Swedish University of Agricultural Sciences
Faculty of Forest Sciences

Department of Forest Products, Uppsala

A Comparison of Three Bioenergy Production Systems Using Lifecycle Assessment

Zakia Hassan

Master Thesis
No 40 2009

ISSN 1654-1367

Swedish University of Agricultural Sciences
Faculty of Forest Sciences

Department of Forest Products, Uppsala

A Comparison of Three Bioenergy Production Systems Using Lifecycle Assessment

Zakia Hassan

Keywords: CO_2, bioenergy, pellets, ethanol, degraded land, LCA

Master Thesis, 30 ECTS credits *Advanced D-level in Forest Management*
(EX0307) MSc European Forestry 06/08

Supervisor: Karl-Erik Johansson, Mats Olsson
Examiner: Anders Roos

Abstract

Fossil fuel contributes to global warming through emissions of greenhouse gases such as CO_2. Measures to reduce these gases may affect food security due to the productive land allocated for bioenergy production. The aim of this study was to show how leguminous tree species can contribute to the sustainability and economy of bioenergy production systems on degraded land. Specific objectives were; firstly, to describe how energy is produced by *Eucalyptus*-pellets, *Sesbania*-pellets and sugarcane-ethanol systems through out the life cycle (LCA), and secondly, analysis of emission reduction by these bioenergy systems. The empirical background data used consists of data collected from different reports and investigations. The studied reports cover a broad range of site conditions and methodological approaches. As the analysis was based on secondary data, an inventory was carried out for energy input and output, emission and uptake of CO_2 from all stages in the life cycle of the assessed products. It is interesting in this study to have incredible bioenergy production yet it is difficult to obtain enough consistent data. However, it reveals some remarkable outcomes that can guide future research. Such outcomes included the high potential for sustainable bioenergy production on degraded land by using improved fallow with *Sesbania* which reduces the energy input, costs and emissions from using commercial N-fertilizers.

Keywords: CO_2, bioenergy, pellets, ethanol, degraded land, LCA.

Acknowledgement

My sincere gratitude and appreciation go to my supervisors Mr. Karl-Erik Johansson, Department of Forest Products, Uppsala and; Prof. Mats Olsson, Department of Soil and Environment, Uppsala, for their intellectual and professional guidance and sincere interest in this study. Their comments, moral encouragement, time, effort and willingness, motivated me to achieve my thesis.

I would like to extend my thanks to Mr. Roland Hörnfeldt for his assistance in administrative and practical matters toward the successful accomplishment of my studies in Uppsala.

I would like to acknowledge Erasmus Mundus for the financial opportunity to support and participate in this master of European Forestry.

Zakia Hassan

Dedication

All thanks and praised be to Allah, the most thoughtful and forgiving. My special thanks to my husband Rajabu and son Tafi for their moral encouragement, appreciation and patience all the way through my study. I would like to express my great respect to my parents who brought me up and showed me the value of education. Also, I would like to dedicate my brothers and sisters for being a continuous source of inspiration and support during my study.

Table of content

List of Tables

List of Figures and Illustrations

1. Introduction

1.1 Background

Global energy use from fossil-fuel combustion, accounts for more than two-thirds of the global anthropogenic greenhouse gas-emissions (Arnalds 2004).The potential consequences of global warming include changes in weather patterns and soil hydrology, loss of snow cover, permafrost melting, and the rising sea level and temperatures. The Kyoto Protocol was signed in December 1997, and established three flexible mechanisms; International Emissions Trading (IET), Joint Implementation (JI) and the Clean Development Mechanism (CDM) to allow countries to meet their emission-reduction targets partly through the use of market-based mechanisms.

IET allows any country that is above its emission-reduction target to trade its surplus quota with countries that do not meet their targets. JI allows developed countries to meet their targets partially by carrying out projects in developing countries that lead to emission-reductions in the host country. Through the CDM an industrialized country can invest in plantation projects in developing countries to meet its greenhouse gas reduction target. The investing country will receive credits for the achieved emission-reduction while the host country will benefit from technology transfer and sustainable development.

One type of project allowed under the CDM is forestry (reforestation or afforestation), based on the underlying principle that trees absorb carbon dioxide (CO_2), one of the main greenhouse gases. CDM creates an opportunity to attract investment and technology transfer through projects such as renewable energy development. The production of bioenergy (pellets and ethanol) from biomass is among these projects. The CDM project approval-process includes an assessment of the ecological and socioeconomic impacts of the measures undertaken.

There is a need for a global energy system to combat climate change and ensure energy security in the future and to create alternatives to fossil fuels. Bioenergy production from sugarcane (ethanol) and pellets from plantation forest are regarded to be such sustainable alternatives for reduction of CO_2 emission (Wahlund *et al.,* 2004). These systems also have the potential to improve local livelihood, decrease dependency on fossil fuel import, increase export earnings and decrease the need for foreign currency (Beeharry 1996 and Kauzeni *et al*., 1998).

However, production of bioenergy is demanding of existing land resources and its massive promotion in developing countries as an alternative to fossil fuels, may compete with land use for food production to surrounding communities (Blomqvist 2007). Furthermore, large quantities of organic material are being continuously removed from the ecosystems, which may gradually decrease their production potential. In addition, if commercial fertilizer is used to replenish soil fertility, CO_2 emission (Ståhl 2005) increases through its production, transportation and distribution.

To solve the potential problems embedded in bioenergy production in developing countries, sustainable solutions must be sought with synergy between social, economic and environmental interests. Improved fallows rotations and /or intercropping using *Sesbania sesban* have been proven to increase soil organic matter and improve soil structure (Kwesiga and Coe, 1994, Palm *et al*., 1988 and Ståhl 2005). *Sesbania sesban* increases the distribution and stability of soil aggregates and decreases soil bulk density by using direct physical action of its roots, and increases production of cementing agents from enhanced microbial activities (Sultan *et al*., 2007). Addition to that, *Sesbania sesban* has ability to fix more than 80% of its nitrogen (N) from the atmosphere (Ståhl 2005).

1.2 Aim and objective

Aim

The aim of this study was to improve the understanding of how leguminous tree species can contribute to the sustainability and economy of bioenergy production systems. A purpose of the study was to improve my understanding of the use of life cycle assessment (LCA) in relation to bioenergy production.

Objectives

The objective was to compare three bioenergy systems, with the criteria of net removal of CO_2 from the atmosphere per energy unit:

A) *Eucalyptus* to pellets
B) *Sesbania* to pellets
C) Sugarcane to ethanol

Different combinations of crop rotation using improved fallow with *Sesbania* are also analyzed:

i) The *Sesbania*-pellet with the sugarcane-ethanol systems and
ii) The *Sesbania*- pellet with *Eucalyptus*-pellet systems

1.3 Problem statement and validation of the study

Sustainable energy production and supply has become a major problem in developed and developing countries. A majority of these countries use non-renewable energy sources such as diesel, petroleum and coal. Further, biomass (wood fuel) is used; however, this might be done in an unsustainable manner. Consequently, there has been a severe environmental degradation (pollution and deforestation) (Karekezi 2002).

The establishing of forest or sugarcane plantations for production of bioenergy are alternative means for reduction of carbon dioxide emission because the biomass produced can substitute fossil fuel. If the plantation is replanted after harvest the new generation will take up the emitted CO_2 from combustion, and hence, the use of biomass as fuel is almost CO_2 neutral (Holmgren *et al*., 2007). The use of bioenergy is in high demand for daily energy consumption in industry, offices and households for different purposes such as cooking, heating and machine operation.

The major problems in bioenergy production and supply are energy availability and security, food security and; environmental protection. It is land demanding, since the production of energy in the form of biomass per ha is low. In some areas, lead to land use conflicts and competition with food production. This might result in poor harvests and a rising food deficit. This is due partly to less land availability, and partly to the use of marginally less fertile and more remote land where expensive commercial fertilizers may similarly be used.

An effective way to overcome these conflicts is the production of sustainable bioenergy that meets the 3 pillars; social, economic and ecology/environment for sustainable development.

This will be achieved by using abandoned land, planting fast growing and multipurpose tree species, utilization of by–product from sugarcane and motivating local capacity to handle bioenergy production.

This study will explore the life cycle of three bioenergy systems; in respect to emission of GHGs. The findings will be useful in making bioenergy production to be sustainable for mitigation of climate change. The problem could be solved through accelerated afforestation/reforestation and by increased use of improved fallow with nitrogen fixing plants to replace the commercial fertilizer.

2. Literature review

2.1 Energy over-view

Energy is a basic need and a crucial input to meet social-economic development goals. Countries must have adequate energy service to meet household needs as well as the needs of the productive, transport and service sectors. Energy availability affects all other economic activities as well as the environment, both directly and indirectly. The social welfare of the people is directly linked with the energy sector through energy supply and consumption.

2.2 Importance of bioenergy

The demand for energy is quickly increasing with a growing population and global development in the north and south. This increasing demand gives rise to further increases in greenhouse gas (GHG) emissions. Bioenergy technologies based on sustainable biomass supply are carbon neutral, or at least almost neutral, and lead to net CO_2 emission reduction as alternative to fossil fuels (Blomqvist 2007). Alternative energy sources are gaining popularity because of concern for the increasing greenhouse gas effect (Beeharry 1996).

Bioenergy has the advantages to deal with sustainable energy issues, in term of environmental, energy security and developing the economy sector as a whole. Furthermore, it will help to facilitate the development in rural areas and improve the energy security (Baral and Guha 2004). From a global warming perspective, bioenergy is one alternative to fossil fuel combustion for power generation and is part of a larger strategy for mitigating greenhouse gas-emissions by removing carbon dioxide from the atmosphere as they grow and storing it in biomass. Biomass is stored energy and can be converted to bioenergy; there is a wide range of biomass sources, for example, energy crops, agricultural wastes, food, fibre and wood process residues (FAO 2008). Bioenergy can be used in so many different ways as fuel either by burning directly (firewood or charcoal) or by processing into solid fuels (pellets) or liquid fuels (ethanol). The use of energy from biomass is a long-term approach since harvesting and replanting can be carried out in many decades. Utilization of tree plantations for bioenergy might be a more successful approach for carbon mitigation rather than growing trees as a carbon sink (Hall and House 2008).

Production of bioenergy by growing short-rotation trees, such as *Eucalyptus*, could sequester carbon at a higher rate than trees with a longer rotation period (Lemma et al., 2006, Holmgren *et al*., 2007). Also, the use of bioenergy instead of fossil fuel will reduce the effect on global warming. However, fossil fuel is still required for land preparation, transport of commercial fertilizer, production of herbicides and insecticides, harvesting and transport of wood to industry and end user. During these processes, there is a considerable emission of $CO_{2,}$ however, there is a possibility to substitute a part of this energy need with biofuels and, thus, further increase the CO_2 neutrality of the system.

