacts.

3 Land availability for bioenergy production

3.1 Introduction

The objective of this Chapter is to assess the potential of sustainable bioenergy production in Mozambique up to 2030. As dedicated bioenergy crops (including tree species) are assumed to be the main part of bioenergy supply (Smeets *et al.* 2007) (and not residues), land availability for energy crop production is one of the main determinants for bioenergy potentials.

Global bioenergy potential studies have indicated high techno-economic bioenergy production potentials in the SADC[5] regions of sub Saharan Africa (Hoogwijk *et al.* 2005; Smeets *et al.* 2007; 2009). Mozambique is considered to be a promising region for biomass production within Southern Africa because of the potential availability of land (Smeets et al. 2004; Namburete 2006) and the favourable environmental conditions for agricultural production (INE 2003; Batidzirai et al. 2006).

There are some studies that assessed the potential land availability for energy crop production in Mozambique (Batidzirai et al. 2006; Econergy 2008; Watson 2011)
Batidzirai et al (2006) assessed the technical biomass energy potential in Mozambique, production costs and the logistic options for Mozambique to produce biomass and biofuels for the export market using a bottom up approach. This study confirmed the large techno-economic potential of bioenergy production for both domestic supply and exports at relatively low cost, taking into account land requirements for future food production (including feed crop production and grazing).

In 2007, the Mozambican Ministry of Agriculture and the Ministry of Energy commissioned a study supported by the World Bank and The Embassy of Italy in Maputo to assess the potential of biofuels in the country. In this study, the potential competitiveness of Mozambique's biofuels production in the domestic, regional and international biofuels markets was assessed (Econergy 2008). Using three scenarios, Econergy assessed first generation bioethanol and biodiesel production potential based on different levels of incremental land use and a set of assumptions.

For the cane resource network for southern Africa (CARENSA), Watson (2010) conducted a research on the potential suitable land for sugar cane production in 6 SADC countries, including Mozambique, using GIS data on soil and climate. Watson concluded that Mozambique offers the best prospects for expanding sugar cane and that 2.3 million hectares of land (80.1% of country's arable land) are suitable and available for sugar cane production.

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[5] Southern African Development Community

The national inventory on land availability for agricultural investments was performed in 2008. The zoning exercise is an initiative of the Ministry of Energy, Ministry of Agriculture, Ministry of Environmental affairs and the Ministry of Planning and Development. The technical development of the zoning was commissioned in 2008 and was performed by DNTF, IIAM and CENACARTA (DNTF et al. 2008). They have developed GIS zoning maps for agriculture in Mozambique. In this zoning exercise, land availability and land suitability for arable crops was assessed.

The spatial scale level of these maps is 1: 1 000 000 000. Several land use functions were excluded: open and closed production forest, national parks and reserves, protected forest, concession forest, mangroves, agricultural land (for annual crops and perennial crops), combined agricultural forest areas and non available land (like villages, river beds, dunes etc) and Direito de Uso e Aproveitamento dos Terros (DUATs) (land use rights) were excluded.

In Table 4, the studies and their estimated potential available land are summarized.

Table 4: Studies about the potential available land for energy crop production in Mozambique

Study	Potential available land	Potential land for energy crops	Time frame	Focus of study	Spatially explicit
	Mha	Mha	Year	Crop	Level of analysis
Batidzirai 2006	45	6.02	2015	Eucalyptus	Province level
Econergy 2008	10.5-19	10.5-13.2	Current	1st generation crops	National level
Watson 2010		2.34	Current	Sugar Cane	GIS 1 km^2 grid
DNTF 2009	6.97		Current	Agri investment projects	Polygon 1:1,000,000

The range in estimated land availability of the studies summarised in Table 2, is a result of differences in objectives, approaches, timeframes, methodologies and resolutions of the studies. Although all these studies provide valuable information, they do not take dynamics of land use into account and therefore provide no information on the development in amount and spatial distribution of land availability over time.

In this chapter, the potential land availability for bioenergy crops now and in the future is assessed in a spatially explicit way, taking into account scenarios for developments that influence land use and considering restrictions from a physical and sustainability point of view. In the subsequent sections, the method to assess the land availability will be discussed. For the purpose of this report, the description of the methods, data, results and uncertainties has been condensed. The paper by van der Hilst et al (2011) provides more detailed information.

3.2 Current land use

In order to assess the current and future land availability for bioenergy crops, current land use needs to be assessed. A large part of the country is covered by natural vegetation (81%) consisting of dense forest, open forest, shrub land and grassland. 16% of the country is (mosaic) cropland, but only a small part is actually cultivated as the majority is under shifting cultivation (see Figure 4). Although just a couple of land use classes are identified here, the diversification within these classes is rather large. Statistics on land use vary to a great extent; this is due to differences in measurement methods, differences in time of measurement (both inter annual as inter seasonal), and to inconsistencies in interpretation and classification.

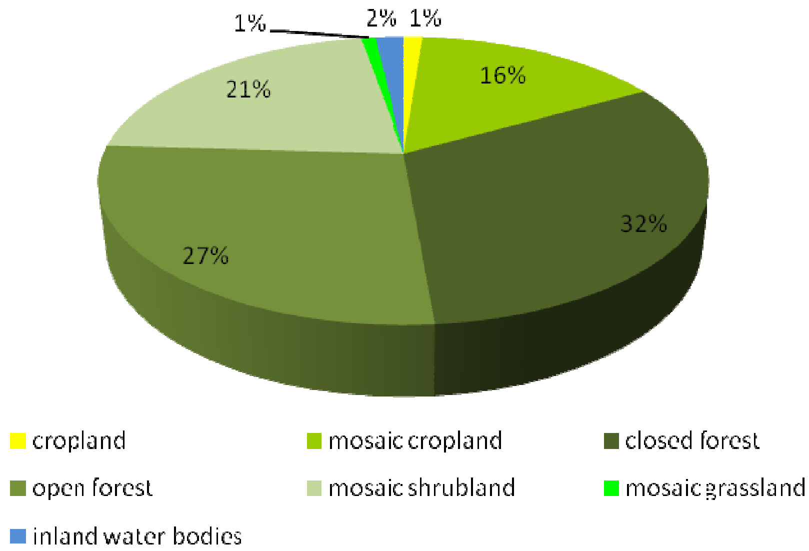

Figure 4: Land cover of Mozambique (based on data from Globcover)

3.3 Scenario approach

Land availability for energy crop production depends on the dynamics of other land uses. Evolution in drivers for land use change is highly uncertain. As prediction of land use developments is impossible, scenarios are an important tool for exploring potential long term developments of land use change. This has been demonstrated by Stengers *et al* (2004), Westhoek *et al* (2006), de Vries (2007) and Hoogwijk *et al* (2005; 2009).

In this study, the narratives developed for the SRES[6] scenarios of the IPCC[7] (Nakicenovic et al. 2000) were translated to Mozambique specific scenarios to develop a consistent set of assumptions for the assessment of future land availability for dedicated energy crop production for Mozambique. Two highly divergent storylines were developed to illustrate the broad scope of possible future developments: A Business as usual and a progressive scenario.

[6] Special Report on Emission Scenarios

[7] Intergovernmental Panel on Climate Change

The high uncertainty in key drivers of land use change like demographics and GDP would justify the use of scenarios that include divergent developments in these key drivers. However, in this study it is assumed that it is more transparent to keep main drivers (population, GDP, diet) constant between scenarios and that a sensitivity analysis on these key drivers is the most suitable tool to address the uncertainty of these parameters in both scenarios. This implies that GDP, diet and Self Sufficiency ratio (SSR) will change over time but that the rate of change is equal for the two scenarios. Therefore, the demand for food is the same for both scenarios but the way this demand is fulfilled is subject of scenario development. The storylines will be used to explore possible developments in policy and technological change.

In the following paragraphs, the assumptions on the developments in the key drivers for land use change will be quantified for the two scenarios.

3.3.1 Business as usual scenario

A business as usual (BAU) scenario implies a continuation of current trends in the development of key drivers of land use change. In this scenario it is assumed that bioenergy production is implemented in an environment without major changes in policies, technologies and current practices.

Although food demand increases significantly, only a modest increase in yield and cropping intensity is assumed in line with current agricultural productivity trends. It is assumed that the agricultural sector remains dominated by subsistence farming and that farmers have limited access to inputs and improved agricultural practices. The increased demand for food and the low productivity growth results in an increased claim on land for food production.

Due to an increase in caloric intake per capita and an increase in meat and dairy consumption, the demand for animal products increases. In the BAU scenario the efficiency of the livestock sector remains low. A modest growth feed conversion efficiency is projected towards 2030. Due to a partial shift from pastoral systems to mixed systems the overall efficiency of the livestock sector increases moderately. It is assumed that there is a shift towards more efficient cooking. The adoption of improved stoves and alternative fuels will reduce the demand for fuel wood and charcoal per capita. In the business as usual scenario, it is assumed that no additional priority is given to environmental concerns and therefore no additional policies, regulation and enforcement is implemented for nature conservation. In the BAU scenario, we assume that this will result in a continuation of current trends in deforestation.

3.3.2 Progressive and sustainable scenario

A more progressive and sustainable scenario has been developed to reflect the Mozambican ambition for more advanced development. This scenario implies a discontinuation of current trends in key drivers of land use change. It is assumed that bioenergy production is implemented in a controlled and sustainable environment. The progressive scenario projects a commercialization of the agricultural sector with a high rate of technological change which results in more advanced and productive agricultural practices. In this projection, it is assumed that an increasing part of the farmers has access to improved seeds, fertilizers and pesticides and to knowledge by means of a widespread network of extension workers and that local markets and related institutions are increasingly facilitating trade. This is reflected in higher yields and higher cropping intensities. Although the demand for food crops is the same as the BAU scenario, the increased agricultural productivity results in a reduced claim on land. In the progressive scenario, higher efficiencies in livestock production can be achieved, due to higher feed conversion efficiencies in both pastoral and mixed systems and trough a more profound shift from pastoral to mixed systems. It is assumed that there will be a shift towards more efficient means of cooking. The adoption of improved stoves and alternative fuels in the Progressive scenario is assumed to be much higher compared to the BAU scenario. It is assumed that in the progressive scenario there is more emphasis on environment and nature conservation. It assumes additional policies, regulation and enforcement is implemented to prevent further deforestation.

Table 5, provides an overview of the main characteristics of the Business As Usual (BAU) and the Progressive scenario developed in this study.

Table 5: Developments of key drivers of land use change (LUC) in two scenarios

LUC drivers	BAU	Progressive
Population	High increase	
Diet	Modest increase	
Self Sufficiency Ratio	Current levels	
Technological change	Modest increase	High Increase
Agricultural sector	Self subsistence	Shift towards commercial
Crop intensity	Modest increase	High Increase
Agricultural productivity	Modest Increase	High increase
Livestock production system	Mainly pastoral	Mainly mixed
Feed conversion efficiency	Modest increase	High increase
Environmental consciousness	Low	High
Deforestation	Current rate	Prevention

3.4 Methodology

In order to project the dynamics in future land use, the developments of the main drivers for land use change need to be assessed. The **demand** for food and materials is related to development in population growth, GDP, dietary changes and self sufficiency ratio (extent to which domestic supply meets domestic demand) and is assumed to develop in the same rate in the two scenarios. **The productivity** of the agricultural sector and is a key factor for the land requirements to meet the total demand for food, animal products and materials. The **land requirements** to meet the crop and pasture demand is also dependent on the land allocation: if very suitable soils are allocated to cropland less cropland is required to produce the total demand, if marginal soils are used for crop production more land is required. The forest requirements depend on the developments of demand for wood products and are limited by the enforcement of forest protection laws. **The spatial allocation** of land required for the production of food, wood and animal products depends on the relative suitability based on various factors of the location for the various land use types.

3.4.1 Development of demand

According to the FAO, the population increased from 13.5 million people in 1990 to 22.9 million 2009 (average annual growth rate of 2.2%). The proportion of rural population decreased in this time frame from 80% to 62%. In this study, the population growth rate of the medium scenario of the UNDP was used for both the BAU and the progressive scenarios (UNDP 2008b). The annual growth rate of 2.3% in 2000-2015 and 1.8% in 2015-2010 is in line with the historical trend. It is assumed that the proportion of the population living in urban areas increases from 38% now to 54% in 2030 (FAO 2010b).

Since the end of the civil war, large economic reforms have implemented in Mozambique which resulted in high GDP growth rates. The average annual growth rate between 1994 and 2009 was 7.7% but fluctuated to a large extent (1.5-12.6%). Due to dynamic developments, future GDP growth rates are hard to estimate. In this study, the outlook provided by IMF up to 2015 was used and was extrapolated linearly to 2030. This results in an average GDP growth of 5.6%, and an average increase in GDP per capita of 3.4% (IMF 2010). The GDP growth rate is assumed to be equal for the both scenarios.

Although last decades show an increase in caloric intake per capita -, a large number of people still suffer from malnutrition. Based on the time series 1992-2008 on production and consumption in FAOSTAT, production figures from the Censo (INE 2003) and the FAO outlooks for Mozambique and Sub Saharan Africa, an estimation of the kcal intake per capita and dietary composition for 2015 and 2030 was made. An average annual increase in Kcal capita-1 of 0.6% up to 2015 and 0.5% in the timeframe 2015 and 2030 is assumed. In addition, it is expected that increase in per capita GDP is reflected in increased animal product consumption towards 2030 (to 4%).

The total wood demand can be differentiated in demand for fuel wood (93%) and demand for industrial round wood (7%) (FAO 2010c). The main part of the logged industrial round wood is currently exported. The average fuel wood consumption is estimated at 1.2 m^3 per capita per year in urban areas compared to 1.0 m^3 per capita per year in rural areas (Cuvilas et al. 2010). - Developments in fuel wood consumption are assumed to be related to the proportion of the population living in urban areas, the developments in GDP and the rate of adoption of improved stoves. This results in an increase in fuel wood demand in the BAU scenario based on GDP growth, an increase in urban population and only a modest shift towards improved stoves. In the progressive scenario it is assumed that the shift towards new fuels and improved stoves can balance out the increase in demand due to GDP and population growth which implies that the demand will remain at current level. For both scenarios it is assumed that the demand for industrial round wood remains at today's level. In this study, a distinction is made between the wood harvest that is done on a sustainable basis and the wood demand that results in deforestation. The proportion of demand that results in deforestation depends on the proportion of logging that is defined as illegal, the proportion of the illegal harvesting that takes place in forest (and not in other woodland), and the proportion of illegal harvest in forest that results in deforestation. It is estimated that 50-70% of the total round wood production is clandestine (Nhancale et al. 2009) and that 95% of the fuel wood is illegally harvested. It is assumed that in the BAU scenario, the proportion of wood that is illegally harvested and results in deforestation will remain constant over time. For the progressives scenario it is assumed that environmental and protective laws are enforced to an extent that no deforestation will take place after 2010.

The self sufficiency ratio (SSR) reflects the extent to which domestic supply meets domestic demand and includes exports (thus when domestic supply exceeds domestic demand the SSR >1). There are large differences in the SSR of various crops. For food and materials, it is assumed that for both scenarios SSR ratios will continue to develop according historical and current trends and are based on the FAO outlook. Because of the low densities and non-commercial character of fuel wood it is assumed that SSR ratio of fuel wood is 1 and remains at that level for both scenarios. The majority of the industrial round wood production is currently exported (80% to China). It is assumed that in both scenarios the domestic demand is continue to be met and that export rates will remain on current levels

3.4.2 Development in Productivity

The land required to meet the demand for crops, animal products and materials depend on the agricultural productivity. Despite the relatively advantageous climate and soil conditions, current agricultural productivity is very low in Mozambique. The agrarian sector is almost entirely dominated by smallholders (95% of the total agricultural GDP) which generally attain a very low productivity (World Bank 2006). The most common range of cultivated area of these small scale producers is 0.5-1.4 ha in shifting cultivation. The use of improved seeds (5-10%), fertilizers (3.9%), pesticides (4.5%), irrigation (5%) and animal or mechanical traction (11% and 3%) is very low (Bias *et al.* 2003; INE 2003; World Bank 2006)(Donovan 2010). Both a lack of financial resources and a lack of (access to) market cause the low penetration of inputs (Amane 2010; Kolijn 2010; World Bank 2006). In addition, the lack of knowledge (amongst others due to low enrolment in education, discontinuation of education during the war, low knowledge transfer between generations, high illiteracy rates, low levels of organization and little excess to extension workers) prohibits adoption of new agricultural practices and productivity increase. There is little incentive to increase production because of a lack of market, a lack of a viable market price and a lack of storage capacity. Due to a low level of organization, the position of the individual farmer is quite fragile.