Ethanol

A biomass contains the significant amounts of sugar, or materials that can be converted into sugar such as starch or cellulose, can be used to produce ethanol. These are including sugar cane, sugar beet, sweet sorghum, maize, wheat and cassava. Ethanol can be used either pure or be blended with petrol gasoline and diesel to improve fuel combustion in vehicles, thereby reducing the emission of carbon dioxide .Presently, approximately 85 percent of the global production of liquid bioenergy is in the form of ethanol. The two largest ethanol producers, Brazil and the United States of America, account for almost 90 percent of total production. Ethanol produced from sugar cane biomass considers as one of the modern forms of bioenergy that has the potential to be a sustainable transportation fuel for gasoline engines. Ethanol can be used for a wider range of applications, including transport, high-temperature industrial processes and cooking stoves (FAO 2008).

Pellets

Pellets are solid form of bioenergy can be directly combusted to provide cooking fuel, heating or electricity production. They are easier to transport and store than any other form of solid bioenergy. The use of firewood and charcoal as fuel sources are traditional methods which cause insufficient utilization of bioenergy and air pollution (Karekazi 2002). Also, they have low energy content and are therefore lands demanding with increasing deforestation as a result. The use of pellets is a possible alternative with the potential to improve this situation and enhance development by having access to modern energy technology.

2.3 Plantation for bioenergy options

Plantations can be established for afforestation and/or reforestation by using seedling, seed and/or coppicing. *Eucalyptus* is an important species for bioenergy plantation because of its propagation ability through coppicing, and short rotation age. Establishment starts with planting, and the stand is harvested every 6 years and regenerated by coppicing. The production cycle of *Eucalyptus* comprises establishment (soil preparation, planting and fertilization), management operations and harvesting (cutting) and transportation to the end user (Broek *et al.,* 2000).

Eucalyptus is a fast-growing tree species used as a biomass source for bioenergy and for pulp and paper manufacturing. With its high biomass yields, it might in the future be used more and more for the production of bioenergy. *Eucalyptus Camaldulensis* has an ability to produce 15-40m^3/ha/yr within 5-15 years rotation age (Cosalter and Smith 2003). Zewdie (2008) reported 9 years old *Eucalyptus*-coppice with a total yield of 153 ton /ha.

In addition, *Sesbania* trees have potential for bioenergy production. The plantation of *Sesbania sesban* could produce a total amount of woody biomass (oven-dry) between 44.6 ton/ha to 101 ton/ha at 4 years age (Rao and Gill 2000) and according to the findings by Kwesiga and Baxter 1998, *Sesbania sesban* at 1-3 years old gives a yield range of 10-35 ton/ha of fuel wood.

Sugarcane can be used for production of bioenergy. A sugarcane plantation can be harvested more than once because it has the ability to regenerate new stalks after harvesting. A total of 150ton/ha/yr of biomass can be harvested from well managed sugarcane plantations (Tarimo and Takamura1998).The use of ethanol as bioenegy from sugarcane has contributed to the mitigation of CO_2 emissions and would help to add value to producer , in that way improving their incomes .

2.4 Degraded land

According to Koh and Ghazoul 2008, greater demand for bioenergy will lead to greater demand to food as productive lands used for bioenergy production. Competition for land becomes a hot topic particularly when a number of the food crops (e.g. maize, oil palm and Soybean) used for bioenergy (FAO 2008) or force agricultural crops produced on degraded lands. This could lead to food shortages and higher food prices.

Degraded land is land that was previously used for agriculture or pasture but that has been abandoned due to low soil nutrient and deficient in water availability (FAO 2008). *Sesbania* *sesban* and *Eucalyptus* can tolerate these conditions and let bioenergy not compete with food production as the same time reduces carbon dioxide emission as alternative to fossil fuel.

2.5 Mitigating climate change by carbon sequestration

Greenhouse gas emissions during establishment of bioenergy plantation are made up of carbon dioxide from cultivation, fertilizers, pesticides and fuel used in farming, during processing, transport and distribution, up to final use (FAO 2008). Carbon dioxide is the green house gas which is the main contributor to the global warming. Forest plays a great role of reducing global warming by sequestering of carbon from the atmosphere. Plants take up carbon through photosynthesis and act as a carbon sink during their life cycle or rotation period. The carbon stock (Figure 1) which is allocated above the ground (leaves stem and branches) and below ground (roots) is released back to the atmosphere after combustion (as bioenergy) or decomposition (as tree left in the forest) (Baral and Guha 2004). Bouwman and Leemans 1995 (in Lemma 2006), reported that, a total amount of 50 ton/ha of carbon might be sequestered within 3 decades by establishing a new trees plantation. This process could be particularly successful when trees are fast-growing (Montagnini and Porras 1998, in Lemma 2006); with an ability to sequester 4.5-8 tons of C/ha/y (Baral and Guha 2004).

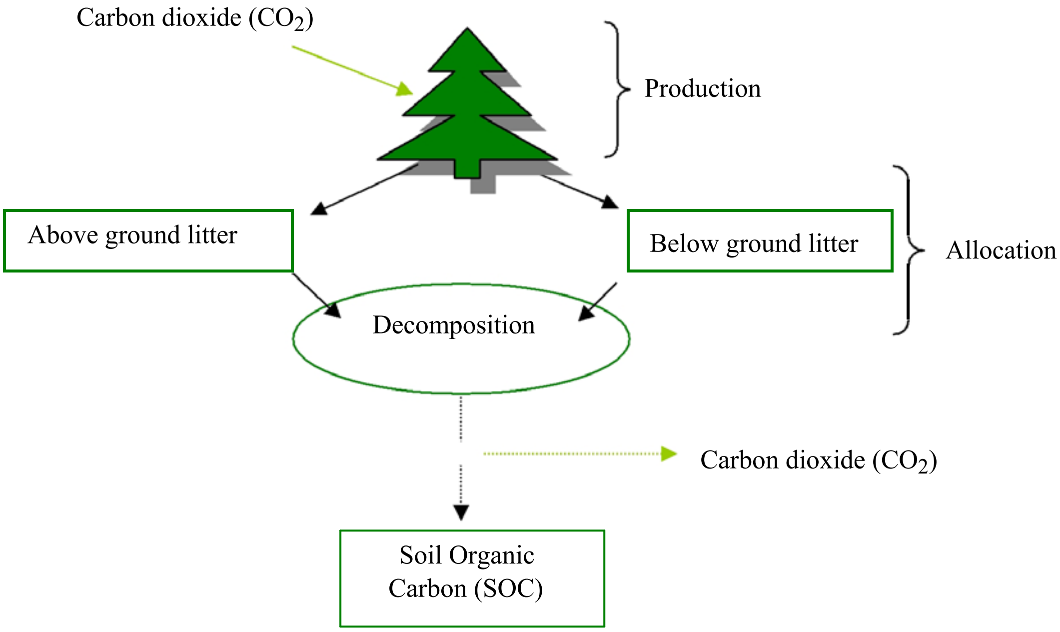

Figure 1. The process of carbon sequestration showing production, allocation and decomposition of organic matter.

2.5.1 Carbon sequestration in the soil

Soil carbon sequestration is the process of transferring carbon dioxide from the atmosphere into the soil. The carbon sequestrations rate depends on the trees rotation length, litter supply, decomposition rate, the past land use and management (Baral and Guha 2004 and Lemma 2006). Also, litter raking or removal by animals, erosion of top soil and leaching (dissolved organic C) may have an impact. The conversion of agricultural land into forest land increases the amount of carbon in the soil (Schlamadinger and Marland1996).According to Lemma (2006) 43% of net SOC (75.4 ton per ha)[1] is lost after forest clearing and subsequent cultivation during 75 years and 20-50% of the original level (Davidson and Ackerman 1993: In Lemma 2006).

[1]Author convert 75.4 Mg per ha to 75.4 ton per ha

2.6 Nitrogen fixation (improved fallow)

Nitrogen fixing trees have an ability to capture nitrogen (N) from the atmosphere and store it into the branches, leaves and roots and recycle it into the soil (Ajayi *et al*., 2005). *Sesbania sesban* is a fast growing nitrogen fixing tree with high nutrient content and high litter quality (Ståhl 2005). The trees can be intercropped with other crops or as fallow for 1 or 2 years in rotation with non-nitrogen fixing plants. Tree growth is highly dependent on the availability of nutrients in the soil. Nitrogen fixation by trees may increase organic matter in the soil and biomass harvest (Jonsson 1995 and Holmgren *et al*., 2007).

The problem of handling and transporting huge quantities of commercial fertilizers could be avoided by using *S. sesban* intercropping or as fallows rotations with sugarcane or *Eucalyptus*. According to Ajayi *et al*., 2005, the cost for carrying fertilizer bags from the selling area to the crop growing land amounts to about 10-25% of the buying cost of fertilizer.

The advantage of commercial fertilizer is that it can be easily utilized; however, it may not be economically affordable or environmentally friendly in-terms of CO_2 emission. Alternatively, improved fallow with *S. sesban* as fertilizer makes energy production more sustainable (Palm *et al*., 1988) and cost- effective. The crop yield can increase considerably with a fallow period of 1-3 years (Kwesiga and Coe, 1994).

2.7 Lifecycle assessments (LCA) overview

LCA is a tool to evaluate the potential impacts associated with a product and process through compiling an inventory of relevant energy and material inputs and the associated emissions to the environment (World Energy Council 2004).The LCA process is divided into four steps according to Malca and Freire 2006; includes the goal and scope of the study, inventory analysis, impact assessment and interpretation of the results.

2.7.1 Goal and scope of the study

The goal and scope present a general description of LCA of a certain product in relation to the environmental impacts with respect to defined system boundaries. Since, LCA would study the impacts of product or service within a specific time boundaries. In addition, the LCA could be ‘cradle to the grave’ as technical boundaries, that means all stages of the production; for instance, cultivation and production of biomass as raw materials from the forest and pellets as product emit carbon dioxide during combustion and re-absorbed back by the forest (World Energy Council 2004). This is a full lifecycle analysis since analyses all emissions throughout the production phases to waste utilization phase of the pellets (Koh and Ghazoul 2008).

Functional unit

A functional unit is the one which decide all the inputs and outputs of the product. Hence, it is a metric for inputs and outputs of LCA. Functional units depend on setting of goal and the scope of the study and thus are important to consider when comparing LCAs (Davis *et al*., 2008). It is very important feature provides a full description of the product consequent results to be interpreted correctly and compared with other results in an appropriate way (Malca and Freire 2006).

2.7.2 Inventory Analysis

A life cycle inventory (LCI) assessment is the process of establishing all elementary flows of the raw material requirements for the entire life cycle of a product or process. In this phase a qualitative and quantitative data of all inputs and outputs is collected, organized (designing the flow diagrams or tables with unit processes) and compile the results (World Energy Council

2004). The life-cycle inventory influences the results of an LCA and can be used to interpret which inputs or stages have the greatest effect on environmental impacts of the product (Davis *et al.,* 2008).

2.7.3 Impact Assessment

A life cycle inventory assessment (LCIA) analyses the impacts associated with the products during their life cycle such as carbon dioxide released or removed in relation to climate change (World Energy Council 2004). In addition, determine which product emits more carbon dioxide and causes the rise of global warming.

2.7.4 Interpretation

This is the last step in a LCA, analyzes all data and come up with a conclusion as to what are the impacts of the specific product over a lifecycle, which should be the best choice when comparing different product.

2.7.5 Advantages of LCA

LCA is a valuable approach that provides better information for decision-makers to choose the product that has the least impact on the environment amongst alternative products. In addition, LCA identifies on which stage of a product's life cycle needs higher input energy or results into higher carbon dioxide emission or removal (World Energy Council 2004). It helps to present information which is significant for further scientific, decision-making and technical development to make the right option achieving sustainable bioenergy production.

2.8 Previous similar studies

In this part, I present a summary of the previous similar studies recently published. In the recent literature reviews, authors describe bioenergy production in relation to the amount of carbon dioxide emitted. Furthermore, latest reports provide more details of how bioenergy combat climate change. Therefore, I came up with the idea to compare three bioenergy systems by using LCA.

A variety of studies have been done in 2 decades concerning the production of bioenergy and its carbon dioxide emissions and this study is similar to earlier study done by Holmgren *et al* 2008 concerns to the Biofuels and Climate Neutrality–System Analysis of Production and Utilization. In chapter (5) the Lifecycle perspectives are described in details, these include how LCA has been applied, describes the goal and scope of the study, functional unit, and system boundaries. In addition, all the stages of LCA have been described; establishment, harvesting, transport, processing, storage and utilization. LCA for greenhouse gas emissions from a number of solid biofuels were made based on data available in the literature (Table 5.10).The authors have previously been describe the distribution, ecological requirement, growth, yield and uses of the selected bioenergy species (*Eucalyptus camaldulensis*, *Sesbania sesban* and sugarcane) includes (Arbonnier 2004; Bassam 1998; Eldridge *et a*l ., 1994; Mrini *et al.,* 2001; Perera *et al.,* 2005; Smith *et al*., 2001; Sotomayor *et al*., 2000; Tarimo and Takamura 1998; and WAC 2008). Also, Stahl *et al*., 2002; and Stahl 2005 describe an ability of *Sesbania sesban* as organic fertilizer to increase the level of nitrogen (N) through nitrogen fixation by its roots nodule.

3. Study approach

3.1 Methods

The data for this study was collected through various literature reviews. The literature gathered on energy and Carbon dioxide emissions of three bio-energy systems. Lifecycle Assessments (LCA) is a methodological approach that has been used to estimate the energy flows in bioenergy systems (Mohee and Beeharry 1999). The goal of this study was to use LCA approach to compare the three bioenergy systems performed in two decades as time boundaries. The systems that have been considered are the *Eucalyptus*-pellets, *Sesbania*-pellets and sugarcane-ethanol. It includes all energy inputs and outputs for the production cycle such as establishment, harvesting, transportation, refining, combustion, storage and utilisation but excludes waste handling.

LCA was also used to analyse the amount of carbon dioxide emitted from a bioenergy i.e. carbon dioxide fluxes that are associated with the production and usage cycle, meaning all fluxes of CO_2 involved in cultivation, industrial process (production) and utilization (end-product). The comparison between the three systems was made over net energy value (GJ/ha/yr) (output - input data), net energy ratio (output/ input data) and carbon dioxide emission.

A comparison was also made between sugarcane-ethanol (residual fuels) and *Eucalyptus*-pellet (refined fuels) systems with and without *Sesbania* fallow over several rotations using the *Sesbania*-pellets system as a control.

3.1.1 Limitation of the study

It was not possible to find empirical data for *Sesbania* and *Eucalyptus* from published work as was first anticipated. This is due to the fact that, conducting an LCA by reviewing published data is intensive job in term of time and resources and the presentation of data can greatly influence the accuracy of the final results. Since the study covered a wide geographical area under a variety of different conditions, it was not possible to include all emissions of carbon dioxide, or all stages of LCA. The lack of background information, mainly soil characteristics, was the most serious shortcoming. Another problem was to convert different measurement of production into total biomass.

Only one study covering *Eucalyptus* and *Sesbania* in the same experiment with the necessary data (Ståhl, 2005) was found. After a serious effort only 10 sites with *Sesbania* and 14 with *Eucalyptus* were selected but still some important data were missing for a comprehensive comparison between the three systems. For instance, a comprehensive presentation of soil characteristics was also preferred but in most cases weak. With consistent data over a wide range of site conditions a comprehensive comparison between the three systems would have been possible. With the data available a comparison could be carried out but not to a scientific standard that allows generalisations. Three production levels were determined from the 10 *Sesbania* and 14 *Eucalyptus* sites:

- Mean of the 50% lowest producing sites, representing the production level of *Sesbania* and *Eucalyptus* on land not suitable for agriculture.

- Mean of the 50% highest producing sites, representing good arable sites suitable for cultivation of sugarcane.

- The third production level was determined by the optimum rotation period through regression and a fitted line-plot of the annual mean production of the selected sites (excluding three outliers for *Eucalyptus*). This level is used to represent the mean production of *Sesbania* and *Eucalyptus* over sites including arable and non-arable land, land marginal to production of sugarcane.

Four sites were selected to determine the production of sugarcane over a range of site conditions from marginal to high producing sites. Two production levels were used for sugarcane.

- Mean of the 50% lowest producing sites, representing the production level of sites marginal to the production of sugarcane.

- Mean of the 50% highest producing sites, representing good arable sites.

The lower and higher means of sugarcane was compared to the lower and higher means respectively of *Sesbania* and *Eucalyptus*.

3.1.2 Assumptions and validation of the methods

A lot of assumptions were taken into consideration while making an LCA, because some of the studies did not report results in a way that could be directly compared. Also, due to unavailability of enough data to fulfils LCA requirements.

It is assumed that all above ground biomass excluding leaves and pods of the trees (*Sesbania and Eucalyptus*) is used for pellets; hence, it was assumed that there is no loss of biomass from field phase to industrial phase. Also, it was assumed that, chips have 50% moisture content and pellets 10% moisture content. Energy for chips production and drying is assumed to come from fossil fuel and bioenergy respectively while electricity from hydropower is used for grinding, pressing, cooling and storage. Also, carbon dioxide released during combustion of pellets is reabsorbed by photosynthesis during the growth of trees in the following season. Hence, they are not accounted for in this study.

In addition to that, an assumption was made for the case of the sugarcane -ethanol system; Sugarcane–ethanol industry all input energy assigned for ethanol production as end–product, which means, all cane–juice was assumed to be used for ethanol production. The cane–juice amounts to 85% of the total harvest (Baucum *et al*., 2006) and 10–15% of juice is sucrose.

Also, it is assumed that carbon dioxide is released from sugarcane by burning their leaves at harvest, and fermentation of sucrose to ethanol and combustion of ethanol in automobile engine are reabsorbed by photosynthesis during the growth of sugarcane in the following season (Macedo 2004 and Oliveira *et al*., 2005). In addition, planting the seed and harvesting is manual work with no emissions. Also, Electricity energy from hydropower is used for sugarcane washing and chopping, mixing with water, crushing and pressing.

Since the study is based on data from different studies under different conditions, some assumptions had to be established, such as that the nutrient of the soil was the same. Thus, the nitrogen (N) level from different *Eucalyptus* plantation /field was assumed to be equal. The same assumptions were applied in the case of sugarcane plantation. Improved fallow of *Sesbania sesban* was used as organic fertilizer to increase the level of nitrogen (N). Furthermore, it is assumed that any soil emissions of N_2O from fertilization are not included in the LCA.

The work was divided into four steps as follows:

Step 1. As the analyses were based on the literature, an inventory of available data was carried out including data for; energy input and output, emission and uptake of greenhouse-gas from all stages in the life cycle of the assessed products. Online and documented materials such as journals, papers, books, reports, and other related life cycle assessment studies were used.

Step 2. The data for biomass production and energy output were compiled (table 1, 2 and 3) and two fitted line plots were made for different ages of different *Sesbania* and *Eucalyptus* plantations to aid an optimum rotation analysis.

Step 3. Life cycle inventory spreadsheets were designed (Table 4-6) for the three bioenergy systems. The three systems (A, B and C) are based on GJ/ha/yr and g CO_2-eq/MJ as functional units for analysis of energy and emissions of carbon dioxide respectively. Among of 60 reviewed papers, only 14 included in inventory data that were used to calculate the energy or and carbon dioxide emission.

Step 4. The conclusion and recommendation were drawn based on life cycle assessment results as compiled and presented from reviewed recently publication.

3.4 Species characteristics

According to Bassam 1998, the most criteria used for selecting the three systems (*Eucalyptus*-pellets, *Sesbania*-pellets and sugarcane-ethanol as valuable systems for bioenergy production:

- They need low input for plantation establishment and industrial activities such as agricultural /plantation management and machine operations.
- They produce a sustainable energy during their lifecycle.
- They have high dry matter production.
- High energy density (MJ/kg)

The criteria have been used to limit my review for choosing *Eucalyptus Camaldulensis*, *Sesbania sesban* and sugarcane for bioenergy production as substitute to fossil fuel; they are mostly widely planted in the world; grow very fast, simple plantation management and their superiority to other species in high production of biomass. Also, they have considerable collection of knowledge /documents relating to these species. In addition, for the case of *Sesbania sesban* and sugarcane; they minimize land use conflicts since have ability to produce a variety of products; from sugarcane - sugar, ethanol, fodder, electricity-from baggase, fertilizer and from *Sesbania sesban* - improve soil (restore degraded land), fodder and can be used as a pellets.

Eucalyptus camaldulensis

Distribution

Eucalyptus camaldulensis (river red gum) is native in Australia. It is mostly widely planted *eucalyptus* in Brazil, Ethiopia, Congo, Cameroon, India, Kenya, Srilanka, Zambia, South Africa, and Tanzania; Due to its natural adaptation, it has the ability to grow in many climates such as Temperate, Mediterranean, Tropical and Subtropical and also produces high yield on comparatively poor soils (Bassam 1998).

Ecological requirements

Eucalyptus camaldulensis adapts well to alluvial silts, sands or shallow soils over limestone but the species is not adapted to calcareous soils. It is a drought resistant species and grows on a wide altitudinal range from 0 to 1500m a.s.l., with mean annual rainfall between 250 and 2500mm. Also, it survives in high summer temperature and even when dry seasons are prolonged (Eldridge *et al* 1994).