Although there is much room for improvement, historical trend show that increases in agricultural productivity are hard to accomplish. In the BAU scenario, it is assumed that in line with historical trends the adoption of technological improvements is relatively slow. The figures on yield improvements up to 2030 of the FAO outlook are used to estimate future productivity in the BAU scenario. The FAO outlook is adapted by taking into account more recent figures in productivity of FAOSTAT. The cropping intensity (the percentage of the arable land that is harvested) is assumed to increase moderately from 60% now towards 66% in 2030. The progressive scenario describes a development towards a more productive and more sustainable agricultural sector in which a shift from mainly subsistence towards a more commercial agricultural sector is achieved. It is assumed that the implementation of actions, programs, measures, and policies articulated in the strategic plan for agricultural development (Republic of Mozambique 2010) and the individual action plans for poverty reduction (Republic of Mozambique 2006) and development of the agricultural sector (Republic of Mozambique 2007) result in a supportive environment for growth in the agricultural sector. In this scenario supportive conditions in terms of health care, education and infrastructure are increasingly developed. In addition, establishment of markets and financial institutions in rural areas will increase trade and access to capital and inputs. In the shift towards commercial farming, current practices on shifting cultivation will progressively be abandoned. It is assumed that the adoption of more advanced technologies results in higher yield levels, higher cropping intensities and better conservation of agricultural soils. Projected productivity figures are based on literature (Jeje *et al.* 1999; Uaiene 2004; Magaia *et al.* 2005; Coughlin 2006; Zavale *et al.* 2006; Buss 2007; Republic of Mozambique 2010), and personal communication (Kolijn 2010; Uaiene 2010; Plexus 2010; Madal 2010) and based on currently and historically achieved yield levels in the region (FAO 2010b).

The efficiency of livestock production depends on the type of production system, the feed composition and the feed conversion efficiency. Pigs and poultry/eggs are produced in mixed systems in which feed is supplied from crops and scavenging/residues. Cattle and goats are currently mainly produced in pastoral systems (mainly grazing). For the BAU scenario, a modest shift from mainly pastoral to increasingly mixed systems for cattle and goats and muttons is assumed in accordance with the FAO outlook (FAO 2003) and the figures assumed for sub Saharan Africa by Smeets *et al.* (2007) and Bouwman *et al.* (2005). Feed composition (fraction of feed supplied by grazing, scavenging, residues, feed crops) per production system is not expected to change over time. However, due to a shift in production system, an increase in the contribution of feed crops and residues to animal feed is expected. The feed conversion efficiency is assumed to increase over time and is higher for mixed systems compared to pastoral systems. For the progressive scenario, it is assumed that the shift towards mixed systems is more profound. In addition, in the progressive scenario the feed composition and feed conversion efficiencies in both pastoral and mixed systems are assumed to approach the composition and efficiencies of pastoral and mixed systems of Eastern African countries in 2030. The development of the distribution of the production over pastoral and mixed systems, of the feed composition within each system and of the feed conversion efficiency of each system determines the development in feed requirements to meet animal product demand and is based on Bouwman *et al.* (2005), FAO (2003) and Smeets *et al.* (2007).

3.4.3 Development in Land requirements

In the model, the land requirements for crop production depend on the total demand for crops and the efficiency of production. The productivity of crop production also depends on the suitability of the location of production and is therefore dependent on land allocation for crop production. The land requirements for animal production depend on the total feed demand, the feed composition and the efficiency of feed production. The land required for grazing depends on the total grass demand (based on the total feed demand and the fraction of feed that is supplied by grass) and the carrying capacity of pastures. The carrying capacity is defined as the potential number of animal units that a given area of pasture can support on a sustainable basis (Timberlake *et al.* 1986). The carrying capacity depends on the productivity and therefore location of the pasture and ranges from 0-0.68 head/ha. The area of forest that is sacrificed depends on the total demand for wood, the proportion of the demand that is met by illegal harvesting, the proportion of illegal harvesting that takes place in forests, the proportion of illegal harvesting of forest that results in deforestation and the productivity of the forest. As there is a high spatial heterogeneity in the productivity of forest, spatial allocation of deforestation is key for the total amount of land that is deforested. The total amount of land required to meet the demand for food, wood and animal products is highly related to the location of land use changes.

Land use changes are the result of complex interaction between human and biophysical driving forces that act over a wide range of temporal and spatial scales (Verburg *et al.* 1999). Several methodologies and models have been developed to simulate and explore land use change (Veldkamp *et al.* 2001).

The land use map of GlobCover (ESA GlobCover Project 2005) was used as the starting point of the spatial assessment of current land use. The grid cell size of 1000m was selected for practical modelling reasons (this is well beyond the initial resolution of ±300m). In order to develop a dynamic spatial-temporal land use change model, the number of land use classes was narrowed down to 10.

The projected developments in demands need to be translated in spatially explicit land use changes. The land use map of 2005 was calibrated on the statistics of the demand for crops and livestock grazing of 2005. The year 2005 was used as a starting point for modelling the land use change because the GlobCover map of 2005 was the most recent detailed land use map available and statistics on production and consumption are updated up to 2008. As 3–year averages of production and consumption are used to correct for weather related inter-annual fluctuations, the most recent relative reliable figures are dated from 2007. That means that there is only data available for two year after the year of calibration.

The proportion of the demand (crops/grazing) met by a specific land use category (pure cropland / mosaic cropland-pasture / mixed pasture) was determined based on current distributions and on scenario projections. The productivity of a specific land use category was determined by combining the maps of land use with productivity maps for crops, pasture and forest. The calibrated land use map for 2005 was the starting point for the modelling of land use changes towards 2030. The allocation of a specific land uses class to a certain location is done based on the 'suitability' of a the location for the specific land use. This 'suitability' is determined by several spatial explicit driving forces for land use change. In this study, both environmental and socio-economic indicators are taking into account. The driving forces are specific for each land use class. For every driving force, the direction of relation (positive or negative), the shape of correlation (exponential, linear, inversely related etc), the friction (in case of exponential function), the maximum distance of effect and the relative importance of the driver for land use change of the particular land use category was determined. In Table 6, the drivers for all land use classes and their characteristics are depicted.

Table 6: Characteristics and weights of the driving forces of land use changes

Land use type	nr	driving forces	direction	distance	relation	fr	weights
cropland	1	nr of neighbours same class	positive	linked cell	linear		0.20
cropland/grassland	2	distance to roads	negative	5 km	inv proportional		0.10
	3	distance to water	negative	10 km	inv proportional		0.10
	4	distance to cities	negative	50 km	inv proportional		0.10
	5	yield	positive		exponential	1	0.20
	6	population density	positive		proportional		0.20
	9	current land use					0.10
							1.00
pasture	1	nr of neighbours same class	positive	Linked cell	linear		0.30
	2	distance to roads	negative	5 km	inv proportional		0.05
	3	distance to water	negative	10 km	inv proportional		0.25
	4	distance to cities	negative	50 km	inv proportional		0.05
	5	yield	positive		exponential	1	0.10
	6	population density	positive		proportional		0.05
	7	cattle density	positive		proportional		0.20
	9	current land use					0.10
							1.00

Land use type	nr	driving forces	direction	distance	relation	fr	weights
cropland pasture	1	nr of neighbours same class	positive	linked cell	linear		0.20
	2	distance to roads	negative	5 km	inv proportional		0.10
	3	distance to water	negative	10 km	inv proportional		0.10
	4	distance to cities	negative	50 km	inv proportional		0.10
	5	yield	positive		exponential	1	0.15
	6	population density	positive		proportional		0.15
	7	cattle density	positive		proportional		0.10
	9	current land use					0.10
							1.00
deforestation	2	distance to roads	negative	5 km	inv proportional		0.30
	4	distance to cities	negative	50 km	inv proportional		0.20
	6	population density	positive		proportional		0.30
	8	distance to forest edge	positive		exponential	1	0.20
							1.00

Notes:

1 The driver 'no of neighbours in the same class' in Table 6 refers to the amount of grid cells in the immediate surrounding that are already part of the particular land use class. For example: for the land use change towards cropland it counts the cells in the immediate surrounding that are already cropland. As a result, cropland is more likely to expand on the edges of cropland instead of a random location. As land use change over time, the number of neighbouring cells in the same class have to be assessed for each individual time step (every year up to 2030).

2 The distance to roads is based on the map of road infrastructure provided by the Administração Nacional de Estradas (ANE) (national administration of Road infrastructure). Only primary and secondary roads were selected for this assessment. It is assumed that land close to roads are more susceptible to land use change as these areas are more accessible for the population. Therefore it is expected that the pressure on land is more profound in these areas. Including this driver assures that areas close to road infrastructure have a higher probability to change to man-made land use types compared to more remote areas.

3 The distance to water resources was calculated based on the map provided by the National Directorate of Land and Forests(DNTF) in which the main water resources (rivers and lakes) were mapped. It is assumed that pasture areas and cropland are more likely to expand in areas with access to water compared to areas without water resources.

4 The distance to cities expresses the pressure on land from urban areas on the surroundings. In this assessment only the province capitals were included (based on the map provided by ANE).

5	The yield map provides information of the relative suitability of land for a specific land use. For cropland and pasture it provides information on the attainable yield. This driver ensures that the expansion of cropland or pasture is more likely to expand in areas which have high potential yield levels compared to areas which are not suitable for crop production or grazing. The relative yield map is derived from FAO and IIASA (FAO *et al.* 2000) and the biomass density map that provides information of the amount of wood that could be extracted from forest is provided by DNTF.
6	The general pressure on land related to population is expressed in the driving force of population density. The map of population density was retrieved from FAO GeoNetwork (FAO 2000). Although progressive urbanization is assumed towards 2030, no estimations were made about shifts in spatial distribution of the population. These two drivers ensure that expansion of cropland and pasture and deforestation is more likely to occur close to large cities and in areas with a high population density
7	The cattle density is an important driver for the expansion of pasture land. As both goats and cattle have grazing requirements, the spatial distribution of both species influence the spatial distribution of grazing area. In order to develop a general map of the spatial distribution of grazing animals, the cattle and goat density maps of the FAO and IIASA (FAO *et al.* 2000)were combined in a weighted summation based on the ratio of feed requirements of cattle and goats. This driver ensures that expansion of pasture areas is more likely to occur in areas with a high density of grazing animals.
8	The yield map provides information of the relative suitability of land for a specific land use. For cropland and pasture it provides information on the attainable yield. This driver ensures that the expansion of cropland or pasture is more likely to expand in areas which have high potential yield levels compared to areas which are not suitable for crop production or grazing. The relative yield map is derived from FAO and IIASA (FAO *et al.* 2000) and the biomass density map that provides information of the amount of wood that could be extracted from forest is provided by DNTF.
9	The driver 'current land use' consist of a matrix in which is depicted which a land use type can be converted to another and the relative probability of this conversion. For example: it is stated in the matrix that mixed cropland-grassland is relatively easy converted to pure cropland but that forest is more difficult to convert. This matrix is also used to exclude some land use changes. For example urban areas or bare eras can't be converted to other land use classes.

For each land use, a priority grid was constructed based on the weighted summation of the standardized maps of the driving forces. In Figure 5 , an example of the spatial joint of the driving forces is depicted.

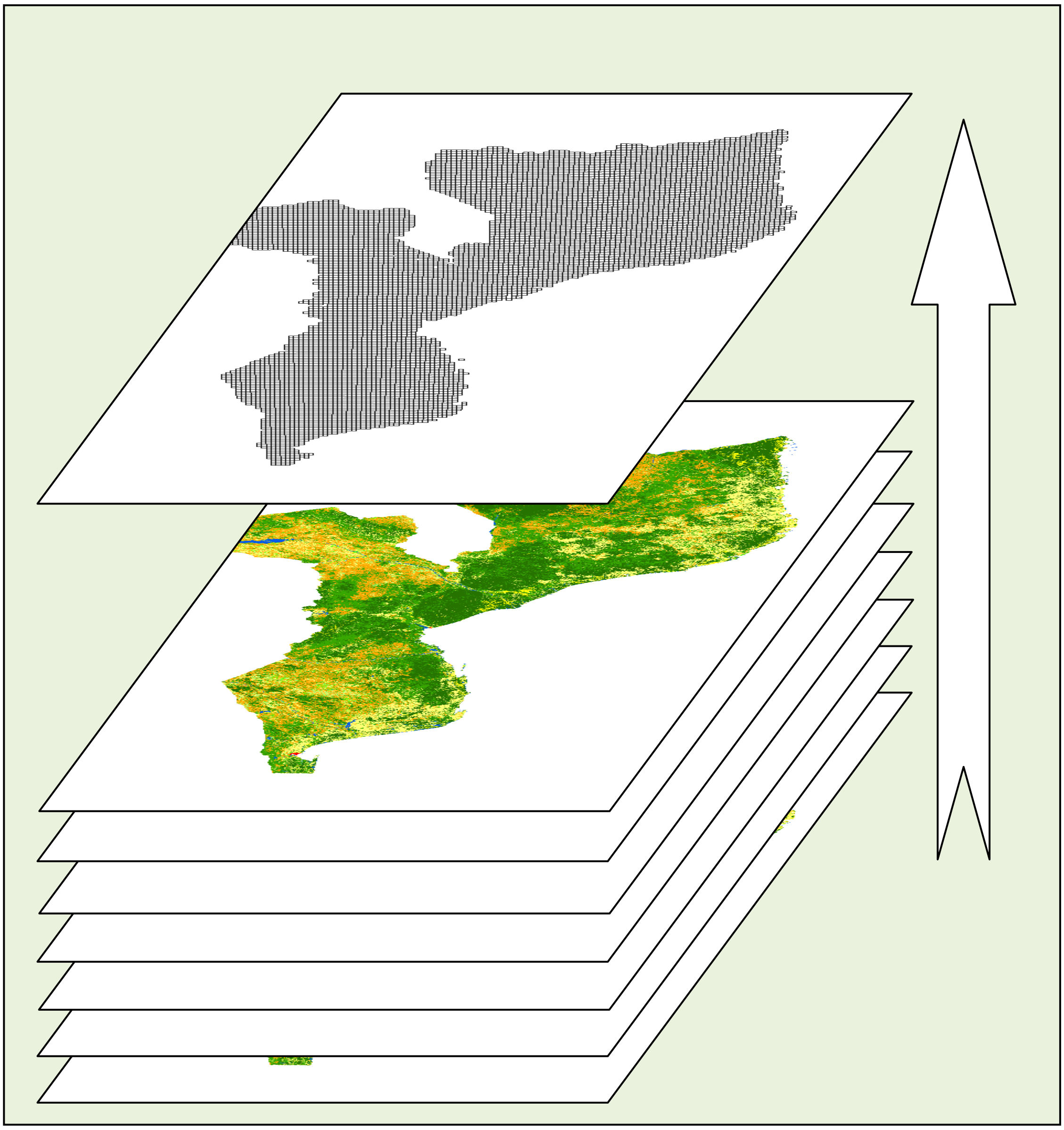

Figure 5: Standardised maps of driving forces are combined in a weighted summation to develop a preference grid for land use change for each land use category. In this example the driving forces for cropland are depicted.

In Table 7 the categories land use, land cover and physical constraints that are excluded for land use change are summarised. In addition, the (spatial) data which is used to exclude these categories in included in the table.

Table 7: Categories of excluded land use types, land cover types and physical constraints

Category	Excluded land categories	pasture and cropland	bioenergy crops	Sources of spatial data
Land use	Urban areas	√	√	(ESA GlobCover Project 2005)
	Community area		√	(DNTF 2008b)
	Infrastructure	√	√	(ANE 2010)
	Concessions		√	(DNTF 2008a)
	Land use rights (DUAT)		√	(DNTF 2008c)
	Protected areas	√	√	(DNTF 2008d)
	Cropland		√	(ESA GlobCover Project 2005), output allocation model for subsequent years
	Cropland-pasture		√	(ESA GlobCover Project 2005), output allocation model for subsequent years
	Cropland-grassland		√	(ESA GlobCover Project 2005), output allocation model for subsequent years
	Pasture		√	(ESA GlobCover Project 2005), output allocation model for subsequent years
Land cover	Forest[1]	√	√	(ESA GlobCover Project 2005), output allocation model for subsequent years
	Deforested areas[2]		√	(ESA GlobCover Project 2005), output allocation model for subsequent years
Physical constraints	Static unsuitable areas	√	√	(ESA GlobCover Project 2005)
	Steep slopes (>16%)	√	√	SRTM digital elevation data (NASA 2000)

[1] in the BAU scenario it is assumed that cropland and pasture can expand in forest areas (in line with current practices). In the Progressive scenario it is assumed that enhanced policies and increased enforcements can prevent deforestation. Therefore are forest areas excluded for land use change in the progressive scenario

3.4.4 Land use change model

In order to model future land use developments and land availability for bioenergy crops based on current land use, the projected developments in demand and productivity, the driving forces of land use change and allocation rules, a spatio-temporal model is developed based on building blocks of PCRatster Phyton framework. The PCRaster is construction framework offers a combined interface for spatio-temporal modelling and geospatial analysis (Karssenberg *et al.* 2010; PCRaster 2010). This framework was used to construct a Spatial decision support system (SDSS) that integrates simulation, uncertainty analysis and visualization for land use changes. The software package Aguila was used for the visualisation of the results. More information on the model can be found in Verstegen *et al* (2011) and van der Hilst *et al* (2011).