Establishment

Eucalyptus camaldulensis performs very well, if the planting site has similar ecological condition to the site where seeds have been collected. It takes 1-3 years from planting to the production of the first seed crops .The seedlings established in nursery, then transplant in the plantation. There is no need to treat the seed and even to incur cost for fencing the plantation against livestock or wildlife as the leaves are not palatable for fodder. *Eucalyptus camaldulensis* attains up to 20-50m in height and has good production. In addition, this species has the ability for coppicing.

Yield

Eucalyptus camaldulensis grows very fast with mean annual growth increment of 2 m in height and 2 cm in diameter (Bassam 1998). A well managed *Eucalyptus* plantation is productive during 25 years and 5-6 harvests can be performed. Results from *Eucalyptus camaldulensis* from different plantations show the site description, rotation length, biomass production and energy output (Table 1). *Eucalyptus camaldulensis* has calorific value of (20.11GJ/ton)[2] (WAC 2008); however, there is little variation among species in total energy content per unit weight of wood (calorific value) but this variation is actually small between similar trees and decreases with increases total moisture content (Smith *et al*., 2001).

Uses

Eucalyptus camaldulensis has highly valued wood for fire wood, charcoal, pellets and poles production. Also, it has long been known as a useful tree plant for afforestation in drought regions.

Sesbania sesban

Distribution

Sesbania sesban is said to be one of the first garden grown in Egypt, subsequently, is widely-spread in Cameroon, tropical Africa, Asia, and Australia (Sotomayor *et al.,* 2000).

Ecological requirements

Sesbania sesban is commonly planted at an altitude of 100-2300m a.s.l. with a mean annual rainfall of 500-2000mm (WAC 2008).It is adaptive to a wide range of soil conditions, and even grows better on moist or marshy soils (Arbonnier 2004).

Establishment

Sesbania sesban is a shrub or small tree which grows up to 7m in height and 12cm in diameter with many branches low-branched, fast-growing although short-lived tree 1-3 years. It produces a lot of seeds (seedpods) which are slightly twisted up to 25cm long (Arbonnier 2004).

[2] Author convert 4,800 kcal/kg to 20.11GJ/ton (see Table 1)

Yield

Sesbania sesban has calorific value of (18.23GJ/ton)[3] (WAC 2008). Therefore, *Sesbania* has a good potential for energy production as the results (Table 2) from different *Sesbania sesban* plantations and their site description, rotation length, biomass production and energy output. The leaves and young branches of *Sesbania sesban* produce quality and palatable foliage which promote milk production for livestock (Sotomayor *et al*., 2000).

Uses

Sesbania sesban is mostly planted for firewood, charcoal, and the bark fiber is used for making ropes. It useful for soil improvement due to it is ability of fixing nitrogen (N) from the atmosphere by using its root nodules (WAC 2008).

Sugarcane

Distribution

Sugarcane (*Saccharum*) is a tall perennial grass, native to warm temperate and tropical regions (Tarimo and Takamura 1998). It has been planted in Zimbabwe, Brazil, Morocco, Mauritius, India, Tanzania, Kenya and Australia.

Ecological requirements

Sugarcane is cultivated on loamy soils with good water storage and drainage. It needs a sufficient amount of water (1200 -1500mm per annum) and temperature (15° C -38° C.) to reach viable production levels (Tarimo and Takamura 1998).

Establishment

Sugarcane is propagated from cuttings and planted by hand. A sugarcane plantation can be harvested more than once because it has the ability to regenerate new stalks after harvesting, a process that is called *ratoons*. The second ratoon crop can be harvested after 10-12months. Three to five ratoon crops can be produced on one plantation (Mrini *et al*., 2001).

Yield

Sugarcane is harvested by hand or mechanically by cutting down the plant stalks. According to Tarimo and Takamura (1998), a total of 150ton/ha/yr of biomass can be harvested from well managed sugarcane plantations. Sugarcane has calorific value of (15.8GJ/ton)[4] (Perera *et al*., 2005). Results from sugarcane plantations grown on suitable land show the biomass production and energy output (Table 3).

Uses

Sugarcane is a multipurpose crop that can be used for production of food (sugar), bioenergy, improving soil organic matter/carbon content and animal feed. The use of ethanol as bioenegy from sugarcane has contributed to the mitigation of CO_2 emissions and improved the incomes of farmers who engage in sugarcane production.

3.5 Description of Energy refinement process

Pelletisation

Pelletisation of woody biomass is a method in which sawdust or chips are compacted to cylindrical shaped pellets with a diameter (end-product) of 6-12 mm and length at least 4 times the diameter.

[3] Author converts 4,350 kcal/kg to 18.23GJ/ton (see Table 2)
[4] Author converts 15.8MJ/kg to 15.8GJ/ton

This shape makes transport, handling and storage easier (Holmgren *et al.,* 2007) compared to charcoal, firewood and wood chips. Pellets have a low moisture content of about 8 -10% whereas sawdust and chips have 50% (Holmgren *et al.,* 2007).

During the pelletisation process (Figure 2), the raw materials are prepared by removing all unwanted substances such as stones, gravel and metal. The materials are then grinded to a fine powder. Since, the raw material (chips) has a high moisture content; it is dried and then fed into a rotating press. Lignin and moisture content within the raw material are used as glue to fasten together the powder, therefore there is no need to put in additivities (Holmgren *et al.,* 2007). The dried fine powders are compressed into pellets. As the pellets are heated during the pressing process, they need to be cooled before storage. Production and uses of pellets as alternative energy for fossil fuel not only gives the highest CO_2 reduction compared to other bioenergy options, it also provides a sustainable way for decreased CO_2 emissions.

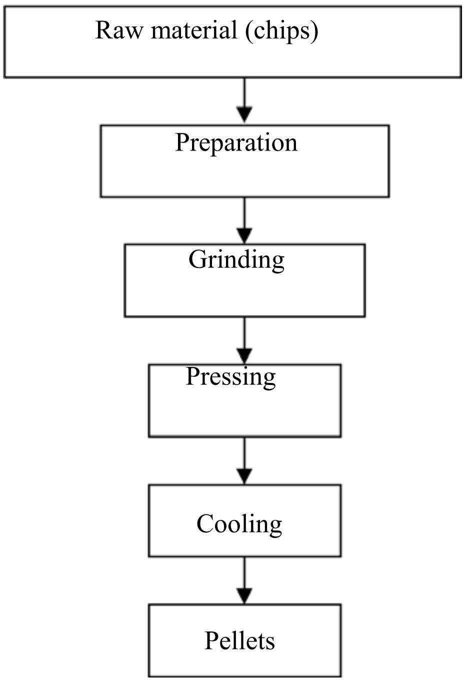

Figure 2. Flow diagram for pellets production from Eucalyptus/Sesbania.

Residual Energy (Sugarcane-Ethanol)

Sugarcane has the ability to produce affordable liquid (ethanol) and solid fuels (bagasse). The production of ethanol versus bagasse depends on the type of the sugarcane mill; it can be sugarcane–sugar and/or ethanol as end products and bagasse (*by-product*).

This study is based on sugarcane to ethanol as the *end product* only and bagasse as the *by-product*. After harvest the sugarcane is transported to the industry. The cane is washed, chopped, and shredded.Then, it is mixed with water, crushed and pressed several times to extract the juice. This is followed by a fermentation process of the cane juice by the addition of yeast to form carbon dioxide and ethanol (see Figure 3).

Ethanol can also be produced from molasses as a by-product after crystallization of cane juice to form sugar (*end-product*). However, this procedure is not investigated in this study. The molasses is fermented to produce ethanol. In addition, the molasses can be used to produce food for livestock or raw material for breweries. The bagasse can be used as fertilizer for sugarcane plantation or other crops. It can also be a source of energy for industry or other users as an alternative to fossil fuel. The process of burning the bagasse to produce energy is called *cogeneration*.

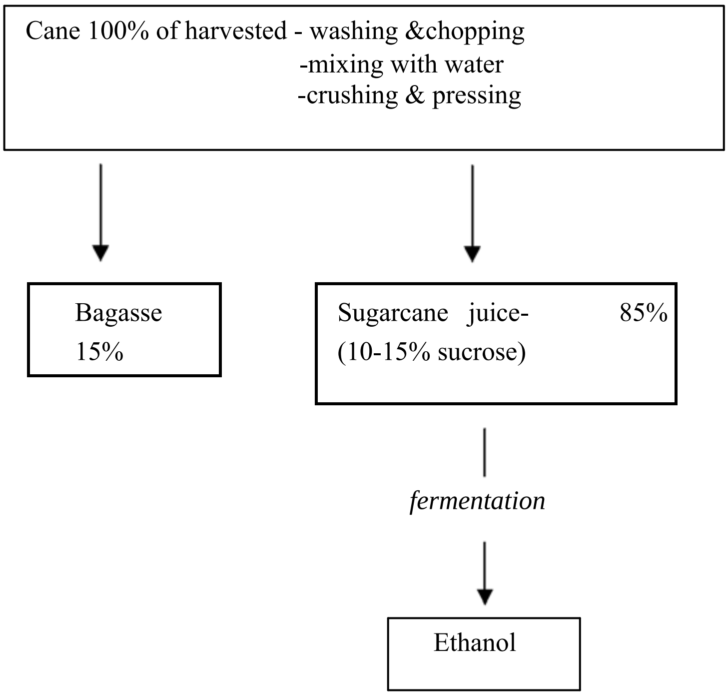

Figure 3. Flow diagram for ethanol production from sugarcane.

Ethanol production from sugarcane is cheaper than ethanol production from other crops such as corn (Beeharry 2001). The reason is that no further processing other than fermentation is needed, whereas in the case of corn the extracted starch has to be transformed to sugar before being converting to ethanol. The use of ethanol as bioenergy is increasing since it can be produced by small scale farmers. Ethanol is a very useful fuel for motor vehicles and for cooking stoves because it is a clean fuel, environmentally friendly and it does not cause harmful smoke.

4. Results

4.1 Energy output; species and sites

Eucalyptus camaldulensis

Biomass production, rotation length and energy output from *Eucalyptus* plantations grown on 14 different sites presented in (Table 1). Energy output calculated in terms of GJ/ha/yr as follows:

Energy =Energy value*biomass production

Sesbania sesban

Results from *Sesbania sesban* plantations show the site description, rotation length, biomass production and energy output (Table 2). The data for biomass production and energy output compiled from 10 plantation sites and energy output was calculated as:

Energy (GJ/ha/yr) =Energy value*biomass production.

Table 1. Compilation of biomass production (ton/ha/yr) and energy output (GJ/ha/yr) for Eucalyptus Camaldulensis species

Soil pH	**Soil texture, Carbon (C), Nitrogen (N), Organic C (OC) & management**	**Soil Classification**	**Country**	**Rainfall** (mm)	**Altitude** (m.a.s.l.)	**Temp.** (mean annual (temp. ^{o}C)	**Rotation Length** (yrs)	**Total biomass production** (ton/ha)	**Annual biomass production** (ton/ha/yr)	**Annual energy output** (GJ/ha/yr) [a]	**Ref**
No	Poor C & N, degraded land	Alfisol	Cameroon	1050	300	28.2	7.0	39.9	*5.7*	114.6	1
5-7	Sandy loam,unthinned	No information	Srilanka	1100	2	29.1	6.0	38.4	6.4	128.7	2
5-7	Sandy loam,unthinned	No information	Srilanka	1100	2	29.1	8.0	68.0	8.5	171.0	2
5-7	Sandy loam,unthinned	No information	Srilanka	1100	2	29.1	10.0	94.0	9.4	189.1	2
5-7	Sandy loam,unthinned	No information	Srilanka	1100	2	29.1	12.0	115.2	9.6	193.1	2
5-7	Sandy loam,unthinned	No information	Srilanka	1588	170	29.1	4.0	20.4	5.1	102.6	2
5-7	Sandy loam,unthinned	No information	Srilanka	1588	170	29.1	6.0	51.0	8.5	171.0	2
5-7	Sandy loam,unthinned	No information	Srilanka	1588	170	29.1	8.0	103.2	12.9	259.4	2
5-7	Sandy loam,unthinned	No information	Srilanka	1588	170	29.1	10.0	130.0	13.0	261.5	2
5-7	Sandy loam, unthinned	No information	Srilanka	1588	170	29.1	12.0	135.6	11.3	227.3	2
5-7	Sandy loam, unthinned	No information	Srilanka	1588	170	29.1	14.0	144.2	10.3	207.2	2
5.9	Fertilized, N=0.08%, Exp site	*Lateritic*	India	800	900	No informa.	3.0	40.2	13.4	269.5	3
5.6	Organic matter=1.42%, N=0.04%	Luvisol	Zambia	880	1280	18.8	2.3	46.0	20.0	402.2	4
6	Sandy clay loams,1.1% OC	Udic Paleustoll	Kenya	900	1920	No informa.	1.8	35.5	19.7	396.2	5

[a] Calculation = 1ton=1000 kg, 1Mcal=1000 kcal, 1Mcal= 4.19 MJ, 1GJ=1000 MJ, Energy value for *Eucalyptus camaldulensis* = 4800kcal/kg=4.8Mcal/kg.Energy output=**Energy value*biomass production** = (4.8Mcal/kg)*ton = ((4.8*4.19) MJ/kg)*ton= (20.11GJ/1000kg)*ton= **(20.11GJ/ton)*ton.**

[1] Harmand and Njiti 2004 [2]Ranasinghe and Mayhead 1991 [3] Hunter 2001 [4]Kamara & Maghembe 1994 [5]Stahl 2005.

Note: -The mean of the 50% lowest producing sites = ((5.1+5.7+6.4+8.5+8.5+9.4+9.6) ton/ha/yr)/7(lowest sites) =7.6ton/ha/yr; Energy production= (20.11GJ/ton)* 7.6ton/ha/yr=**153GJ/ha/yr** - The mean of the 50% highest producing sites = ((10.3+11.3+12.9+13.0+13.4+19.7+20)ton/ha/yr)/7(lowest sites) =14.37ton/ha/yr; Energy production= (20.11GJ/ton)* 14.37ton/ha/yr=**289GJ/ha/yr**.

Table 2. Compilation of biomass production (ton/ha/yr) and energy output (GJ/ha/yr) for Sesbania sesban species

Soil pH	Soil texture, Carbon (C), Nitrogen (N), Organic C (OC)	Soil Classification	Country	Rainfall (mm)	Altitude (m a.s.l.)	Temp. (mean annual (temp. ^{o}C)	Rotation Length (yrs)	Total biomass production (ton/ha)	Annual biomass production (ton/ha/yr)	Annual energy output (GJ/ha/yr) [a]	Ref
5.5	Degraded	Luvisol	Kenya	1678	1500		1.8	15.5	8.6	156.7	1
6.0	Sandy clay loams,1.1% OC	Udic Paleustoll	Kenya	900	1920	No informa	1.5	27.5	18.3	333.5	2
5.6	Organic matter=1.42%, N=0.04%	Luvisol	Zambia	880	1280	18.8	2.3	38.4	16.7	304.4	3
6.0	C=0.37%, N=0.03%	Acrisols	Tanzania	880	1150	23	1.0	6.9	6.9	125.8	4
8.0	Field exp, N=0.08%, C=0.5%	No information	India	700	245	No informa	1.0	12.1	12.1	220.5	5
8.0	Field exp, N=0.08%, C=0.5%	No information	India	700	245	No informa	1.2	38.8	32.3	588.7	5
8.0	Field exp, N=0.08%, C=0.5%	No information	India	700	245	No informa	2.0	64.0	32.0	583.2	5
8.0	Field exp, N=0.08%, C=0.5%	No information	India	700	245	No informa	2.3	99.1	43.1	785.6	5
8.0	Field exp, N=0.08%, C=0.5%	No information	India	700	245	No informa	2.5	71.8	28.7	523.1	5
8.0	Field exp, N=0.08%, C=0.5%	No information	India	700	245	No informa	3.0	75.0	25.0	455.7	5

[a] Calculation = 1ton=1000 kg, 1Mcal=1000 kcal, 1Mcal= 4.19 MJ, 1GJ=1000 MJ,
Energy value for *Sesbania sesban* = 4350kcal/kg=4.35Mcal/kg.Energy production=**Energy value*biomass production** = (4.35Mcal/kg)*ton = ((4.35*4.19) MJ/kg)*ton= (18.23GJ/1000kg)*ton= **(18.23GJ/ton)*ton**

[1]Heineman *et al* 1997(*Sesbania sesban* (ss4) =15.5 t/ha) [2]Stahl 2005 [3]Kamara & Maghembe 1994
[4]Karachi *et al* 1994(*Sesbania sesban* – (Ex Tumbi)=6.9t/ha/yr) [5]Rao *et al.*1989

Note: -The mean of the 50% lowest producing sites = ((6.9+8.6+12.1+16.7+18.3) ton/ha/yr)/5(lowest sites) =12.5ton/ha/yr; Energy production= (18.23GJ/ton)* 12.5ton/ha/yr=**228GJ/ha/yr**.

- The mean of the 50% highest producing sites = ((32.0+32.3+43.1+28.7+25.0) ton/ha/yr)/5(lowest sites) =32.2ton/ha/yr; Energy production= (18.23GJ/ton)* 32.2ton/ha/yr=**587GJ/ha/yr**.

Sugarcane

Biomass production and energy output from sugarcane plantations grown on different sites (1-4) suitable for sugarcane is presented in Table 3.

Table 3. Compilation of biomass production (ton/ha/yr) and energy output (GJ/ha/yr) sugarcane-ethanol system

Reference	1	2	3	4	**Average**
Biomass production (ton/ha/yr)	80.0	37.4	84.0	71.5	**68.2**
Energy output (GJ/ha/yr)	150.4	63.8	100.8	85.8	**100.2**

[1]Oliveira *et al*., 2005 [2]Macedo 1992

[3]Mrini *et al* 2001 large scale sugarcane [4]Mrini *et., al* 2001 small scale sugarcane.

Note: -The mean of the 50% lowest producing sites = (85.8+63.8)/2(lowest sites); Energy production=**74.8GJ/ha/yr**.

- The mean of the 50% highest producing sites = (100.8+150.4)/2(lowest sites); Energy production=**125.6GJ/ha/yr**.

4.2 Lifecycle assessments – bioenergy systems

The energy inputs and outputs for the pellets production cycle includes establishment, harvesting, transportation, refining, combustion, storage and utilisation, but excludes waste handling. Emissions of carbon dioxide are expressed in relation to energy input (Table 4, 5 and 6), excludes utilization phase, expressed in relation to output energy but, in this study assumed that, there is no emission during this process since the amount emitted is reabsorbed in next plantation. Therefore, the total emission of carbon dioxide are expressed in relation to total energy input and not net energy output because, there is no enough data (value) expressed as saved emission during the lifecycle. For example, avoided emission when electricity/bioenergy or transport-based on ethanol engine are used to replace fossil fuel or manure fertilizer to replace industrial fertilizer, even the exactly amount emitted CO_2 absorbed by these bioenergy systems.

Table 4. Inventory sheet for energy input/output (GJ/ha/yr) and carbon dioxide emissions (gCO_2-eqv./MJ) in bioenergy system A–pellet production and utilization from Eucalyptus

Phase	Energy input (GJ/ha/yr)	Energy output (GJ/ha/yr)	Net-energy (GJ/ha/yr)	CO_2 Emission (gCO_2-eqv./MJ)
Field activities	**17.11**	**221**[3]		**9.80**
Establishment	0.60[1]			0.40[2]
Nitrogen fertilisation	11.73[1]			1.90[4]
Phosphorus fertilisation	0.36[1]			} 5.90[2] (Phosphorus, Potassium, Herbicides)
Potassium fertilisation	0.92[1]			
Herbicides	0.60[1]			
Harvesting	2.20[2]			1.20[2]
Transport	0.70[2]			0.40[2]
Industry activities	**32.45**[1]			**1.81**
Chips production				1.71[5]
Drying				0.10[5]
Grinding				0.00[5]
Pressing				0.00[5]
Cooling				0.00[5]
Storage				0.00[5]
Total (production + industrial)	**49.56**	**221**[3]	**171**	**11.61**
End user				**0.10**
Transport to end user				0.10[5]

[1]Patzek and Pimentel 2006
[2]Börjesson (2006) in Holmgren *et al.,* 2007
[3]Author's calculation (see Table 7)
[4]Wihersaari (2005a) in Holmgren *et al.,* 2007
[5]Petersen Raymer (2006)

Also, carbon dioxide released during combustion of pellets is reabsorbed by photosynthesis during the growth of trees in the following season. Hence, they are not accounted for in this study. Also, Electricity energy from hydropower is used for grinding, pressing, cooling and storage.