3.5 Results

3.5.1 Demand for food and feed

In Figure 6 , the development in food consumption per capita and the development in total crop production is depicted. The steep increase in total food production is caused by the increase in food intake per capita but more profoundly by the high population growth. The figures of 2000-2006 are based on historical trend lines, the figures for 2015-2030 are based on the outlooks on FAO (FAO 2003) on dietary changes for Mozambique.

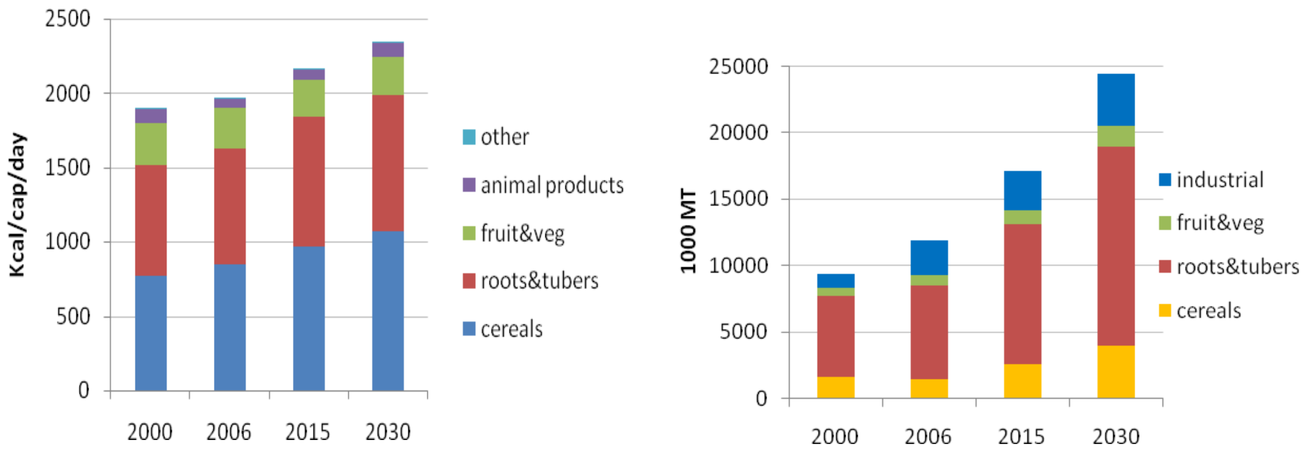

Figure 6: development of diet (in kcal per capita and in composition) (left) and total crop production (right)

In Figure 7, the feed requirements for animal production is depicted. Although the proportion of feed crops in the total feed demand is much higher in the progressive scenario due to a shift towards mixed systems, the total feed demand is much lower due to a higher feed conversion efficiency.

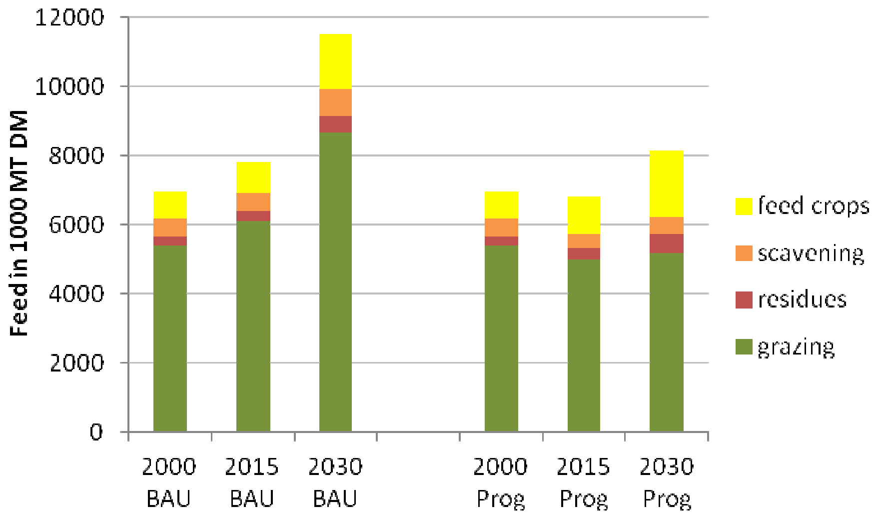

Figure 7: Annual feed requirements to meet animal product requirements

3.5.2 Land requirements for crop production

The land requirements to meet the total crop demand depend on productivity and are therefore scenario specific. In addition, as soil suitability is an important factor the allocation of cropland influence the required amount of land to a large extent. In Figure 8, the land requirements to meet total crop demand are depicted for the BAU and the progressive scenario assuming a continuation of current distribution over suitability classes. The line markers above the stacked columns indicate the total amount of land required assuming the developments in cropping intensities (area harvested/arable land).

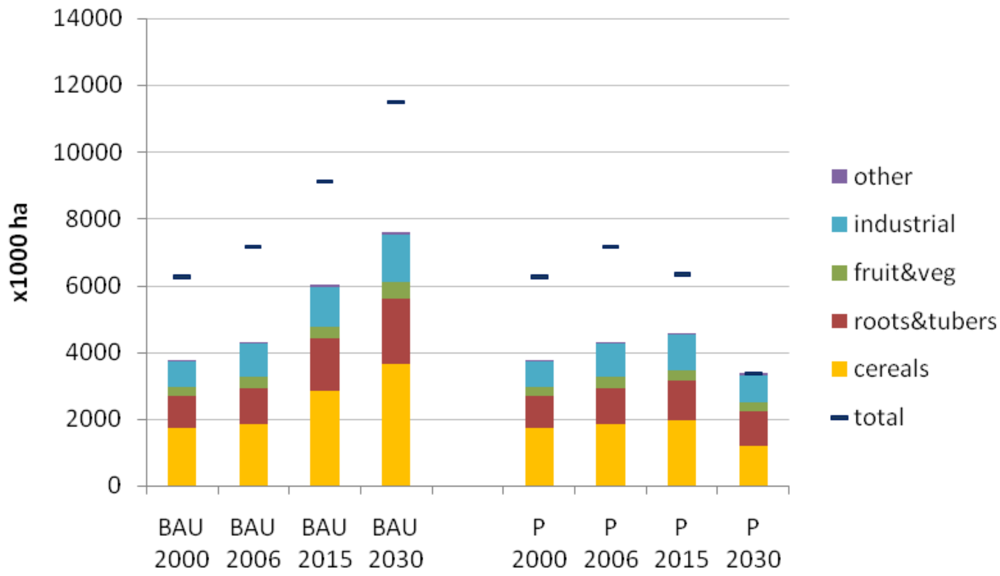

Figure 8: Total area crop production (for food, feed and non-food)

The land requirements to meet the total demand for grazing depend on the productivity of grassland and are therefore scenario specific. As in the progressive scenario the total demand for grazing declined due to a shift in feed composition and the total productivity of grassland is higher compared to the BAU scenario, the area required for grazing is much lower in the progressive scenario. In Figure 9, the land requirements to meet total demand for grazing are depicted for the BAU and the progressive scenario assuming a continuation of current distribution over suitability classes.

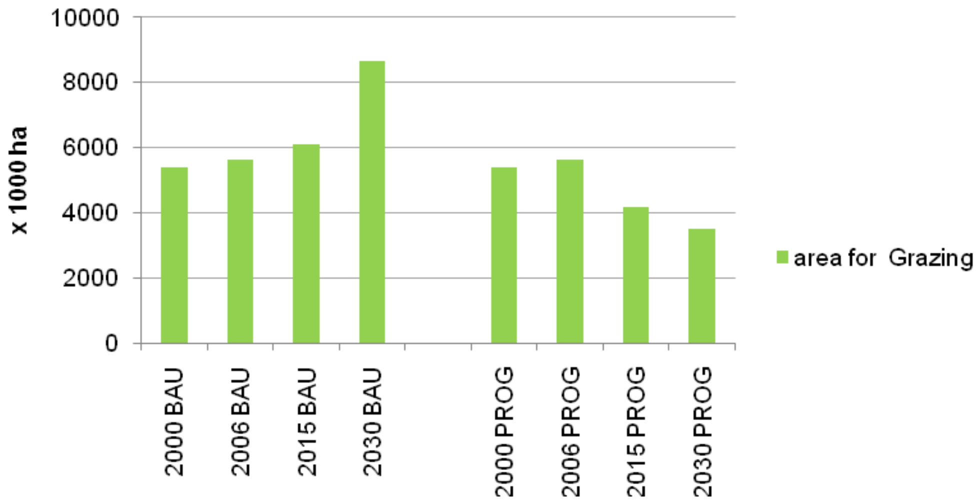

Figure 9: Area required for grazing up to 2030 in BAU and progressive scenario

3.5.3 Land availability for bioenergy crops

The land use change land requirements to meet the demands for crop and pasture and the deforestation were modelled for each time step (1 year) up to 2030 for the BAU and the Progressive scenario. In this report the results for 2005, 2015 and 2030 will be demonstrated. The map of 2005 is based on the GlobCover map of 2005. In Figure 8, the development in land use is depicted for 2005, 2015 and 2030. On the left hand side, the land use for the BAU scenario is depicted; on the right hand side the land use for the Progressive scenario. In the BAU scenario, the expansion of cropland, cropland-pasture and pasture areas over the years is apparent. This is especially true in the coastal areas and along road infrastructure. Also the continuing deforestation close to cities and road infrastructure is evident. In the progressive scenario, large crop and pasture areas are abandoned due to a more efficient production. The areas abandoned are the areas that are more remote, have a relative low population density, and have less suitable cultivation conditions. In this progressive scenario it is clear that more mosaic cropland-pasture areas are converted to pure cropland, compared to the BAU scenario. As in the progressive scenario it is assumed that deforestation is prevented form 2010 onwards, and regeneration is assumed to take 10 years, no deforested areas are visible in the projection of the progressive scenario in 2030.

Based on the land use dynamics, the developments in land availability for biofuels over time can be mapped up to 2030. In Figure 12, the land availability for bioenergy crops is depicted for 2005, 2015 and 2030 for both the BAU scenario and the progressive scenario. The red areas indicate the areas that are not available for bioenergy crops. These areas are exclude because they are in use for other land use functions like cropland, pasture but also forest and urban areas; or because they are not suitable i.e. regularly flooded areas or steep slopes. The green areas indicate the areas that are available for bioenergy crop production. In the BAU scenario the green areas are rapidly decreasing as land required for pasture and crops is expanding. In the progressive scenario, the growth in productivity exceeds the growth in demand. Therefore, the area required for crops and pasture decreases over time and the availability of land for bioenergy corps increases towards 2030.

In Figure 9 the development in available land for bioenergy crop production over the years up to 2030 is depicted for the BAU and the progressives scenario. For the BAU scenario the land availability decreases over time. For the progressive scenario, the land availability for bioenergy crop production increases because of a reduction in land requirements for pasture and cropland.

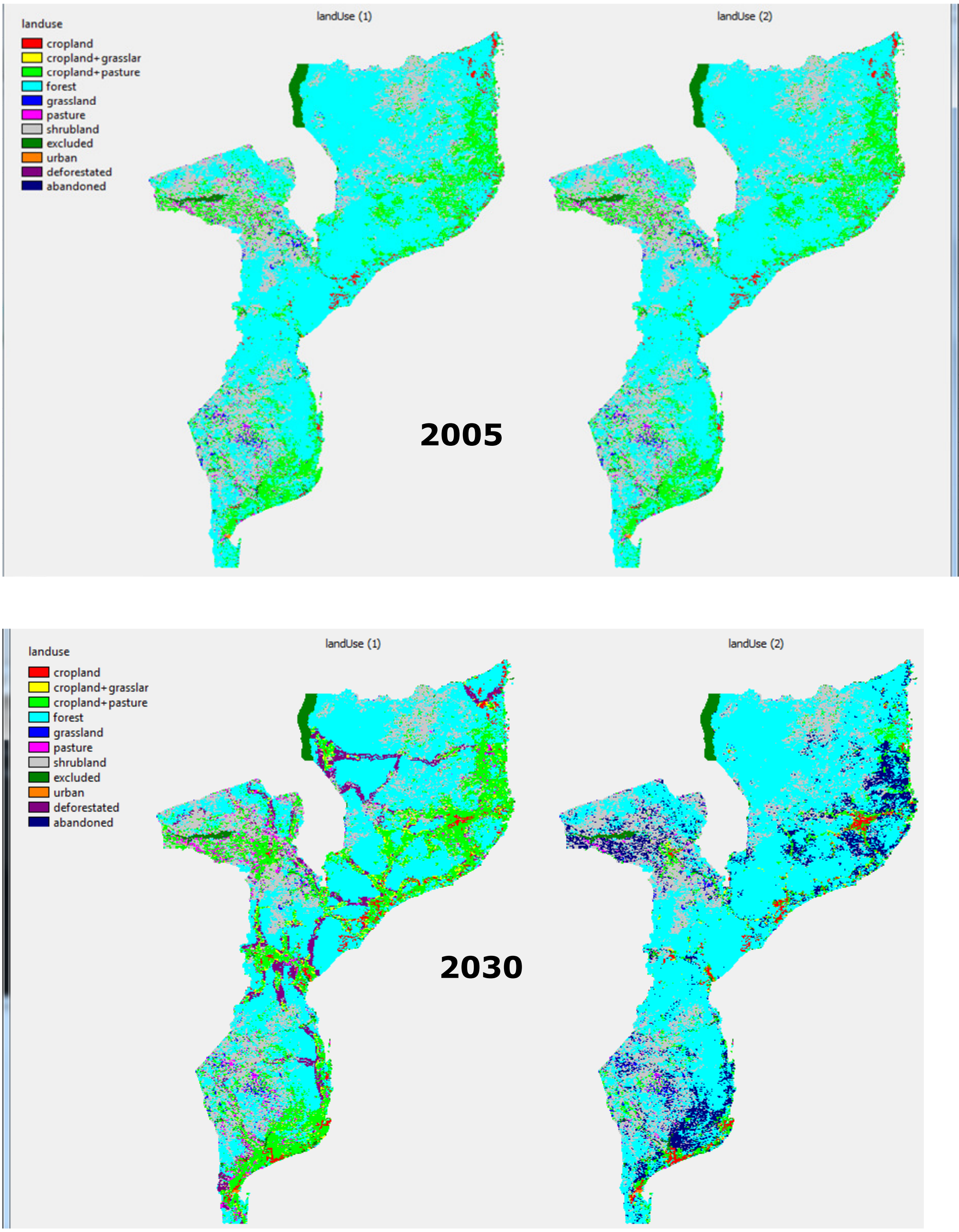

Figure 10: Land use dynamics up to 2030 for BAU (left) and Progressive (right) scenario

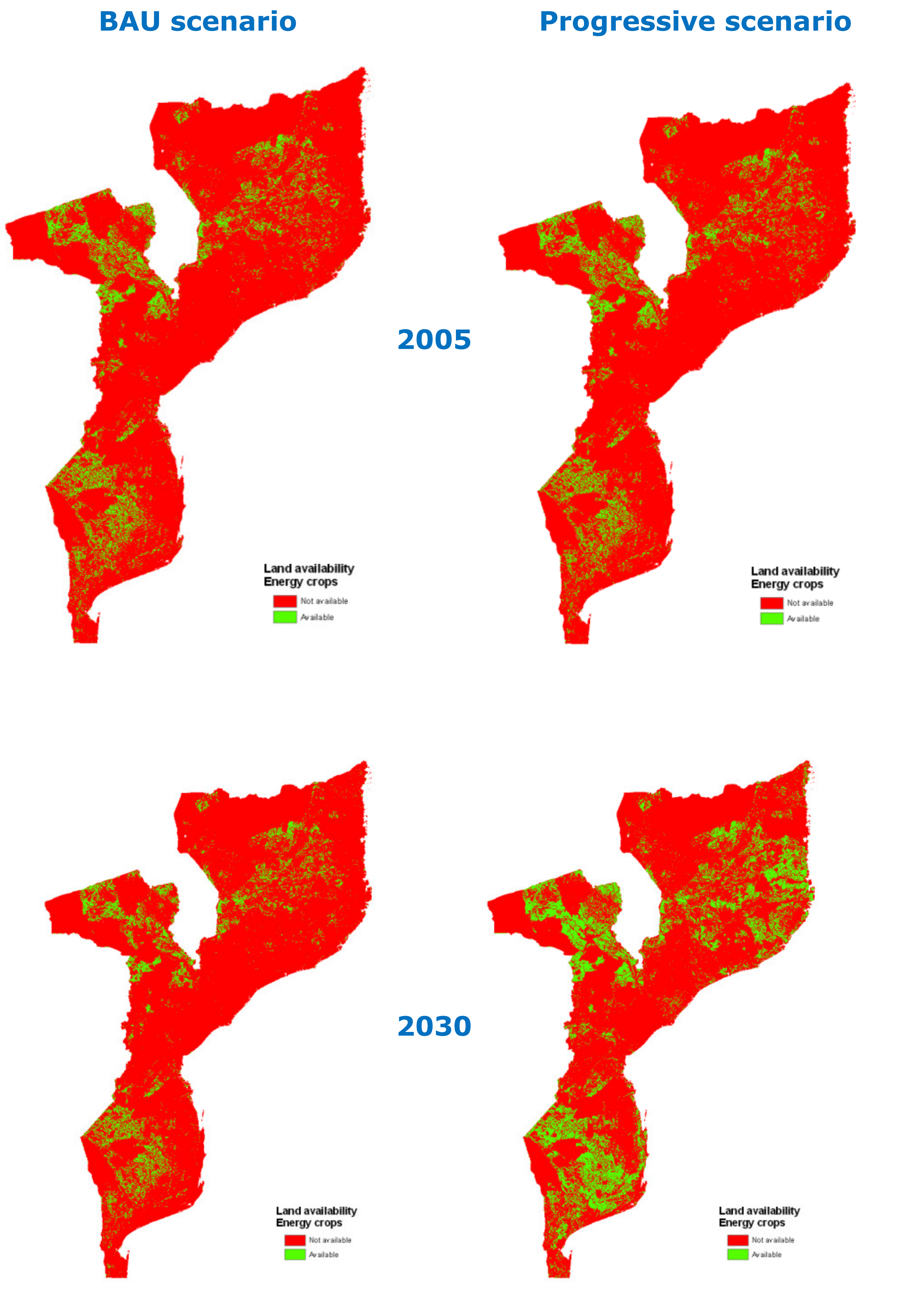

Figure 11: Land use availability for Bioenergy crops in 2005, 2015 and 2030 for BAU (left) and Progressive (right) scenario

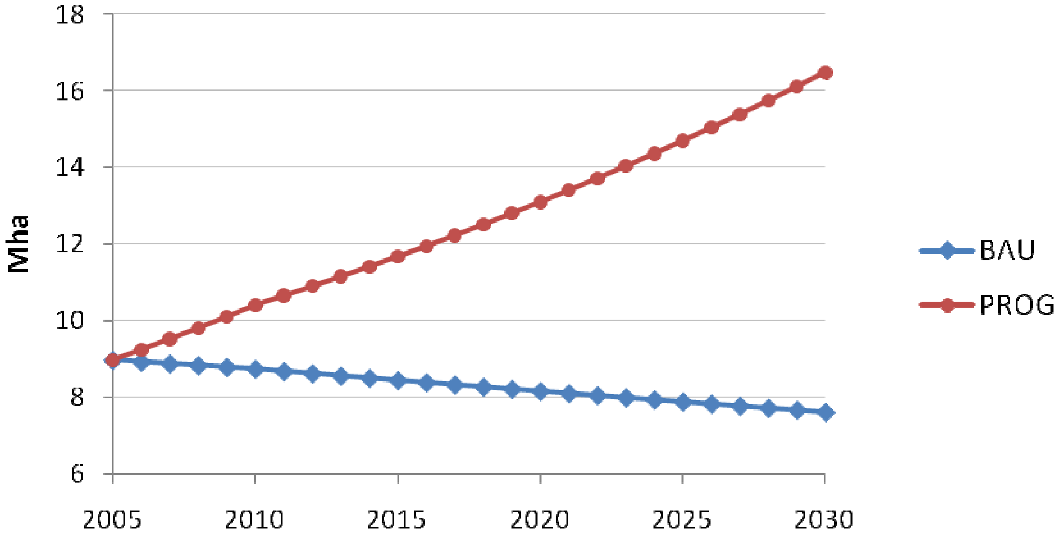

Figure 13: the development of land availability for bioenergy crop production over time for the BAU scenario (lower trend line) and progressive scenario (upper trend line)

In Figure 13 the development in available land for bioenergy crop production over the years up to 2030 is depicted for the BAU and the progressive scenario. For the BAU scenario the land availability decreases over time. For the progressive scenario, the land availability for bioenergy crop production increases because of a reduction in land requirements for pasture and cropland. Trend lines of 2005 up to now show little improvements in productivity, which means that at this point it seems that developments are on the 'BAU track'. The later the pathway towards a progressive scenario is chosen, the less of the total potential of the progressive scenario is achieved by 2030.

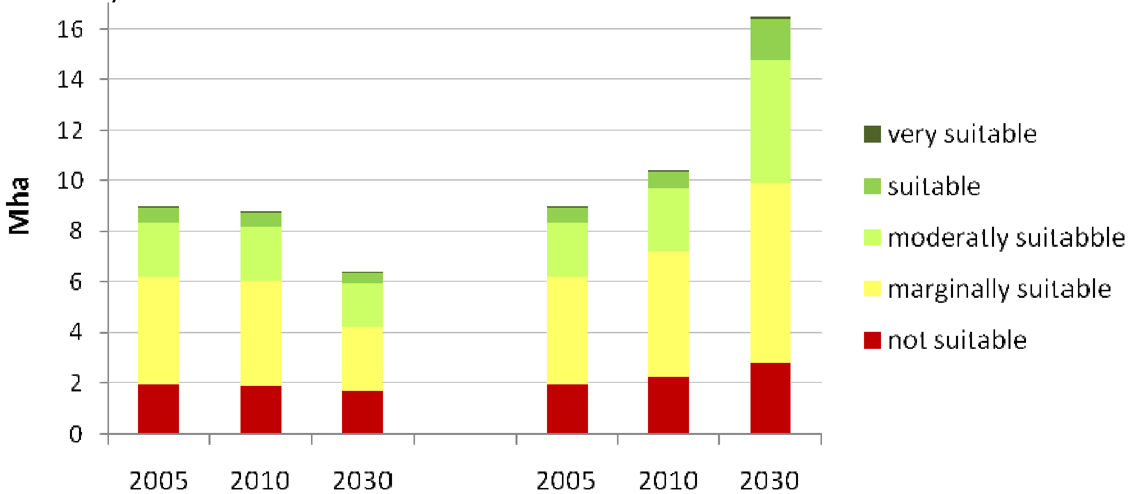

Figure 14: The development of land availability over time differentiated for suitability classes for the BAU scenario (left) and the Progressive scenario (right).

In Figure 14, the developments for land availability for 2005, 2010 and 2030 for the two scenarios is depicted differentiated for five suitability classes. The non-suitable category includes area that produce <20% of the maximum attainable yield given a technological state of art. The marginal suitable soils are not very productive (20-40% of maximum yield). However, these areas should not be excluded beforehand for energy crops (as productivity of the area is just one of many criteria for site selection) but crops should be selected with care.

3.6 Discussion and conclusions

As the scenarios developed in this study are highly divergent, the outcome of the assessment provides a broad range of possible future developments. The land availability in the business as usual scenario is decreasing over time from 8.9 Mha to 6.4 Mha. This is caused by the expansion of cropland and pastures required to meet the demand for food and animal products. The progressive scenario however, shows an increasing land availability for bioenergy crop from 8.9 in 2005 to 16.5 Mha in 2010. In this scenario, land currently in use for crops and pasture could become available by means of more efficient production. The land availability on the progressive scenario, is almost twice high as in the BAU scenario. Considering only the suitable areas (excluding non suitable and marginal areas), the potential land availability is even three times higher in the progressive scenario (6.6 Mha) compared to the BAU scenario (2.2 Mha) in 2030. It could be concluded that in both scenarios still a considerable amount of land is available. However, the decreasing potential in the BAU scenario indicates a higher competition for land in the future which could hamper the development of a sustainable large scale bioenergy sector in Mozambique. It should therefore be stressed that the a large scale sustainable bioenergy sector can only be established if it is developed simultaneously with a more productive and sustainable agricultural sector. This means the agricultural sector needs to develop from mainly subsistence farming to more commercial farming for which investments in education, knowledge diffusion, infrastructure, market establishment and financial institutions are required. Investors in the biofuel sector could and should contribute to this in order to ensure sustainable development.

The outcomes of this assessment are slightly different form the outcomes of the Zoning exercise performed by DNTF in 2008. The different outcomes are a result of differences in land use map used (satellite, recording, classification, resolution), objective and approach, modelling method (grid vs. vector data), time frame and excluded areas.

The land use model developed in this study is a very advanced tool to assess future dynamic line land use and land availability for bioenergy crops. As the land use change model concerns a new type of model with new allocation rules which is based on a set of spatial data with high variation is quality and fed with projections of possible future developments, the number of uncertainties is significant. Since the results for land use changes in one year are highly related to the land use of the previous year, errors are propagated over the years. In order to assess the robustness of the model, several uncertainty and sensitivity assessments have been done. Despite the uncertainties, the modelling of land use change over time provides detailed spatial information of land use dynamics over time and therefore a powerful tool to assess land availability for bioenergy crops in the in detail on a national level.

4 Business cases

The objective of the business cases is to determine the economic viability of developing large-scale biomass export supply-chains from Mozambique to the Netherlands - from the perspective of a potential investor. These business cases could be developed with positive effects for social and environmental sustainability and are relevant for different end-use markets, both national and international. In the following sections we describe two selected supply-chains (sections 4.2 and 4.3). We evaluate their economic viability through a cash-flow analysis, the results of which we present in section 4.4. Finally, the input data and assumptions are presented in section 4.5.

4.1 Selection of business cases (supply chains)

There are a multitude of potential bioenergy production chains that could be considered for bioenergy export from Mozambique to the Netherlands. The selection of the cases was based on the following criteria:

- Possibility to achieve large volumes by 2030;
- High yields per hectare desired;
- Possibility to involve smallholders;
- Diversity in final energy carrier (one liquid, and one solid);
- Options that are interesting for foreign investment;
- Products that are interesting for both EU and MZ market

Based on the visit and interviews in Mozambique in June 2010, we consider the following two cases to be the most realistic and feasible in the Mozambican context in the short term and thus promising chains for the export to the port of Rotterdam:

- ethanol from sugar cane
- wood pellets from plantation Eucalyptus trees

Advantages of sugar cane are its high yields, existing local experience with the crop, and the availability of conventional and proven cane to ethanol conversion technology. Moreover, the possibility to switch between sugar/ethanol production, depending on market attractiveness of these products, helps in reducing investor risk. The development of large scale plantations could furthermore benefit the development of infrastructure, where the investor would take responsibility. Moreover, sugar cane is one of the two crops (alongside sweet sorghum) targeted by the biofuel policy of the government of Mozambique. Disadvantages could also be noted such high water consumption (requiring irrigation) as well as intensive chemical input requirements.

Although Eucalyptus is not part of the Mozambican Policy and Strategy for Biofuels, this short rotation coppice tree species was chosen for its suitability for outgrower schemes, as well as its project development cycle, which offers significantly different insights from 1st generation energy crop projects.

Advantages of this ligno-cellulosic crop are the extensive experience that exists in Mozambique and elsewhere in the world, low management and soil fertility requirements and possibilities for agro-forestry. Moreover, if biomass production yields exceed the pellet plant capacity alternative local sales markets exist (for production of charcoal, construction and telephone poles, paper/pulp, utilization in sawmills etc.). The eucalyptus tree also brings some disadvantages, like high water requirement (although not more than sugar cane) and longer growing cycles as compared to annual crops (seven years on average in Mozambique). This longer growing cycle could also be an advantage, especially in areas where qualified labour is scarce. The longer cycle also implies a less intensive use of agrochemicals and allows for more efficient harvesting.

Although Jatropha is one of the crops highlighted by the Government of Mozambique as suitable for biofuel production, many techno-economic studies already exist on the subject, so we chose not to cover this crop in our business cases.

The bioenergy supply-chains evaluated consist of several linkages. For each of the selected supply chains the following steps are distinguished:

- Feedstock crop production;
- Transport of the feedstock to a central facility;
- Pre-treatment and conversion into the final energy carrier;
- Transport of the end product to a harbour and overseas shipment to Europe.

For each supply chain a number of choices have to be made with respect to crop type, management type, and end product.

Table 8 summarises the main choices that have been made for the two selected supply chains. Further details are given below in Sections 4.2 and 4.3.

Table 8: Supply chains for business case

	Sugar cane	**Eucalyptus**
Type of crop	Semi-perennial (ratooning)	Short rotation coppice
Type of management	Intensive (option for smallholders)	Semi-intensive (option for outgrowers and agroforestry)
Harvesting	Mechanical	Semi-mechanical (chainsaws)
End product	Ethanol	Wood pellets

4.2 Case 1: Eucalyptus to wood pellets

In this section we describe the supply chain from planted Eucalyptus to pellets in more detail. Then, we present the results of the economic analysis in the form of a cash flow analysis, payback time, and internal rate of return.

A model of this supply chain is shown in Figure 15.

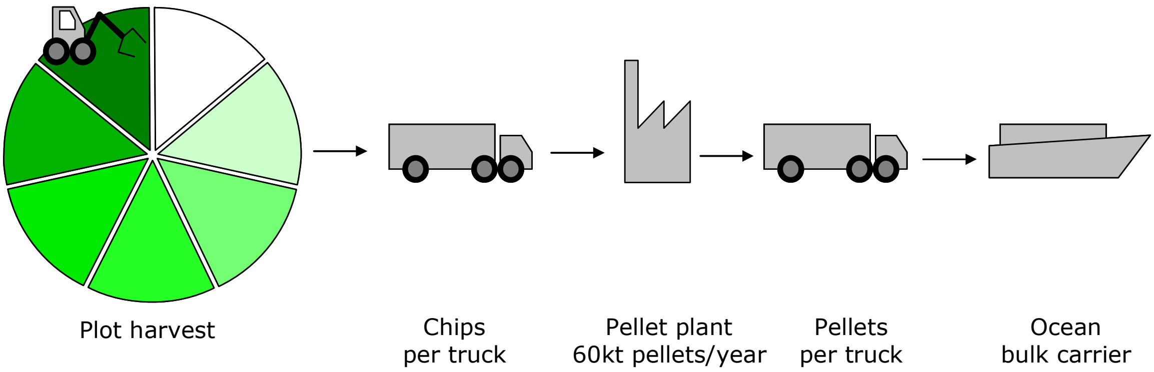

Figure 15: Eucalyptus to wood pellets supply chain. The total feedstock production area (module) measures 3.6 kha, of which 1/7th (one plot) is harvested each year

Eucalyptus trees are planted in year 1 and left to grow for 7 years. Harvesting takes place in the form of coppicing: the stump is left in the soil and re-grows sprouts to full plants again in 7 years. In total there are 3 cycles of 7 years, so that seedlings and heavy land preparation tasks are only required every 21 years.

For the harvesting of Eucalyptus trees, we assume that harvesting occurs semi-mechanically, i.e. with chainsaws, as is common in natural forestry operations (Nhancale 2009). This option reduces the need for expensive harvesters and can be performed by smallholders.

The business case for Eucalyptus biomass production is built around a so-called 'module'. A module is the area to be cultivated in order to supply a yearly amount of biomass to the conversion plant that matches the capacity of this plant. The capacity of the pelletisation plant chosen for this case is 60 ktonne/year, which is a standard size for the industry. The planted area required for feeding such a plant is then 3,600 hectares, considering an average productivity of 30 tonnes of fresh biomass per ha per year, or about 15 tonne/ha/year on dry matter base[8] (see Appendix A for a discussion on yields) and pellet moisture content of 10% dry base (db).

[8] At harvest, moisture content is typically 50%, and specific density of oven-dried wood is about 500kg/m^3 so 1m^3 of fresh harvested wood, yields 0.5 $tonne_{dm}$

In case the quantity of harvested biomass exceeds the plant capacity (if the average productivity exceeds 15 tonne$_{db}$/ha/year, or the production area is increased), the excess biomass could be sold to other industries as sawn wood, poles, chips for pulp, or charcoal.

Plantation establishment and biomass production

Each module is divided into seven sub-modules (see Figure 15) or 'plots', which are cleared and planted one after the other at yearly intervals. At the end of the seventh year, the first plot is harvested and production of pellets can start. The harvesting is in the form of coppicing, so that the plants grow new shoots from the stump that was left, and the cycle starts over, such that one plot is harvested every year and can provide a similar yearly quantity of biomass to the conversion plant. The planning and management costs for each such sub-module are given in Appendix A.

The plantation areas described above could be managed and owned by large scale industrial forestry companies, but also be outsourced to smallholders. In the case of smallholders, one way for pellet plants to source wood is through so-called 'outgrower schemes'. Typically, the company provides the material (machinery, seedlings, fertilizers, herbicides and pesticides) and technical know-how for establishing the trees on the farmer's land and the farmer may use his own family or contract local workers for the labour requirements. The company then agrees with the farmer to buy some or all of the first harvest for an agreed or market price. Farmers are willing to cooperate as the trees provide an additional source of income from a low-risk market, allow the productive use of marginal areas, and higher yields than if they were to manage the plantations on their own, thanks to the know-how and genetically improved seedlings provided by the company. Companies tend to like outgrower schemes because capital investments are lower (land and labour effectively become opportunity costs for the smallholder) and in areas where most of the land is owned or managed by smallholders, it still allows for biomass production to occur close to the conversion plant. Also smallholder schemes are appreciated by European consumers if they improve the social and economic situation of farmers. Disadvantages of smallholder schemes are the risk for the company that supply is not guaranteed, and the complexity of the organisation, administration and contracting. The main disadvantage for the smallholder is the long time of upfront investment without certainty of product take-off.