Table 5. Inventory sheet for energy input/output (GJ/ha/yr) and carbon dioxide emissions (gCO_2-eqv./MJ) in bioenergy system B–pellet production and utilization from Sesbania

Phase	Energy input (GJ/ha/yr)	Energy output (GJ/ha/yr)	Net-Energy (GJ/ha/yr)	CO_2 Emission (gCO_2eqv./MJ)
Field activities	**5.48**	**510**[3]		**7.90**
Establishment	0.70[1]			0.40[1]
Phosphorous fertilisation	0.36[2]			5.90[2] (Phosphorous fertilisation, Potassium fertilisation, Herbicides)
Potassium fertilisation	0.92[2]			
Herbicides	0.60[2]			
Harvesting	2.20[1]			1.20[1]
Transport	0.70[1]			0.40[1]
Industry activities	**32.45**[2]			**1.81**
Chips production				1.71[4]
Drying				0.10[4]
Grinding				0.00[4]
Pressing				0.00[4]
Cooling				0.00[4]
Storage				0.00[4]
Total (Production+Industrial)	**37.93**	**510**[3]	**472**	**9.71**
End user				**0.10**
Transport to end user				0.10[4]

[1]Börjesson (2006) in Holmgren *et al*., 2007 [2]Patzek and Pimentel 2006
[3]Author's calculation (see Table 7) [4]Petersen Raymer (2006) in Holmgren *et al,* 2007

Also, carbon dioxide released during combustion of pellets is reabsorbed by photosynthesis during the growth of trees in the following season. Hence, they are not accounted for in this study. Also, Electricity energy from hydropower is used for grinding, pressing, cooling and storage.

The energy inputs and outputs for the sugarcane production cycle includes establishment, harvesting, transportation, washing, mixing with water, crushing, pressing, fermentation, storage and utilisation, but excludes waste handling. Emissions of carbon dioxide are expressed in relation to energy input or output (Table 6).

Table 6. Inventory sheet for energy input/output (GJ/ha/yr) and carbon dioxide emissions (gCO_2-eqv./MJ) in bioenergy system C–ethanol production and utilization from sugarcane

Reference	1	2	3	4	Average	[1]**Emission** (gCO_2-eqv./MJ)
Field activities energy input (GJ/ha/yr)	35.98	7.41	27.03	21.37	**22.94**	**14.57**
Nitrogen fert.	3.74	2.59	10.20	9.50	6.51	1.31
Phosphor fert.	0.36	0.00	1.10	0.83	0.57	0.20
Potassium fert.	0.68	0.00	0.00	0.00	0.17	0.28
Liming	1.05	0.70	0.00	0.00	0.44	0.51
Seed	3.35	0.30	3.00	2.70	2.34	0.00
Insecticides	0.14	0.00	0.21	0.14	0.12	0.06
Herbicides	0.80	0.00	0.00	0.00	0.20	0.33
Harvesting	2.86	1.67	0.79	1.04	1.59	0.00
Transport	23.00	2.15	11.73	7.16	11.01	11.88
Industrial activities energy input (GJ/ha/yr)	3.63	2.69	31.50	22.05	**14.97**	**0.00**
Total energy **input**	39.61	10.10	58.53	42.74	**37.92**	**14.57**
Total energy **output**	150.40	63.81	100.80	85.80	**100.20**	
Net-energy **output**	110.79	53.71	42.27	43.06	62.28	
Transport to end-user						1.51

1 Oliveira *et al,* 2005

2 Macedo 1992 (equipment & building data excluded) and Author's calculation (222t/4.3ha total harvested)*72.4% =37.38t/ha used for ethanol production; (MJ/t)*37.38t/ha.

3 Mrini *et al.,* 2001, large scale sugarcane (machinery data excluded),

4 Mrini *et al* ., 2001, small scale sugarcane (machinery data excluded).

It is assumed that carbon dioxide released during fermentation of sucrose to ethanol and combustion of ethanol in automobile engine reabsorbed by photosynthesis during the growth of sugarcane in the following season (Macedo 2004 and Oliveira *et al*., 2005). Harvesting and planting (seed) were done manually. Also, Electricity energy from hydropower is used for sugarcane washing and chopping, mixing with water, crushing and pressing.

4.3 Woody biomass production

The establishment of bioenergy plantation on degraded land revealed that, *Sesbania* attains the highest mean biomass production amounting to 28ton/ha/yr at an age of approximately 2.5 years (mean biomass= $-10.92+30.08\text{years}-5.845\text{years}^2$) (Figure 4) .*Eucalyptus* needs a longer growth period after its establishments and reach 11ton/ha/yr at an age of approximately 11 years as demonstrated in figure 5 (mean biomass= $-4.25+2.657\text{years}-0.1162\text{years}^2$). Over a period of 10 years the biomass production from 4 rotations of *Sesbania sesban* amounts to almost 280 ton/ha whereas the *Eucalyptus* stand after 10 years only produced about 110 ton/ha. Consequently the *Sesbania* production exceeds that of *Eucalyptus* during 10 years by 170 ton/ha, corresponding to about 155% of the *Eucalyptus* production.

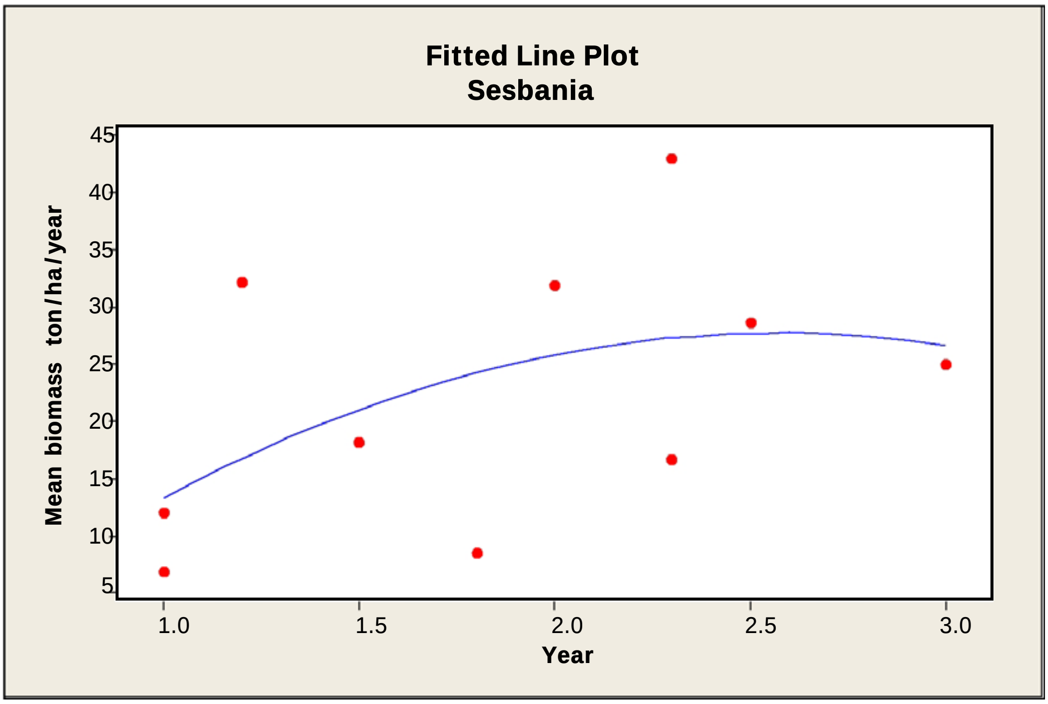

Figure 4. Mean biomass production (ton/ha/yr) for different Sesbania stands with different age.

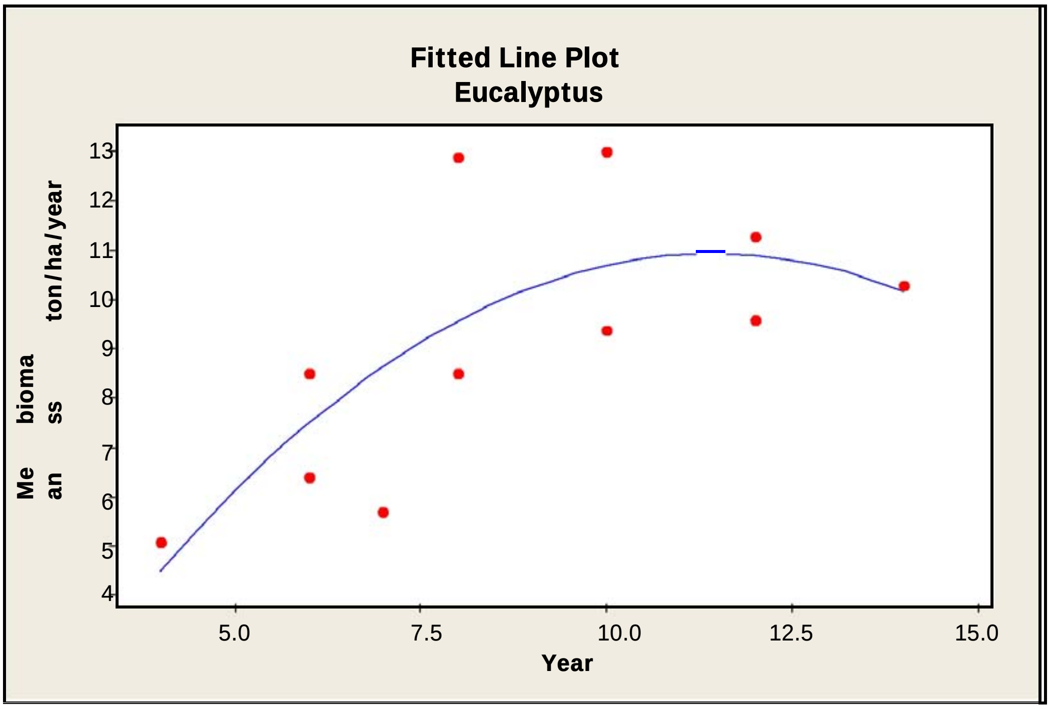

Figure 5. Mean biomass production (ton/ha/yr) for different Eucalyptus stands with different age.

4.4 Bioenergy systems

In comparison to the three bioenergy systems (as shown in Table 7), the *Sesbania*- pellet system has a 3 and 5 times higher net energy ratio on productive sites suitable for food production compared to *Eucalyptus*-pellets and sugarcane-ethanol system respectively. Also, for the case of marginal land or degraded land, *Sesbania*-pellet system gave a higher net energy ratio. The *Eucalyptus* -pellet system needed a high energy input due to N fertlization (Table 4) compared to the *Sesbania*-pellet system. The *Sesbania*-pellet system also had the lowest contribution of carbon dioxide to the atmosphere during the entire life cycle from production to utilization. In addition, the pellet system had 5 times higher energy ratio compared to the sugarcane-ethanol system even at the extremely high production. In the sugarcane-ethanol system much diesel was used for transportation during the agricultural or field phase, corresponding to 64% of the energy input. Therefore, the sugarcane –ethanol system was the system that emitted most carbon dioxide (16.1gCO_2-eq/MJ).