The business case assessed does not account for the type of scheme (plantation or outgrower).

Since it takes on average seven years for a Eucalyptus plantation to mature, one could consider different, readily available feedstocks to start operating a pellet plant right away, in order to bring the first revenue forward. Feedstocks that have been suggested include deceased coconut palm, cotton straw, rice husks etc. Although there are many possibilities, many of these options still represent some challenges, and would need to be carefully considered by the investor. For example, the low energy density of residues, combined with a wide geographic spread of producers, tend to make the logistics of collecting the feedstocks more expensive than in the case of dedicated bioenergy crop (Solidaridad, 2011).

Table 9. Major cost elements in the estabilishment and operation of eucalyptus production.

	Costs
Land rent	2.5 USD/ha/yr
Land clearing and site preparation	1000 USD/ha (once)
Land preparation	250 USD/ha (once)
Seedlings	360 USD/ha (once)
Planting	240 USD/ha (once)
Pesticide/herbicide	70 USD/ha/yr
Pesticide/herbicide application	30 USD/ha/yr
Fertiliser	150 USD/ha/yr
Fertiliser application	50 USD/ha/yr
Irrigation	50 USD/ha/yr

Harvest and road transport

Harvesting is defined as the sum of operations performed on the plantation from the preparation for cutting to loading the wood on the trucks that will transport the biomass to the industrial processing plant. This can be performed by a professional forestry company, but it could also be done by outgrowers, in which case the costs are opportunity costs for the farmer. In this business case these operations are assumed to include:

- Felling, branching and debarking;
- Short distance transport of trunks to the roadside (forwarding);
- Loading the wood onto a truck for principal transport towards the processing plant.

Cost items for harvesting operations are given in Appendix A.

Once the trunks are loaded onto a truck, they are transported by truck to a central pelletisation facility. After densification, the pellets are further transported by truck to the nearest suitable port, from where they are shipped to Rotterdam. For an overview of transport cost items see Appendix A.

Conversion of wood to pellets

In order to increase the density, and thereby reduce the cost of long-distance transportation, woody biomass is densified through pelletisation, which has the additional benefit of producing a standardised energy carrier. Pellets are produced by compressing size-reduced biomass to a cylindrical shape of 5 – 40 mm long and a diameter of 3 – 25 mm. Currently, sawdust and wood shavings are the dominant feedstock, but chipped Eucalyptus logs can also be used. For a detailed description of the pelletisation process see Appendix A.

Long distance transport & shipping

When pellets are delivered at a port, they are stored temporarily, waiting for the ocean freight to be available. Ocean transport is assumed to take place using Suezmax bulk carriers of 150 thousand tonne dead weight capacity, which delivers the pellets to the port of Rotterdam.

Table 10. Shipping costs.

	Pellets	Ethanol
Loading bulk carrier in Mozambique [1)]	11 USD/tonne	11 USD/tonne
Port charges Mozambique [1)]	14 USD/tonne	14 USD/tonne
Ocean freight [2)]	4.9 USD/tonne	2.95 USD/tonne

1) Based on Batidzirai 2006.

2) Based on van Vliet 2010, international freight of pellets in bulk costs 0.2 EUR/GJ or 4.9 USD/tonne and international freight of bioliquids costs 0.1 EUR/GJ or 2.95 USD/tonne.

Pellets end use

Pellets are used in different combustion systems, ranging from small-scale pellet stoves to large-scale utility boilers (like co-firing in traditional coal-fired power plants). This diversity of applications, combined with the advantages mentioned above, result in a growing market with about 12 Million ton of pellets being consumed in 2009. This global market is expected to double in the next 5-8 years (Pellet Atlas).

Results of the techno-economic analysis for eucalyptus pellets

Below the results are displayed, representing the sum of costs for producing the final energy carrier delivered to the port of Rotterdam. Subsequently the resulting cash flow is shown in Figure 17. The cash-flow analysis is used to determine the pay-back time, which is reached when the cumulative cash flow becomes positive.

Cost break-down of eucalyptus pellets delivered in the port of Rotterdam are shown in Figure 16. The production costs have been calculated by dividing the Net Present Value of each cost element by the Net Present Value of the total amount of produced pellets. A discount factor of 10% has been assumed. The averaged costs come out at 143 USD/tonne, which is equivalent to 104 Euro per tonne at the port of Rotterdam[9]. Pellets are currently being traded for a price around 120 Euro/ton in the port of Rotterdam (APX/ENDEX). The feedstock production costs (48%) and the transport costs (21%) contribute largest to the total cost of the pellets in this business case. The investment costs in the pellet plant only contribute 14% (19% when including maintenance). This is partly due to the fact that the investment costs are less sensitive to the inflation rates, as occurring at the start of the project.

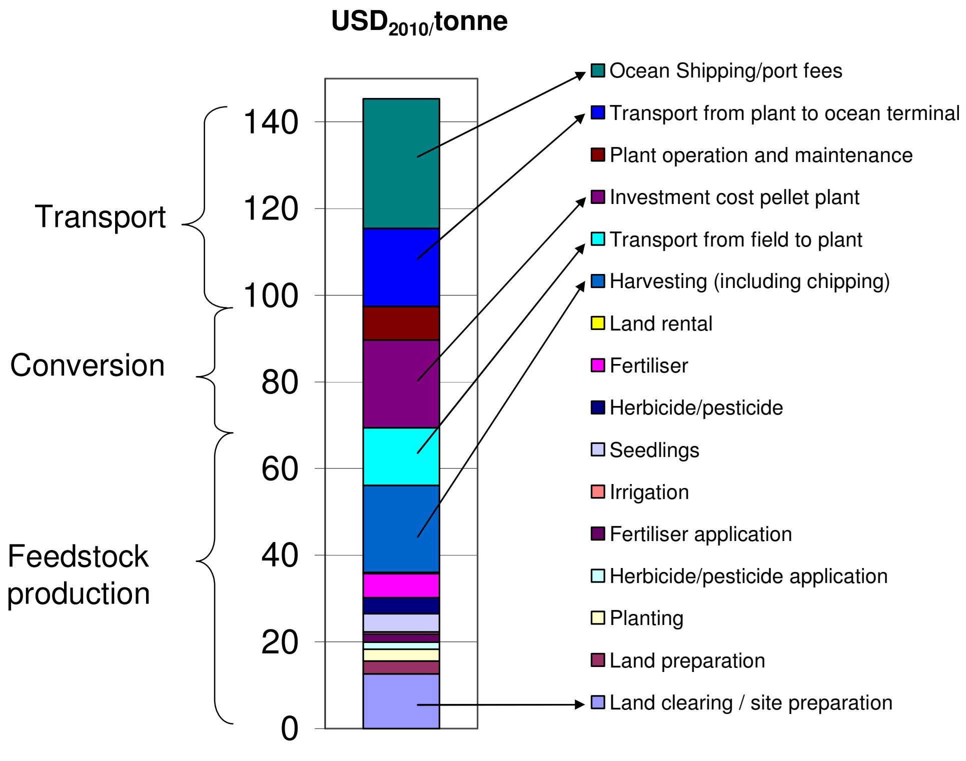

Figure 16: Cost break-down of 1 tonne of Eucalyptus pellets delivered in Rotterdam

[9] At an exchange rate of 1 Euro = 1.4 USD

Results show (see Figure 17) that for current prices of pellets the cumulative cash-flow does not get positive before 2022. The graph shows high cost in 2016 and 2017. These costs represent the investment costs for the pelletisation plant, which is built over two years, preceding the first harvest (in year 7). The long pay-back period (10.3 years) is mainly due to the fact that the first income only occurs after the crop reaches maturity, which is after 7 years for Eucalyptus. Payback times could be reduced considerably by building the conversion plant at the beginning of the project and feeding it alternative feedstocks (see the last paragraph of section 'Plantation establishment and biomass production' from chapter 4.2).

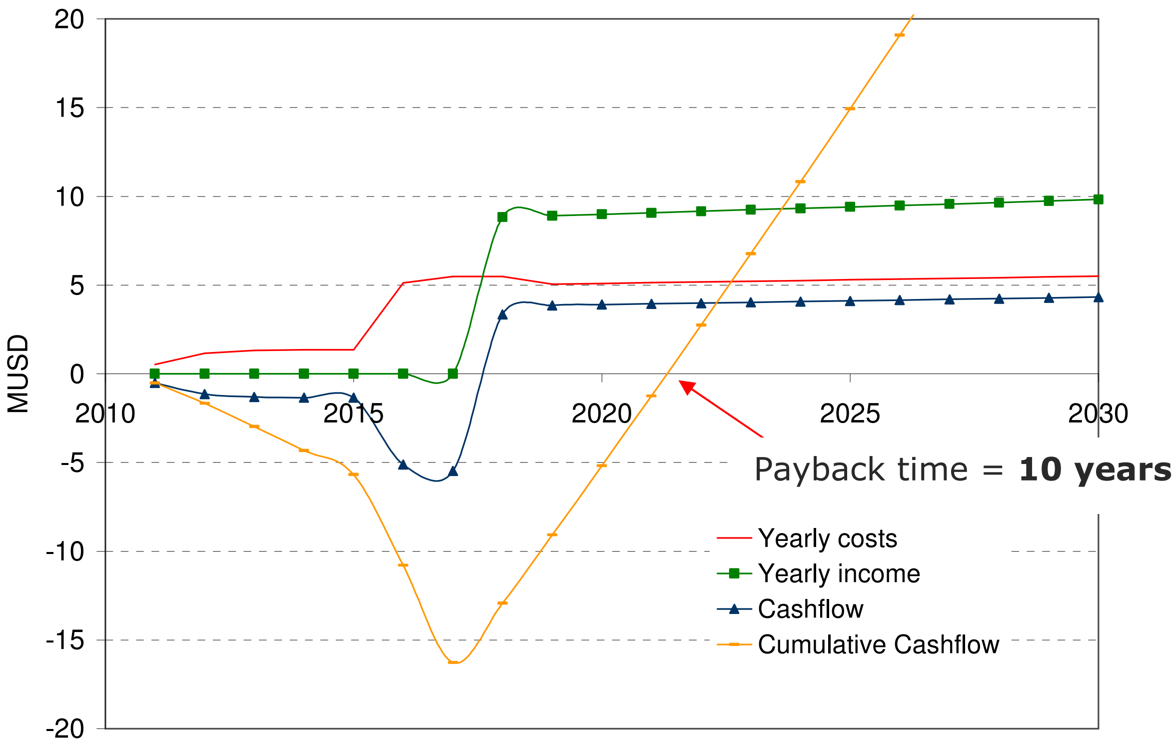

Figure 17: Cash-flow for large scale eucalyptus pellets

Furthermore, the IRR of the project until 2030 comes out at 15%, and the net present value is 4.3 MUSD at a discount rate of 10%.

Sensitivity of project payback time to key parameters

Figure 18 shows how relative changes in a number of key parameters affect the payback time. As could be seen from the cost break-down, the transport of feedstock to the plant represents a significant part of the total costs. In the graph a variation is shown from 20 to 100 km, which impacts the payback significantly, varying from 9.8 to 11.2 years. This shows the importance of the pellet plant being close to the feedstock production. The same is true for the distance of the pellet plant to a port, where a variation in distance from 20 to 300 yields a variation in payback from 9.5 to 11.7. Furthermore, the yield levels of the biomass play an important role, affecting the payback by 2 years from 11.1 to 9.1 years, assuming an average yield increase (over the whole project period) from 200m^3/ha/7 years (equivalent to 14.3 oven-dried-tonne/ha/year) to 300m^3/ha/7years (equivalent to 21.4 oven-dried-tonne/ha/year). This result shows the importance of the selection of productive land. Yields are also impacted by the planting density and the rotation period. The choice between the planting density and rotation period is made depending on the hoped for diameter of the harvested wood at the end of that period. Denser planting and shorter rotation could lead to less optimal net growth per year, but could result in earlier harvests (and income) and easier to handle biomass. Last, the price of the end product has of course a significant impact on the payback time, but this factor can only be controlled to a certain extent by the project developer, for example by negotiating advantageous long-term supplying contracts.

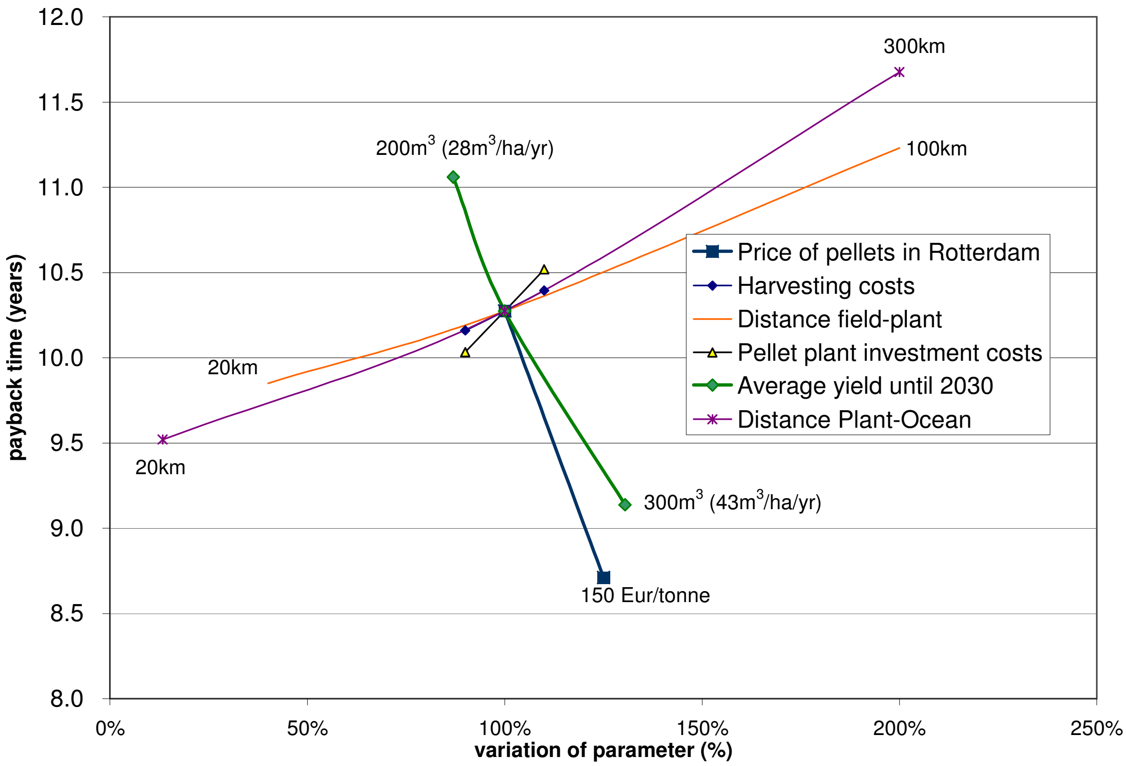

Figure 18: Sensitivity of project payback time to key parameters

4.3 Case 2: Sugar cane ethanol

In this section we describe the supply chain from intensively managed sugar cane, to ethanol delivered in the port of Rotterdam. A model of this supply chain is shown in Figure 19.

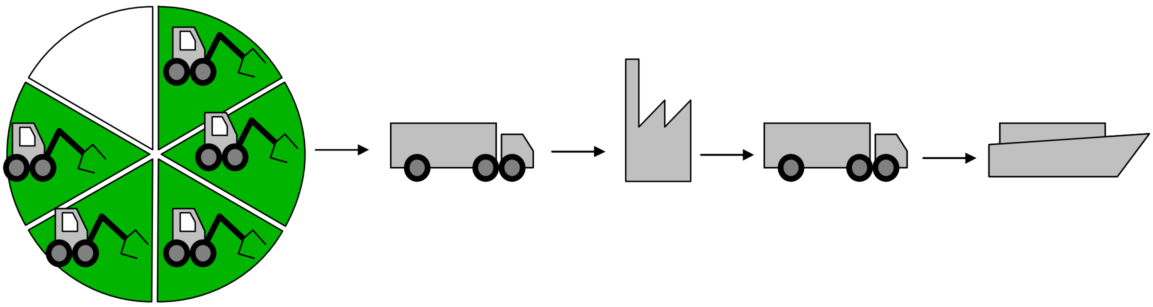

Figure 19: Sugarcane to ethanol supply-chain. The total plantation size measures about 20 kha (details in text). Every year 5 out of 6 plots are harvested, while 1 plot is covered with an intercrop

The crop will be growing in a semi-perennial intensive (industrial-scale) 'ratooning' system, which is replanted following an intercrop in the 6th year. This means that in the first year of a plantation seedlings are planted, and are left to re-grow (ratoon) after the first four consecutive harvests. The advantage of this system is that replanting is only necessary every 6 years, which saves on planting and seedling costs.

Harvesting will be done mechanically, which avoids the need for burning the field before harvesting – a major environmental benefit. Furthermore, the costs of mechanical harvesting are usually lower than manual harvesting (if the machinery is used efficiently and if employees earn a reasonable living). Using mechanical harvesting instead of manual harvesting, however, results in a lower demand for local (unskilled) labour.

The business case for ethanol from sugarcane is based on biomass production from one module, which is split up in sub-modules, called 'plots' (see Figure 19). The area of cultivated in a module is determined by the capacity of the conversion plant, so that the plant gets used close to its optimal capacity. The plant capacity chosen for this case is 120,000 m^3 ethanol/year, based on 600 m^3/day and 200 days/year operation.

With a plantation measuring 20,000 ha, only 16,667 ha actually produce cane for the mill, since 1/6 of the plantation will always grow an intercrop. Besides this, smaller plots for nursery and pre-nursery are required (see Table 12 below). We assume an initial productivity of 80 tonnes of fresh biomass/ha/year, or (see also Appendix B for a discussion on yields), so that the cane to mill is about 1.3 Mtonne eventually. This means that the plant will produce 107,000 m^3 ethanol/year, which is somewhat below the actual capacity at the start of the project. The sugar cane yield is expected to increase; once the yield becomes more than 90 tonne/ha, the harvesting season will have to be expanded, or plant capacity extended (unlikely) in order to process all the annually produced cane. It is expected that the harvesting season can be expanded without problems to some 220 days[10]. Once the yields rise above 100 tonne/ha, the maximum capacity of the plant will be reached and the annual production will even have reached 132,000 m^3 ethanol/year. The outer fields of the plantation may then supply new nearby mills.

Table 11. Assumed yield increase over project time (tonne cane/ha).

2013	2015	2020	2025	2030
80	82	88	94	100

We have evaluated a plant that produces only ethanol and electricity. It may sometimes be more attractive to produce sugar. It could therefore be wise to develop mills that can shift between sugar and ethanol production.

Establishment and biomass production

Before plantation development can physically start, a pre-nursery and nursery stage are developed to provide the planting material for the plantation. Normally, new varieties of seedlings are imported and grown to mature cane in the pre-nursery.

From the pre-nursery, cuttings are produced for clone multiplication on the nursery – the nursery measures 8 times the pre-nursery. The nursery is operated as a normal sugarcane plantation, but instead of harvesting the cane for processing in the mill, again cuttings are made for planting on the actual plantation – each ha of nursery provides cuttings for 10 ha of plantation.

The 20,000 ha plantation is divided into 6 plots (Figure 19), which are cleared and planted one after the other with nursery material at yearly intervals. Each plot is then harvested at the end of its growing year, and the cane is let to grow back from its stump (ratoon). At the end of the 5th year, the stump is removed and an annual intercrop is grown during the sixth year. This intercrop should preferably be a nitrogen fixing plant, which will reduce the need for fertilisers (a significant part of the costs) in the next year. After the sixth year, the first plot is planted again, and the cycle starts over for each plot, such that each year, five plots are harvested and can provide a relatively constant yearly quantity of biomass to the conversion plant.

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[10] The existing Xinavane sugar mill already has a 32 week crushing season.

Table 12: Major cost elements in the establishment and operation of the plantation

	Cost	Area involved (eventually)
Land rent (total project area)	2.5 USD/ha/yr	21,875 ha/yr
Land clearing and site preparation[1)]	4300 USD/ha	21,875 ha (once)
Pre-nursery	20 USD/ha/yr	208 ha/yr
Nursery	146 USD/ha/yr	1,667 ha/yr
Plantation (feedstock for mill)		16,667 ha/yr
Soil preparation [2)]	210 USD/ha/yr	3,708 ha/yr
Planting [3)]	300 USD/ha/yr	3,667 ha/yr
Weed control	35 USD/ha/yr	21,875 ha/yr
Fertilisation[4)]	220 USD/ha/yr	21,875 ha/yr
Irrigation	250 USD/ha/yr	21,875 ha/yr
Harvesting [5)]	650 USD/ha/yr	18,334 ha/yr
Intercrop [6)]	0	3,333 ha/yr

1) Land clearing (once off) consists mainly of shrub clearing. Site preparation (once off) consists of soil preparation, hydraulic engineering, irrigation system, agricultural equipment and roads.

2) For pre-nursery, nursery and main plantation.

3) For nursery and main plantation.

4) We assume that part of the fertiliser will be recovered from the vinasse.

5) The intercrop will be outsourced cost-neutrally.

A detailed costs overview is given in Appendix B.

Sugar cane harvesting and primary transport

Harvesting of the sugar cane is done mechanically, and loaded onto trucks for transport to the conversion plant.

Conversion of sugar cane to ethanol

The trucks bring the sugar cane to a central gathering point, where the mill and distillery are located. Here, the cane gets crushed and the resulting sugar is converted into ethanol. The end product has to be anhydrous ethanol, in order to be eligible for blending with fuels in Europe (and/or Mozambique).

A detailed overview of the conversion process is given in Appendix B.

Results of the techno-economic analysis for sugar cane ethanol

Cost break-down of the net present value of ethanol from sugar cane delivered in the port of Rotterdam is shown in Figure 20. The production costs have been calculated by dividing the Net Present Value of each cost element by the Net Present Value of the total produced ethanol volume. A discount factor of 10% has been assumed.

The production costs are nearly 430 USD per m³ (540 USD/tonne). Major contributors to this result are the plant investment, the costs for harvesting and for land clearing.

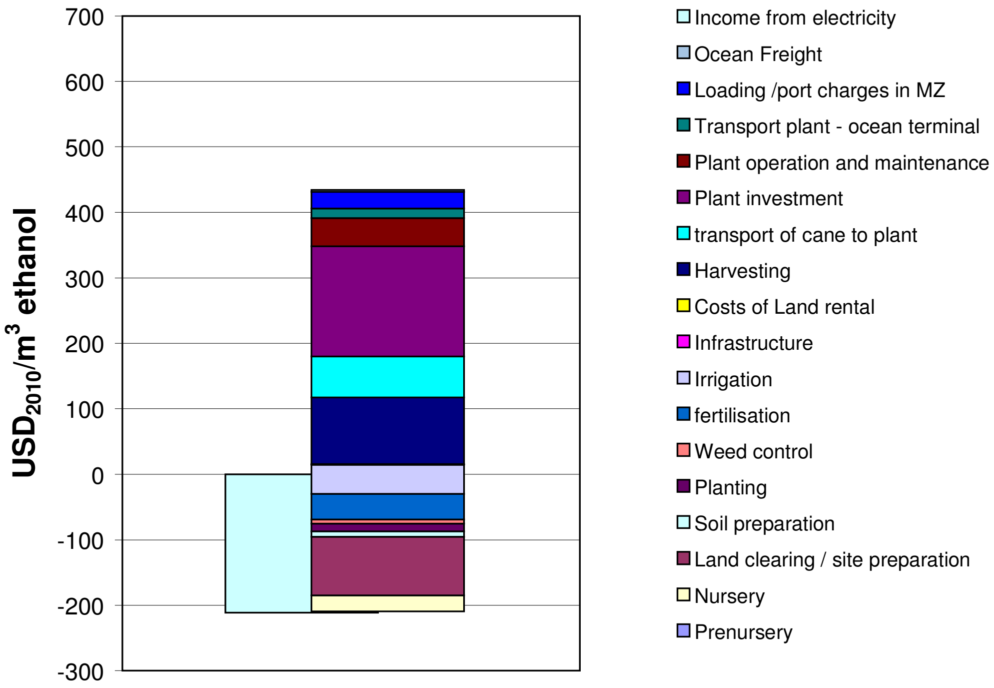

Figure 20: Cost break-down for 1 m³ of ethanol delivered in Rotterdam

The current price for ethanol imported to Rotterdam ("T1") is 690 USD/m³ CIF (Platts 2011). The price has increased from about 570 USD/m³ in 2008 and can be expected to rise further for ethanol that meets the RED sustainability requirements, especially as the volumetric demand increases over the next years. This leads to an IRR of almost 21%.

The cash flow results are shown in Figure 21 and show a positive cash flow from 2015 onwards. The cumulative cash flow turns positive in 2019, which means that the payback time is slightly more than 7 years, which is very much acceptable for this kind of projects.

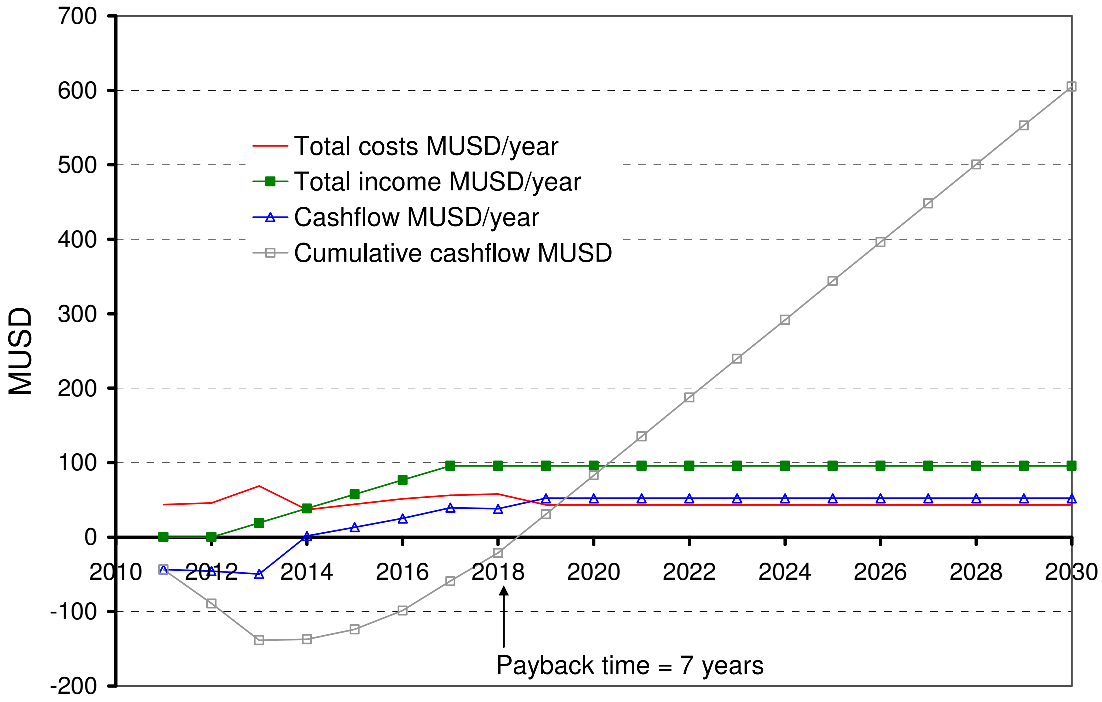

Figure 21. Cash-flow for sugar cane ethanol until 2030.

The payback time is especially dependent on the eventually sales price on the EU market as can be seen from Figure 22. It is important to note that ethanol from Mozambique imported to the EU does not face import tariffs and therefore have a competitive advantage of 100-200 Euro/m^3 (depending on the imported form) compared to ethanol from Brazil. The ethanol sales value on the European market can be expected to increase with increasing sustainability performance. Obviously, the ethanol sales value may also increase with increasing crude oil prices, but then also some cost elements in the ethanol production will increase.

On the other hand, the payback time significantly improves with higher yields per hectare, as the fixed costs per hectare can then be divided by a much higher ethanol volume. With yields of 120 tonne cane/ha, production costs would drop to 290 USD/m^3 and payback to less than 6 years, while the IRR would become about 32%.

The investment costs are highly variable. Around 2008, in the high-time of ethanol project development and when iron ore prices were extremely high, the investment costs were significantly higher.

Since the credit crunch, investment costs have dropped significantly. Also, the investment costs are very sensitive to scale, however, the scale of cane installations are limited by feedstock supply distances.

Several future developments could make the business case even more attractive. For example, additional ethanol can be produced from the ligno-cellulose part now ending in the bagasse or in the trash that is currently left on the field. Technological learning will lead to limited cost reductions, since the existing global mill capacity is already very large.

Note that the tax conditions for investing in ethanol projects are currently attractive in Mozambique, where corporate taxes will be gradually increased over the next decade. The potential cost reductions that could be achieved by the future improvements that we have discussed, will be partially compensated by the tax induced cost increases.

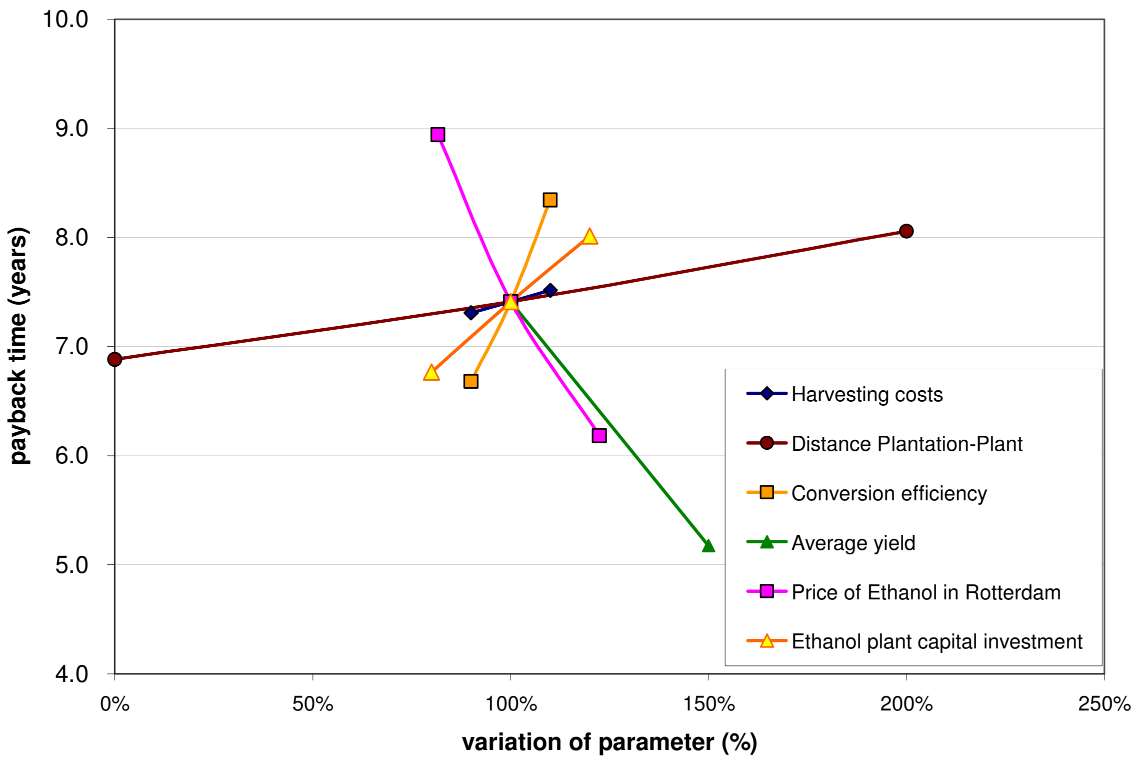

Figure 22. Sensitivity of payback time to various parameters.

5 Recommendations

5.1 Synthesis of results

Between 6.4 and 16.5 Mha of land could be available in 2030 in Mozambique for the production of bioenergy feedstock. If the developments in the agricultural sector continue along the current trends (Business As Usual Scenario), it will only be possible to realise the lower end of this range. However, if agricultural practices significantly improve, the higher end of the range can be achieved (Progressive Scenario).

The Progressive Scenario reflects the Mozambican ambition for more advanced development. The additional land primarily comes available because the existing land use functions become more efficient, with higher food and feed yields per hectare. The scenario assumes commercialisation of the agricultural sector with a high rate of technological and land management practice changes. An increasing part of the famers will need to have access to improved seeds, fertilisers, pesticides and (above all) knowledge by means of education (literacy in Portuguese or English would give access to much agricultural knowledge) and a widespread network of extension workers.

Despite the ambitions, the current trends show only modest annual yield increases in an agricultural sector that is dominated by subsistence farming. Agricultural improvements are implemented only slowly, amongst others because there is barely a market for the end-products.

The necessary agricultural improvements could be realised in conjunction with the development of a bioenergy production sector in Mozambique. And vice versa, a sustainable and economically viable bioenergy sector can only be realised if the existing agricultural sector develops in the same fast pace.

5.2 Roadmap

The two case studies have shown the principle feasibility of two large-scale biomass production routes that could be realised in Mozambique and could provide import of bioethanol and biomass pellets in the Netherlands.

By creating the right institutional and infrastructural systems, the development of such routes can be managed and accelerated, while ensuring a certain level of sustainability of the bioenergy carriers and optimising the benefits for Mozambique.