Table 7. Performance comparison for three bioenergy systems

Indicator	**System A** *Eucalyptus*-pellets (GJ/ha/yr)				**System B** *Sesbania*-pellets (GJ/ha/yr)				**System C** Sugarcane-ethanol (GJ/ha/yr)		
	xhigh[1]	high[2]	low[3]	mean[4]	xhigh[1]	high[2]	low[3]	mean[4]	xhigh[5]	high[2]	low[3]
Input energy	75[6]	50	50	50	57[6]	38	38	38	57[6]	38	38
Output energy	1006	289	153	221	786	588	228	510	145	126	75
Net energy value (output-input)	931	239	103	171	729	550	190	472	88	88	37
Net energy ratio (output/input)	13.4	5.8	3.0	4.4	13.7	15.5	6.0	13.4	2.5	3.3	2.0
Emission (gCO_2-eq/MJ)	11.7	11.7	11.7	11.7	9.8	9.8	9.8	9.8	16.1	16.1	16.1

1. 'xhigh1' for system A and B represent the highest production value obtained. Otavio Pontes Stora Enso, state in KSLA (2007:5) that the production in Brazil can reach up to 50 m3/ha/year using improved clones. *Sesbania* the highest value in table 2 has been selected, i.e. 43m3/ha/year represent an extreme production of *Sesbania* (not from improved planting material).

2. 'high' for system A, B and C is the mean of the 50% highest producing sites, representing the potential production level on good arable sites suitable for agriculture. A=289GJ/ha/yr, B=587GJ/ha/yr and C=125.6GJ/ha/yr (see Table 1, 2 and 3 respectively).

3. 'low' for system A, B and C is the mean of the 50% lowest producing sites. Represent the potential production for *Eucalyptus* and *Sesbania* on land not suitable for agriculture and sugarcane on land marginal to agricultural production. A=152.9GJ/ha/yr, B=228GJ/ha/yr and C=74.8GJ/ha/yr (see Table 1, 2 and 3 respectively).

4. ‘mean’ for system A and B is the mean production of *Eucalyptus* and *Sesbania* over sites including arable and non-arable land representing the potential production on land marginal to production for agriculture. This mean was determined by the optimum rotation period through regression and a fitted line-plot of the annual mean production of the selected sites. The value for *Sesbania* =28ton/ha/yr at an age of approximately 2.5 years (mean biomass= -10.92+30.08years-5.845years^2) (Figure 4) and *Eucalyptus* =11ton/ha/yr at an age of approximately 11 years as demonstrated in figure 5 (mean biomass= -4.25+2.657years-0.1162years^2).Energy production=Energy value*biomass production (see Table 1 and 2). Therefore, the mean energy production for *Sesbania* and *Eucalyptus* are (18.23GJ/ton)*28ton/ha/yr=510GJ/ha/yr and (20.11GJ/ton)*11ton/ha/yr=221GJ/ha/yr respectively.

5 ‘xhigh1’ for system C represent the potential energy production on good agricultural land (high) if all sugarcane biomass is turned into energy (output energy for ‘high’ system C have been increased by 15% representing the baggase). ‘xhigh’ =‘high’ + (15%*‘high’) = 126GJ/ha/yr+ (0.15*126GJ/ha/yr)=145GJ/ha/yr.

6. The energy input for the ‘xhigh1’ and ‘xhigh5’ production level have been increased with 50% to cater for the higher production volumes per ha and higher input and management levels.‘Xhigh’ =‘high’ + (50%*‘high’).

4.5 Comparing the systems (A-C) with and without improved fallows

As commercial N fertilizers have high energy and environmental production costs; improved fallow with N-fixing by *Sesbania sesban* is a more appropriate alternative to increase soil fertility of bioenergy plantation systems. Therefore, planting *Sesbania* followed by *Eucalyptus* or the sugarcane plantation would save a total energy input of 11.7GJ/ha/yr and 6.4GJ/ha/yr respectively (Figure 6) as well as costs for production, transportation and distribution of commercial nitrogen fertilizer. For that reasons, it is important to improve the fallow with *Sesbania sesban* to omit commercial N fertilizers application and to increase biomass production.

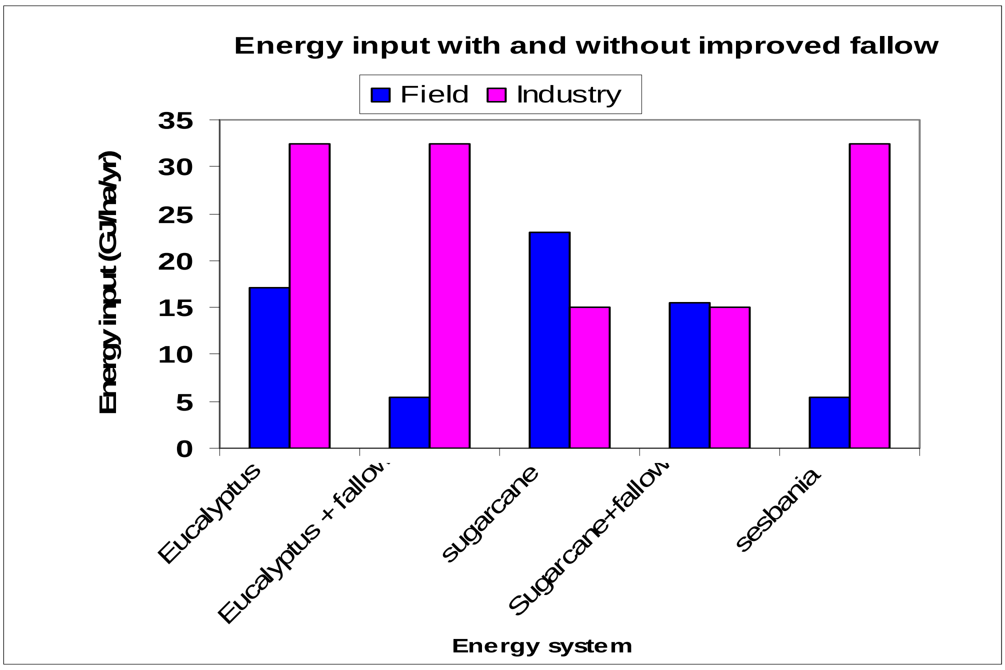

Figure 6. Energy input (GJ/ha/yr) from different combinations of crop rotation.

In addition, it seems that the improved fallow of *Sesbania sesban* motivate the use of marginal land to agriculture for bioenergy production since there is increases of the net energy for the energy crops compared to the production without improved fallow (See Figure 7). It is interesting that, sugarcane with improved fallow has almost the same net energy compared to *Eucalyptus* with improved fallow. This could be due to the input energy because *Eucalyptus* needs a lot of energy input in industrial processing as compared to sugarcane.

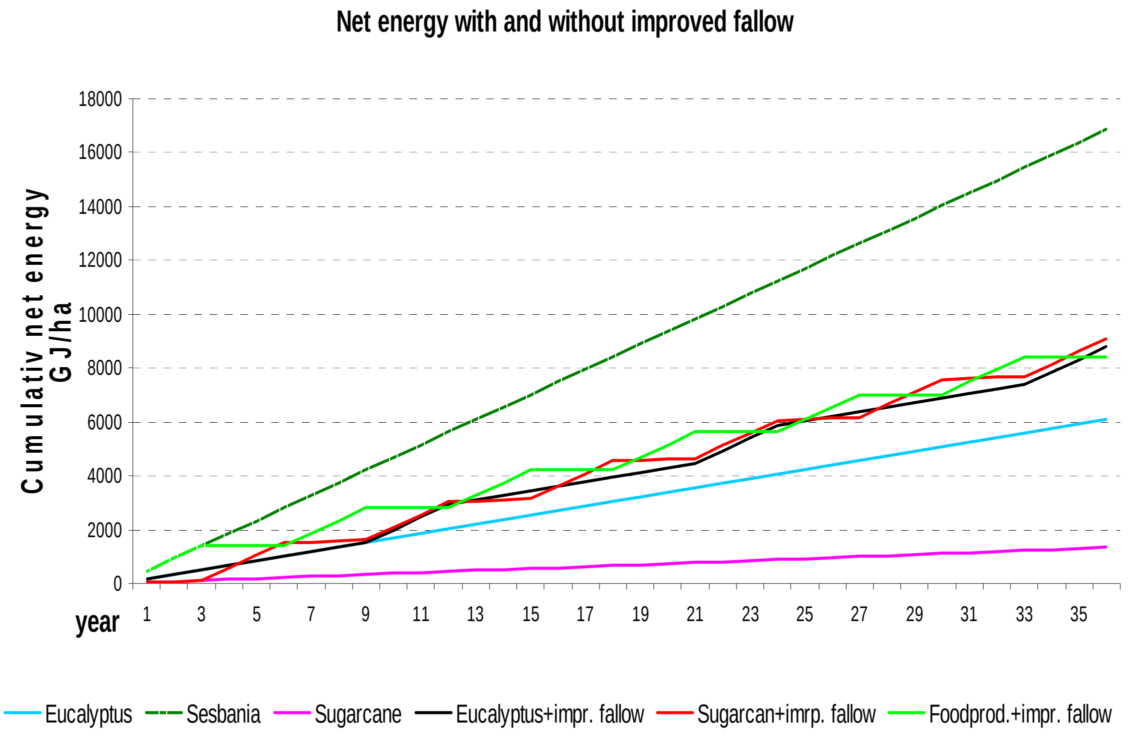

Figure 7. A comparison between system A, B, C and three years improved fallow in rotation with i) nine years Eucalyptus ii) three years sugarcane and iii) three years food production (food production set at zero energy production). The potential net energy production (output-input) of Eucalyptus (System A) and Sesbania (system B) has been calculated from the equation represented by the fitted line-plots in Figure 4 and Figure 5 using rotation period of 9 and 3 years respectively, representing the potential production on land marginal to agricultural production. For sugarcane the 'low' net energy value has been used to represent the potential production of sugarcane on land marginal to agricultural production.

4.6 Emission – reduction (CO_2)

Production and utilization of ethanol and pellets made a significant contribution to the reduction of carbon dioxide emissions. However, fossil fuels are used in the operations of planting, harvesting, transportation and processing. The *Sesbania*-pellet system had a higher energy output, a higher net energy ratio and lower emissions (9.8gCO_2-eq/MJ) than *Eucalyptus*-pellets and sugarcane-ethanol for all sites (Table 7).The net emission of CO_2 to atmosphere from the ethanol production was approximately 16.1gCO_2-eq/MJ. This includes all emissions during cultivation, industrial process (production) and utilization (end-product). The amount of emissions could, however, be significantly reduced if bioenergy is used in the agricultural phase and for transportation to end user, instead of fossil fuel, i.e. use of bio-ethanol.