Crucial elements for this development are:

- Identification of preferred developing zones;
- Attractive legal and financial environment for project developers;

- Creating of essential infrastructure;
- Safeguarding sustainability;
- Rural development;
- Robust selection of feasible projects;
- Assistance to project developers;
- Increase agricultural productivity (crop yields and livestock).

These elements are detailed out below and lead to a roadmap of actions. Several resulting actions match the path that has already been set-out by the Mozambican government in their Liquid Biofuel Strategy. Some resulting actions will be costly and need to be financed in a way that the benefits for Mozambique outbalance the costs in the long run, and that the costs and risks in the short run remain acceptable. Where relevant we will also provide some ideas for financing the desired developments.

This roadmap is intended to create the conditions and setting within which the desired developments are stimulated, so that a viable bioenergy sector can be developed while at the same time improving the existing agricultural sector, so that the agricultural land in Mozambique can be utilized most effectively.

5.1 Identification of preferred developing zones

Investments can be motivated if the government identifies preferred zones for bioenergy production. Project developers are free to develop outside such regions, but will find certain advantages if they choose to develop with a preferred zone, such as shorter or easier permitting procedures. Zoning also helps the infrastructural planning (roads, rail, and harbour) and will eventually lead to regional specialisation (agricultural centres, verifier offices, group certification).

The land availability analysis showed that everywhere in Mozambique land could come available for the production of bioenergy, with concentrations in the south, northeast and northwest of Mozambique. If bioenergy is to be exported, the feedstock production locations will initially be developed rather close to international harbours (<150 km). This means that the northwest part of Mozambique is less attractive for bioenergy production (at least in the first years). Once initial projects have lead to transporting infrastructure new plantations can be realised further from the coast.

5.2 Attractive legal and financial environment for project developers

Foreign investments can be attracted by assisting in administrative procedures related to legal and financial aspects, while at the same time maintaining strict rules on e.g. sustainability. This is currently done by the CPI.

Financing of renewable energy projects in developing countries is often difficult.

Some western banks facilitate the financing of such projects by establishing credit lines. Western Banks provide a guarantee to projects, which makes it easier to attract loans from local/regional banks. The Government of Mozambique could assist a selection of project developers (see Section 5.6 below) in forwarding them to financiers experienced with similar projects.

Mozambique could interest foreign investors by inviting trade missions.

5.3 Creation of essential infrastructure

For the development of bioenergy projects, infrastructure is essential, first of all to bring the installations (cane mill, pellet press) to the right location, and later to bring the final product to the market. This means that at least main roads and a well equipped harbour are required.

A harbour could be developed in association with foreign developers. For example the Government of Mozambique could invite the Port of Rotterdam to generate ideas and options for collaboration.

Project developers can be motivated to build minor infrastructure, such as smaller roads, bridges and hospitals near the projects, to ensure good infrastructure, and a healthy and friendly environment. At present, bioenergy project developers in Mozambique are already encouraged to do this and must dedicate a part of their project proposal to the development of infrastructure and facilities that benefit the country.

5.4 Safeguarding sustainability

For the sustainable development of Mozambique it is necessary that large agricultural projects are carefully considered for their sustainability aspects. This means that project developers have to carry out decent Environmental Impact Assessments, that projects are regularly controlled on agreements made and that the Government has means to enforce compliance with environmental laws. Environmental Impact Assessments are already obligatory for large projects in Mozambique.

Mozambique could involve foreign experts from regions where similar developments have taken place to learn from their experience (capacity building).

Mozambique has established sustainability criteria, which need to be checked during the project acceptance process.

Export to EU may require a certain level of sustainability. For bioethanol it is required to meet the requirements from the Renewable Energy Directive. For solid bioenergy carriers it is currently desired to meet a certain level of sustainability and possibly in the future there may be legal requirements as well. This means that especially if Mozambique wishes to export bioenergy to the European market, it is wise to connect the national legislation on sustainability to the requirements from the European Renewable Energy Directive.

Under the European Renewable Energy Directive, Member States have the possibility to make bilateral agreements with biomass producing countries, on the sustainability of biomass.

If the Dutch Government made such an agreement with the government of Mozambique, this would significantly reduce the administrative hurdle of biomass certification for suppliers, if they want to supply to the NL biofuels market. Alternatively, the GOM could assist sustainability schemes in becoming accepted by the European Commission, to facilitate market access in the EU.

5.5 Rural development

For Mozambique it is important that rural development benefits from biomass projects. One can connect the development of a bioenergy project to improving agricultural practices in the surrounding area. Particularly, if a European developer wants to avoid an indirect Land Use Change effect (iLUC), the development of a so-called Responsible Cultivation Area could involve the improvement of local agricultural practices as part of the plantation development.

The land assessment in Chapter 3 of this report takes into account that iLUC should be avoided.

5.6 Robust selection of feasible projects

In order to ensure that developed projects meet social, environmental and economic requirements, it is important that the project proposals are scrutinized in sufficient detail. We recommend that the Government either plans for increased internal capacity, or develops alternative structures for outsourcing these tasks.

Currently, bioenergy project developers need to submit a project application in Mozambique. The approval mainly depends on the availability of land. Also, the projected economics of projects are evaluated, but these can easily be manipulated by project developers to fall in the acceptable range. It is essential that CEPAGRI and other responsible organisations in Mozambique manage to get good insight in the economic viability of projects and understand the relative attractiveness for the Mozambican market. This allows for focusing guidance on those projects that are really valuable for Mozambique. This probably requires increased capacity as well as capacity building. Also companies can benefit from better insight in the economic viability of projects. This study has shown possible land availability and the principle feasibility of two large-scale biomass production and export routes. This helps to focus investments and efforts to the best alternatives.

Revenue for the Government from the bio-projects is expected to come from various sources, a few of which are listed below:

- Revenue from land renting (currently relatively small)
- Income tax of domestic workers (at present limited collection of income tax)
- Corporate tax
- Potential export tax on final products
- Reduction of fossil fuel imports

5.7 Provide project guidance and support

For the projects that are approved, a large number of activities are to be undertaken by the project developers. In order to make investments more attractive for domestic and foreign investors and developers, the GOM could provide assistance on a number of these activities through a project office, such as the CPI. This office could improve the quality of the projects by:

- Assisting large project developers in accessing finance (for example by organising trade missions from importing countries. The Dutch government could assist in these missions by bringing together investors and representatives from relevant companies);
- Assisting smallholders in getting access to micro-financing;
- Assisting developers in the time planning;
- Providing guidance to developers with environmental impact assessments (EIA) and stakeholder consultations;
- Developing infrastructure in preferred areas;
- Gathering and disseminating knowledge on best agricultural and operational practice;
- Advising on technology, mainly by opening the network, if required.

For the last point, the GOM could strengthen the agricultural knowledge of the office by contracting national or international agricultural knowledge centres. Relevant knowledge thus gathered can then be communicated to local populations through extension workers (see below).

Furthermore, it is recommended that the Government takes a proactive role in designating preferred bio-project areas. Once such areas have been designated, it could make them more attractive to investors by:

- simplifying administrative procedures
- facilitating access to infrastructure development parties (such as foreign harbour and railway companies)
- designating low ILUC-risk areas, for example based on the assessment in Chapter 3 of this report and/or by assisting in implementation of the responsible cultivation area (RCA) methodology

5.8 Increase agricultural productivity

As has been discussed, the availability of land for bioenergy projects depends for a large part on the improvement of agricultural practices of the small rural farmers. This concerns increasing the crop yields as well as the productivity of livestock.

The process to improvement agricultural practices is very complex. Many actions need to take place at the same time. On a general level, improvements are needed for:

- Access to market:
  - A marketplace is needed to sell the agricultural products;
  - Infrastructure to reach the market place;
  - Cooperation of producers to approach the market;
- Means
  - Fertilisers and pestices;
  - Agricultural machinery;
- Know-how
  - Agrarian knowledge;
  - Education (language and mathematics);
  - Extension workers to dissipate best practices;
  - Association to exchange experience and know-how;
  - Exchange with foreign agricultural institutes;
- Access to credit

This list is not meant to be exhaustive, but as an indication of what is needed.

To improve their agricultural practices, the Government of Mozambique is employing so-called 'extension workers' that travel to production areas, and train local farmers on how to get the best returns on their investments, efforts and land. In order to reach a fast build-up of capacity, it is important that enough extension workers are trained. It is recommended that the Government starts an intensive training program for extension workers. This can be done in several forms:

- By requiring project developers to contribute to this process, either financially or by training the workers directly.
- By requiring project developers to make their agricultural machinery available to training centres on weekends, or days that the equipment would normally not be used.

The key to improving agricultural practices is better access to knowledge. Therefore, improving the level of proficiency in Portuguese and/or English in reading, writing and speaking is essential.

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Appendix A Assumptions and data for eucalyptus pellets

A 1 Eucalyptus biomass production

The establishment and management of each sub-module are executed according to the planning shown in Table 13, which is then repeated every seven years. Activities like land clearing and site preparation are only performed once, at the beginning of the project.

Table 13: Planning for an individual Eucalyptus sub-module

Feedstock production	Year -->	0	1	2	3	4	5	6	7
Direct costs (labour)									
Land clearing / site preparation	USD/ha	1000							
Land preparation	USD/ha		250						
Planting	USD/ha		240						
Herbicide/pesticide application/weeding	USD/ha		30	30		30			
Fertiliser application	USD/ha		50	50					
Irrigation	USD/ha		50						
Intermediates									
Seedlings	USD/ seedling	0.3							
Seedling density	trees/ha	1200							
Seedling costs	USD/ha		360						
Herbicide/pesticide	USD/ha		70	70		70			
Total fertiliser	USD/ha		150	150					

The costs of the individual steps are based on cost data from Brazilian Eucalyptus plantations for charcoal production in the state of Paraná (Rodigheri, 2007; IPEF 2009; Melhoramentos 2009). The costs for manual labour have been adapted by reckoning with time and labour involved.

Land clearing and site preparation

Land clearing is mostly a manual operation for outgrowers, but can be mechanised for large-scale estates. Costs can vary significantly depending on the type of terrain to be cleared.

Land preparation

The minimal cultivation system is based on minimal intervention, i.e. minimal ploughing of the soil and leaving organic residues (both of the culture in question and invasive plant species) on the ground as a dead cover. It includes only a localised soil preparation (tilling) in the planting line, and since large spaces between lines (3m) are

typical for forest plantations, the volume of ploughed soil is a lot less than for annual crops.
Minimum cultivation reduces nutrient and organic matter losses and maintains important physical properties like porosity, and has therefore been accepted by many managers as a means of maintaining or increasing soil fertility in the long term (Gonçalves et al. 2004). A study by Oliveira et. al (2009) shows that initial planting costs are reduced as a result of applying minimum plantation techniques.

Costs are based on 10 tractor hours/ha, at a cost of 25 USD/tractor hour.

Planting
When the land has been prepared, planting can be done with the aid of planting tools ("chuchos"). In the presence of termites, the seedlings are first immersed in an anticide solution before they are planted. Plantings for short-rotation coppicing stands generally have spacing of 3m x 3m (1200 stands/ha).

Seedlings are assumed to be imported from South Africa, where seedling production occurs on a large scale, at a cost of 0.3 USD/seedling.

Irrigation
Watering is performed in order to provide enough humidity to the seedlings to survive (see Figure 23). Note that this is not the same as land irrigation, which requires expensive infrastructure. Irrigation can be applied if planting is done during dry season, and more than 3 litres of water per plant are recommended, once, right after planting (Melo-Sixel and Mariani Gomez 2008).


Figure 23: Irrigation at initial stage of plantation. Source: IPEF

Fertilisation

Between 70 to 80% of the nutritional demands for eucalypts occurs in the initial phase of the development (Melo-Sixel and Mariani Gomez 2008). Both base and cover fertilizing occur 3 or 4 times up to the age of 24 months, by the time the crown closes in and nutrient cycling begins. In the initial phase large doses of P are applied, and only from the second application larger doses of N and K.

Plantations are often characterized according to their level of technology. Technology in this context means various degrees of fertilizer and herbicide use.

Costs of fertilizers are assumed to be 150 USD/ha/year over the first 2 years, plus labour costs for application.

Yields

Yields are related to agro-ecological potential, where rainfall, nutrient availability and solar irradiation are the key factors. For Mozambique, the theoretical maximum yield averaged over the years of growth until harvest can be about 35t_{dm}/ha/yr (70m^3). Average wood volume of 512 m^3/ha/yr was reported at IFLOMA (Manica) after ten years, which corresponds to about 26 t_{dm}/ha/yr, or 52 m^3/ha/year (Batidzirai 2006). The average yields are however much lower, when taking into account land suitability.

We assume that both genetic improvements (new varieties) and learning in the forestry industry (and training of new staff / smallholders) will contribute to improved yields over time, from an average of 28 m^3 per year to 36 m^3 per year by 2030, as shown in the table below.

Table 14: Yield improvements assumed

Planting year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Harvest year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
yield at harvest (m3/ha)	**200**	204.5	209.1	213.6	218.2	222.7	227.3	231.8	236.4	240.9	245.5	**250.0**
Mean annual increment (MAI) (m3/ha.year)	28.6	29.2	29.9	30.5	31.2	31.8	32.5	33.1	33.8	34.4	35.1	35.7

According to this table, the full pellet plant capacity (60ktonne of pellets @ 10% moisture content) should be reached by 2015 with 30 m^3/ha/year, which is equivalent to 15 oven-dried-tonne/ha/year.

In reality yields will depend heavily on rainfall, soil conditions, and management practices.

A 2 Eucalyptus harvest and transport

The harvesting and road transport costs used in the model are detailed in Table 9. Most costs are derived from an investment plan for Eucalyptus plantation for pulp production, which is also designed for producing wood chips (Savcor – WWF 2010).

Table 15: Eucalyptus harvesting and transportation costs

Harvesting operations	Unit	Cost	Source/comment
Government royalty	USD/m^3[11]	1.6	from Savcor 2010
Felling, branching and peeling	USD/m^3	2.5	from Savcor 2010
Forwarding to roadside	USD/m^3	2.5	from Savcor 2010
Chipping	USD/m^3	2.3	from Savcor 2010
Total harvesting operations	USD/m^3	8.9	
Primary Transport costs (trunks)	USD/ton.km	0.12	Based on average transport costs in Brazil in 2008 for distance <50 km of 0.3 BRL/ton.km (from STCP 2009) and lower machinery use in MZ.
Secondary transport costs	USD/ton.km	0.12	Same as primary
Loading + unloading costs truck	USD/m^3	0.6	Batidzirai 2006

Table 16: Ocean freight for pellets

Item	Unit	value	Comment
Ocean freight (Suezmax bulk carrier)	USD/ton	5	based on Shipping from Nacala to Rotterdam (about 10,000km) on Suezmax ocean bulk carrier (150,000 ton) Derived from van Vliet et al 2010
port charges	USD/tonne	14	Batidzirai 2006
Loading + unloading costs ocean terminal	USD/ton	11	Batidzirai 2006

A 3 The pelletisation process

Wood from various types of trees can be used trees can be used for the manufacturing of wood pellets. Often the cleaned raw material is mixed from several kinds of wood to ensure homogeneous lignin content. Lignin (a wood component) binds the pellets together. The amount of lignin varies between different types of trees, where

[11] One cubic meter of freshly harvested wood, is equivalent to 1 tonne of biomass, with a moisture content of 50%.

Eucalyptus hard wood normally has a lower content of lignin than soft wood. Therefore, natural binders such as potato starch and maize or vegetable oil may also be used.

From the point that the raw material is received at the pelletising factory to the point that the pellets are ready to deliver, the raw material goes through three main processes - grinding, pelletising and cooling – see Figure 24 for a graphic representation. The water content of the biomass must be about 10%, so a drying step is needed upstream.

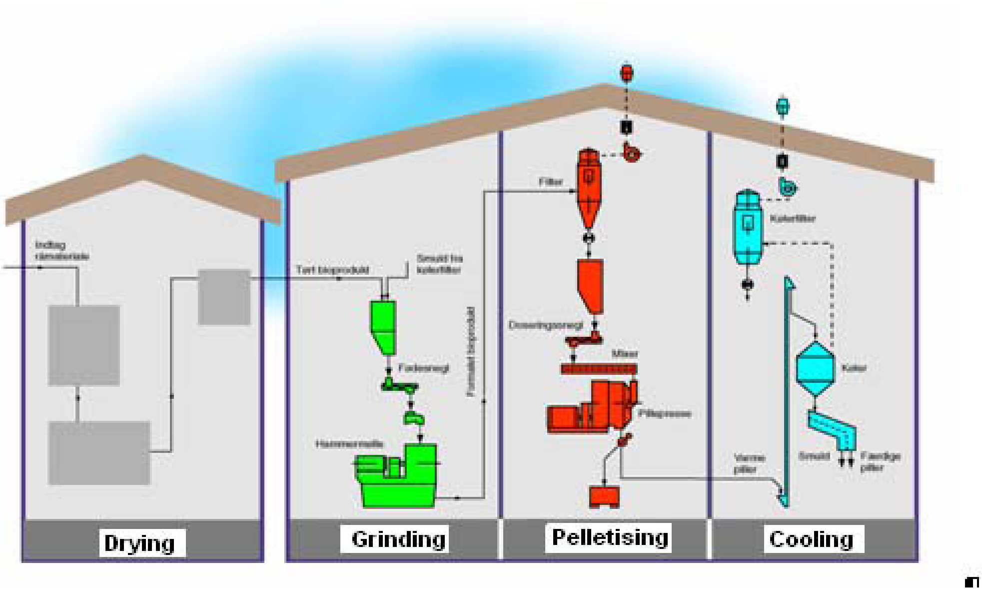

Figure 24: Flow diagram of the pelletisation process. Source: Pellet Atlas 2002

Type of pellets

The dimensions of fuel pellets vary between 3 and 25 mm in diameter depending on the die block that is used in production. The length generally varies between 5 and 40 mm. If the product exceeds 25 mm in diameter it is called a briquette.

Investment costs pellet plant

Investment and operational costs for a pellet plant are derived from the study of Uslu et al (2008) about a plant at the Energy Research Centre Netherlands (ECN). These costs are outlined in table 11.

Table 17: Investment costs pellet plan

Item	Cost	Comment
Investment	€6.2 M Euro	(Uslu 2008, based on 40MWth input
O&M costs	5% of investment costs	

A 4 Price of pellets

Pellets are mostly sold over the counter (OTC) in individually negotiated contracts, but several exchanges also provide indexes which allows for more standardised products and prices. The reference price used in this case is the CIF price at port or Rotterdam, as reported by the APX/Endex (Amsterdam Power Exchange).

Non-torrefied pellet prices for industrial use have varied from 100 to 125 Euro/ton in the period 2005-2010 with peaks at 140 Euro/ton, while pellets for residential use have varied from 150 Euro/ton to 190 Euro/ton during the same period (Consufor, 2010). The base price used for this business case is 120 Euro/ton.

A case for torrefied pellets?

For the business cases of this study we chose to look at the largest market, which is the one for industrial use, mainly through co-firing in coal-fired power plants. One advantage of torrefied pellets for co-firing is their hydrophobic nature, which allows them to be stored in open air, saving the power plant the costs for building a storage silo. Another advantage of torrefied pellets is their grindability, compared to non-torrefied pellets. Although these benefits have assured torrefied pellets a significant premium over non-torrefied pellets in the past, the current market does not seem to value these benefits, as many power plants already have built silos, and therefore see no benefit in the torrefied material.

Coal-fired power plants can typically co-fire about 15% normal pellets, but beyond that percentage, only torrefied pellets are suitable, which means that torrefied pellets are likely to regain their advantage and price-premium towards 2030[12].

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[12] Based on an interview with a coal fired power plant operator.

Appendix B Assumptions and data for sugar cane ethanol

Sugar cane is a sugar producing perennial C4 grass originating from Asia. Over the last decade, sugar cane cultivation has increased significantly in Mozambique: from 27 000 ha in 2000 to 180 000 ha in 2008. The largest area of sugar cane cultivation is located in the Maputo province (INE (Instituto Nacional de Estatística), 2002). Sugar cane is mainly (60%) produced by large agricultural businesses (> 50 ha).

Yields vary significantly according to scale, management and location of production. Average yields of 65 tonne/ha have been reported (2003/2004) (LMC International Ltd, 2004), although yields as high as 120 tonne/ha are possible depending on management and varieties. The harvested yield is 77% of the total fresh sugar cane production. Tops and leaves form 14% of the total biomass (Macedo and Seabra, 2008). Most of the sugar cane is used for sugar production but the use for ethanol production is emerging rapidly. Because of the high water requirements of sugar cane and the irregular precipitation patterns in Mozambique, all commercial sugar cane plantations use irrigation.

B 1 The ethanol conversion process

Sugar cane contains high amounts of sucrose or reducible sugars which can be fermented into ethanol by yeasts. Sugar content is usually expressed as the amount of total reducible sugars (TRS) per ton of cane (TC) [kgTRS/TC].

Sugar cane cannot be stored for more than a few days and mills operate only during the harvest period, irrespective of the type of facility. The initial processing stages for bioethanol are basically the same as for sugar production, as shown in fig 25.

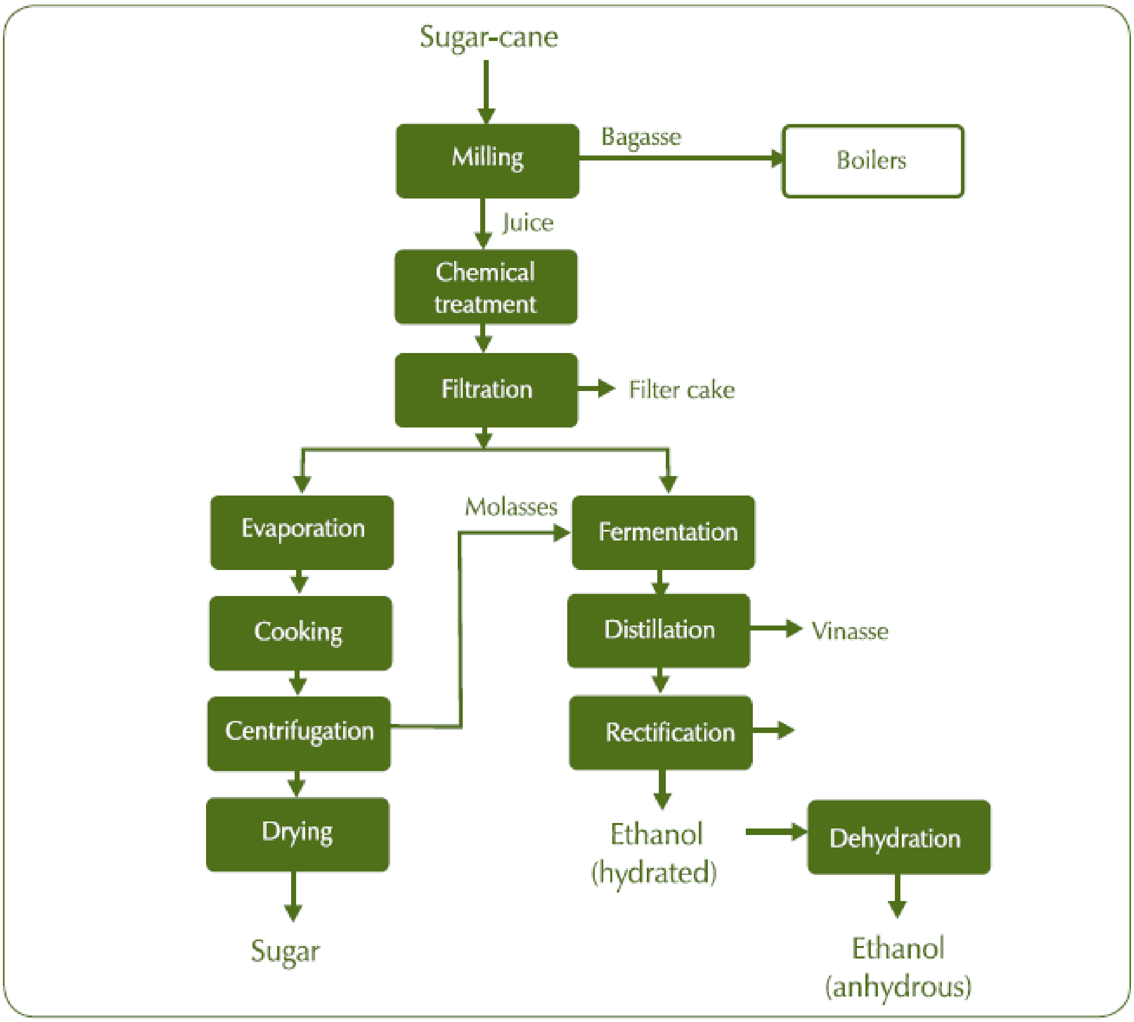

Figure 25: Simplified overview of industrial bioethanol production from sugar cane. Source: BNDES - CGEE 2008

The figure shows two kinds of ethanol, namely hydrated and anhydrous ethanol. **Hydrated ethanol** can be used as a transportation fuel in flexi-fuel vehicles, whereas only **anhydrous ethanol**, also called fuel-grade ethanol, is suited to be mixed with gasoline (gasohol).

During the conversion process the cane is **washed** to remove organic material from the field and **shredded** into smaller pieces of 20-25 cm. After these pre-treatments the feedstock is fed to and **extracted** by a set of 4-7 mill combinations into juice and bagasse. The main objective of the milling process is to extract the largest possible amount of sucrose from the cane. A secondary and increasingly important objective is the production of bagasse with low moisture content to serve as fuel for the boilers. The boilers supply enough electricity and steam for the process to be self-sufficient. If the plant is large and efficient enough, it can even deliver electricity back to the grid.

The cane juice is filtered and **treated** by chemicals and pasteurized. Before increasing the concentration of sugar by evaporation, the juice is filtered once again which leads to the creation of another useful by-product named vinasse[13]. The evaporation process increases the sugar concentration of the juice from 14-16° Brix[14] up to 50-58°Brix. The syrup is then crystallized by either cooling crystallization or boiling crystallization. Crystallization leads to a mixture of clear crystals surrounded by molasses with a concentration of 91-93°Brix. Molasses are removed by **centrifugation**, and the crystals are washed by addition of steam, after which the crystals are dried by an airflow.

Molasses undergo another pre-treatment including pasteurization and addition of lime again, which leads to a sterilized molasse free of impurities, ready to be fermented. In the **fermentation** process sugars are transformed into ethanol by addition of yeast. Fermentation time varies from 4-12 hours, chemical efficiencies range from 80-90%, resulting in an alcohol content of 7-10°vol, called fermented wine. The wine is centrifuged in order to recover the yeast, and distillated in order to increase the alcohol concentration. The result is **hydrated ethanol** with a concentration of 96°vol.

Hydrated bioethanol can be stored as final product or may be sent to the **dehydration** column. Nevertheless, as it is an azeotropic mixture, its components cannot be separated by distillation only. The most commonly-used technology (in Brazil) is dehydration with addition of cyclohexane, forming a ternary azeotropic mixture, with boiling point lower than that of anhydrous bioethanol. In the dehydration column, cyclohexane is added on top, and the anhydrous bioethanol is removed from the bottom, with nearly 99.7° vol or 0.4% of water in weight. The ternary mixture removed from the top is condensed and decanted, while the part with high water content is sent to the cyclohexane recovery column.

Bioethanol dehydration also can be made by **adsorption with molecular sieves** or by means of **extractive distillation** with monoethyleneglycol (MEG), which stand out as providers of **lower energy consumption**, as well as by their higher costs. Due to increasing requirements in foreign markets, bioethanol producers in several countries have been choosing the latter option, since it allows the production of anhydrous bioethanol free from contaminants.

The possibility of using sugars from sugar cane to produce varying proportions of bioethanol and sugar represents a significant adaptation technology in this agro industry, which sugar mills can use to arbitrage — within certain limits — a cost-effective production programme, depending on fuel and sugar market conditions.

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[13] Vinasse can be used as a fertilizer in the field.

[14] Degrees Brix is the amount of soluble solids (fermentable sugars), in 100 parts of liquid

Appendix C Summary workshop Mozambique:

Workshop large-scale production of biomass in Mozambique for the Dutch Market?

Maputo, 18 February 2011

In 2009, the Platform Groene Grondstoffen (Platform Renewable Resources) has given the onset in developing concrete transition paths. In order to define and delineate the transition path Duurzame Biomassa Import (sustainable biomass import), a feasibility study was conducted on large-scale biomass production in Mozambique and biomass import for the Netherlands for the biobased economy, including energy. This study was delegated to Ecofys and the Utrecht University.

Workshop Mozambique

Together with the local counterpart CEPAGRI and assistance of the embassy, NL Agency organised a workshop in Mozambique to discuss the concept results of the feasibility study on February 8. In total 45 participants partook in this event, representing mostly the Mozambican government, companies and NGOs. The workshop was opened by the ambassador of the Netherlands, Mrs. Frederique de Man, and Roberto Albino, director CEPAGRI of the Mozambican Ministry of Agriculture. The ambassador foresees the opportunities for Mozambique, but pointed-out that more local development is needed. CEPAGRI notified that all biofuel projects are carefully evaluated before permission for implementation is provided. After the peak year in 2008, which included 12 projects proposals, six projects proposals were received in the last two years. Since 2007, 7 large scale projects were approved for biofuels; mainly for the production of jatropha for biodiesel and sugarcane for ethanol. One of these projects was revogated in 2009 leading to 6 projects under exploration for an area of 66.056 hectares.

Subsequently Kees Kwant, expert bio-energy at NL Agency, presented the demand for sustainable biomass for a biobased economy. Moreover the authors of the feasibility study illustrated their concept results. The study showed that a large area of 14 million hectares can be made available for biomass production, if the agriculture in Mozambique is to be improved. The participants suggested that the agricultural development could be part of a public-private partnership in order for provide companies specialized in biomass the possibilities to independently carry out initiatives in the field.

Business cases

Within the study, two business cases were dealt with: bio-ethanol from sugarcane and pellets made of Eucalyptus wood. However, the actual implementation of the cases requires substantial time before production can take place. Hence investments will be earned back in the long-term. Therefore, the audience proposed that it is better to make use of agricultural residue material in order to directly make earnings in the short-term. The participants were actively involved in the discussion and contributed much on the opportunities for the sustainable implementation of biomass production. Those present sensed ample potentially prosperous outcomes, which also concerned biofuels in Mozambique. This caused some hesitation towards simply exporting locally produced biomass. This same principle applies to Eucalyptus trees, which are already being exploited for cooking purposes. Some participants stressed that the basic condition of food security must be met sufficiently.

Therefore, developments must be taken step by step which entail improving agricultural practise, elevating rural development and that the production capacity of biomass intended for export is increased. Export of biomass to the Netherlands is a possibility but requires a thoughtful approach because the participants were cautious of the fact that locally produced resources may simply be exported and leaving the country deprived.

Follow-up

The follow-up workshop on this study will take place in Rotterdam on 23/24 March. Hereby it will be assessed whether Dutch companies will embrace the developed business cases and ideas.

More information

The programme of the workshop and the presentations can be downloaded at http://regelingen.agentschapnl.nl/content/large-scale-production-biomass-mozambique-dutch-market

Appendix D Summary workshop The Netherlands

Workshop: Possibilities for sustainable biomass production and export in Mozambique
Rotterdam, 23 March 2011

The workshop was opened by Mr. Ruud Lubbers, former Prime Minister of the Netherlands, chair of the council of the Rotterdam Climate Initiative and ambassador for the Rotterdam biomass approach. He gave a welcome to the participants, especially to Dr. Antonio Said, director Renewable Energy of the Ministry of Energy from Mozambique. He expressed his interest in the development of biomass in a sustainable economy and the role of the harbour of Rotterdam and the need for cooperation with developing countries on this subject.

The potential supply of biomass from Mozambique was presented by Floor van Hilst and Carlo Hamelinck from Utrecht University and Ecofys. When proper Agricultural measures are taken (progressive scenario) the available land for biomass production could double to 14 million hectares and could become available for Eucalyptus plantations or sugarcane for bioethanol. A roadmap was presented to safeguard the development over a longer time (see report).

Dr. Said gave his reaction on the report and expressed his support for the progressive scenario, but also asked the question: what investment is needed for this, and who is going to pay for that? The Mozambican government has developed a biofuels strategy, including a solid biomass strategy and will set up a Commission to look after the proper implementation. Mozambique is interested in biofuels because of oil prices, which result in a burden on the national balance. The land is owned by the government, but companies can lease the land for 50 – 100 years for biofuel projects. These projects have to obtain approval from the government and will be evaluated after 2 years. Private sector will realise the production in Mozambique and the government will facilitate it. A proposal for an obligatory blending of 10 % Ethanol and 5% biodiesel is under negotiation in the government.

Mozambique has a policy to produce more biomass and biofuels in a sustainable way and will try to link subsistence farming and bioenergy with better technologies to create income. Increased food production should be linked to bioenergy production. The Mozambican government works on a more detailed map of the country and zoning will be introduced to avoid the wrong use of land. A national biofuel sustainability framework was set up and integrated in the above mentioned Project Application and Land Acquisition Process. This Framework still needs to be operationalised and implemented and Mozambique is looking for cooperation with the Netherlands on this issue.

The companies from the Netherlands expressed their interest in the potential of the biofuels and biomass production in Mozambique. Due to the local market the first interest appears in production for local consumption. Only when a certain level of scale of operation can be achieved (e.g. 500.000 tons/year) investments in exporting to the Netherlands seem feasible. It will take several years before that situation can be achieved. Mr. Said stressed that Mozambique is also part of the SADEC region and that also a large growing market in this region will take place.

It was concluded that the potential for a sustainable biomass and biofuel production in Mozambique exists. In the short term the local use will increase and in the longer term the export potential can be exploited.