5. Discussion

5.1 Energy production

Sesbania and Eucalyptus – production level

In this study *Sesbania*-pellets has been shown to give a high output of bioenergy as a substitute for fossil fuel. The mean annual output amounted to 510GJ/ha/yr at 2.5 years rotation on land marginal for food production. *Eucalyptus with* a rotation of 11 years gave a substantially lower energy output amounting to an average 221 GJ/ha/yr. Also, on productive land suitable for food production, *Sesbania* had 3 times higher net energy ratio compared to *Eucalyptus*. *Sesbania* raised from unimproved seed source produced under optimum condition (xhigh table 7) is comparable with *eucalyptus* generated from improved clones under optimum condition giving a net energy ratio of 13.7 and 13.4 respectively. This could be due to the ability of *Sesbania* to improve the soil organic matter content and soil total N content.

The energy output for *Eucalyptus* in this study (221GJ/ha/year) was low compared to some other studies. Ståhl (2005) reported 396GJ/ha/year in Kenya, which was about the same value as for *Sesbania*. Broek et al., (2006) showed for 6 years old *Eucalyptus* stands a net energy output of 246,4 GJ/ha/year. The energy output for *Sesbania* was on the contrary in this study (510GJ/ha/year) somewhat higher than in other studies, e, g. 333GJ/ha/year by Ståhl (2005) and 204GJ/ha/year by Chikowo (2004).

Consequently, it has to be stressed that there are inconsistency in data, and the difference in energy output between *Eucalyptus* and *Sesbania* may be overestimated. However, still the energy input for *Sesbania* is lower than for *Eucalyptus* due to no need for N fertilizers, and the emissions are lower for *Sesbania* than for *Eucalyptus*. Thus, the main conclusion that *Sesbania* is more favorable than *Eucalyptus* may be realistic. It should be noted that it was difficult to obtain enough data giving a fair and comparative representation of the production potential of *Eucalyptus* versus *Sesbania* on different land status.

For the case of input energy, the production of *Sesbania*-pellets consumes the least energy, approximately 7.4%, of the total energy produced compared to 22.4% for the *Eucalyptus*-pellets system. The input energy for the establishment of the *Eucalyptus* plantation could be minimized for 3-4 rotations due to its coppicing ability and a total of 153ton/ha produced from 9 years *Eucalyptus*–coppicing plantations (Zewdie 2008), On the other hand in the intensive managed *Eucalyptus* plantations old clones are gradually replaced as better clones are being identified (KSLA 2007:5) probably disregarding the coppicing advantage of *eucalyptus*.

Sugarcane–ethanol, system C

The Sugarcane–ethanol system has by far the highest biomass production with 68.2 ton/ha/yr compared to the *Sesbania*- and *Eucalyptus*–pellet systems (Table 1, 2 and 3). However, the sugarcane-ethanol system gives a lower energy output than the both pellet systems for all levels of production. This could probably be explained by the fact that not all of the sugarcane biomass is used for production of ethanol. About 15% of the biomass remains as a by-product in the form of bagasse, i.e. cellulose. Energy production could increase by 19 GJ/ha/yr if the bagasse is used in the ethanol production process as an extreme production (xhigh) of sugarcane-ethanol system. Sugarcane can in this comparison still not reach the 'low' levels of *Eucalyptus* and *Sesbania* both in terms of output energy and net energy. The reason for the big difference between biomass production and output energy of sugarcane is that only 10-15% of the sugarcane juice (85% of total biomass) is sucrose which can be processed to ethanol. On the other hand, the bagasse can be used as an energy source in the manufacturing process of ethanol/sugar and has a fuel resource of about 5.17GJ/ha/yr (Oliveira *et al*., 2005) or relocated to the fields in order to improve soil organic matter.

The input energy level used for sugarcane–ethanol and *Sesbania* –pellet system, in this study is the same this could be due to the fact that the average input energy has been used for the sugarcane-ethanol system and that there is a large variation among the data. Also 85% of total input energy is used during industry processing of pellet compared to ethanol processing.

Soil improvement – Sesbania sesban

Planting *Sesbania sesban* on marginal land for 2.5 years followed by bioenergy plantation could give exciting and encouraging results. The use of improved fallow with *Sesbania sesban* in sugarcane and in *Eucalyptus* plantations improves soil fertility of degraded/marginal land due to its N-fixing capacity. The reduced need for inorganic fertilizer will in turn decrease CO_2-emission. Emissions decrease because the manufacturing, transport and distribution of inorganic fertilizer are reduced. However, there is a need for phosphorous and potassium application in the soil. The total biomass production on degraded land can be increased with the inclusion of improved fallow in the *Eucalyptus*-pellet and the sugarcane-ethanol systems, since, *Sesbania sesban* potentially add 500-600 kgN/ha (Ståhl 2005) to the soil after 1.5 years. The biomass can be used either to increase the production of pellets and ethanol or used to generate energy for the industrial process, or used as fuel wood by the local households.

5.2 Sustainability of bioenergy production

The production of bioenergy as an alternative means for mitigating greenhouse gas-emissions should be sustainable. Environmental, economic and social concerns can be satisfied through synergy. The inclusions of improved fallow in bioenergy systems improve the ecological, economic and social aspects of the system. That means that the energy supplies are to be secured and environmentally friendly, and that the income of the farmer or producer increases. The system can be further improved through refined silvicultural practices and biotechnology. Bioenergy plantations should be established on degraded land in order to not jeopardize food security. The establishment of CDM projects including afforestation or reforestation to mitigate green-house gas emissions through the production of bioenergy provides job opportunities to local communities. The local people can be employed in plantation establishments, harvesting and in industrial processing of bioenergy. Bioenergy crops can also be produced by farmer in out-growing schemes.

Sesbania/Eucalyptus pellets - energy and food security

Pellets are more efficiently transported from the industry to the end user compared to charcoal or firewood. This will ensure a long term production and supply as an alternative energy to fossil fuel. However, the manufacturing process of pellets is complex and the demand of capital is high compared to that of charcoal and firewood. The demand for bioenergy as an alternative for fossil fuel causes an increase in utilization of arable land and of food crops such as cassava and corn to be used for bioenergy production, leaving the farmers or communities facing food shortages. The landless and the poor in urban areas may suffer from increasing food prices. The production of *Sesbania/Eucalyptus*- pellets on degraded land facilitate the way for minimize or come to an end of the global conflicts of food insecurity as well as misallocation of land use, that means, productive land could be used for food production and degraded land for bioenergy production, Also, the woody biomass of the *Sesbania/Eucalyptus* to be used for processing pellets and leaving the food crops for food.

Sugarcane – ethanol system

Energy security: Sugarcane–ethanol gives a 10% difference on energy outputs than the energy input during its life cycle between low, high and extreme higher production level. Oliveira *et al.,* (2005) reveal that, ethanol yields 25% more energy than the energy invested in its production. Therefore, the sustainability of this system could be significantly improved if ethanol is used for motor vehicles instead of fossil fuel during the agricultural phase.

Livelihood benefits: According to Macedo (2004), the production of ethanol from sugarcane add up 2.2% of Brazil GDP , generating an income of over US$ 8 billion and an increase of about one million employment opportunity. In addition, the production of ethanol as bioenergy from sugarcane reduces the imports of petroleum and, at the same time, reduces the emission of carbon dioxide from transportation of agricultural raw material or products and end products. In addition, bagasse can be utilized as energy to run the industry processes.

The implication of this study for industry owners as producers; by inclusion of a legume like *Sesbania sesban* in the monoculture production of sugarcane and *eucalyptus*; the bioenergy systems will be less susceptible to criticisms. Also, the inclusion of *Sesbania*-pellets as a substitute for fossil fuel and by offering poor farmers contract production of *Sesbania* the possibility to qualify as a CDM project will definitely improve.

In addition, even though the production of bioenegy is motivated on degraded land, but the producer (investors) and policy makers; they have to take into consideration the land right and traditional land use-systems before assign bioenergy plantation on degraded land. This is because some of the area might be planned for nature conservation, religious use, and traditional use or owned by villagers (Jonson and Roman 2008).

6. Conclusions

There are a huge number of literatures; yet, an accuracy and correctness have been taken to give the best energy system. This study shows that there is a high potential for sustainable bioenergy production by using *Sesbania* in continuous plantations or as an improved fallow in rotation with *Eucalyptus* or sugarcane production. Thus a *Sesbania*-pellet system can be combined with *Eucalyptus*-pellet and sugarcane-ethanol systems. This might be an incentive for the establishment of large scale plantation on degraded land with *Sesbania* as a fallow crop to enhance bioenergy supply for industrial and domestic purposes. Although all three systems can be seen as environmentally friendly this study reveals that there may be crucial differences in that an inclusion of a high yielding tree-legume like *Sesbania* presents synergy between environmental, economic and social concerns.

Sesbania has the ability to improve soil fertility and can be used as an alternative energy for fossil fuel. Also, it is an opportunity for small scale farmers to increase their income by getting involved in planting *Sesbania sesban* and selling the wood to pellets making industries while improving soil fertility on their agricultural land. In this way the production of bioenergy as improved fallow has the potential to even increase local food production. For the reason that may not compete with food production, since bioenergy can be produced with a good yield on degraded land unsuitable for food production and leaves the productive land for food production. This is the best opportunity to ensure a significant energy security and energy to be produced without affecting food security.

Indeed, this production depends on short rotation species such as *Eucalyptus camaldulensis* improved fallow with leguminous species such as *Sesbania sesban*. This reduced the energy input, green house gas emission and costs of buying and transporting the fertilizer from industry to agricultural or plantation areas improving the benefits and resilience of the system.

Conversely, the amount of carbon dioxide emitted depends on life-cycle of the bioenergy systems; the higher the input of industrial fertilizer, long distance transport or agricultural operation by using fossil fuel engine and in industrial-phase, if they processing by fossil fuel result the higher carbon dioxide emitted and consequence the higher the rate of increases global warming. But, pellets and ethanol have low carbon dioxide emissions during their life-cycle hence reduce a global warming problem. There is no any emission of carbon dioxide contributed to GHGs, since all the emitted gas during combustion of pellets or ethanol reabsorbed in the next plantation.

Recommendation:

- Life Cycle Assessment should establish a database containing up dated information and consistent representation of the results for further research instead of keeping on data collection in the field; this would save time and money.

- Agricultural phases and industrial phase should use bioenergy sources for optimum reduction of carbon dioxide.

- Assessment of land right and traditional land-use before allocating bioenergy production on degraded land unsuitable for food production.
- Further research is required on the net avoided emission (total avoided emission-total emission) of carbon dioxide for *Eucalyptus*/*Sesbania*-pellets and sugarcane – ethanol.

References

Ajayi, O.C. Kwesiga, F. Mafongoya, P and Franzel, S. 2005. Impact of Fertilizer Tree Fallows in Eastern Zambia. A study on Impacts of Agroforestry. A world Agroforestry Centre, Nairobi, Kenya, 28 pages.

Arbonnier, M. 2004. Trees and Shrubs, and Lianas of West African dry zones.Published by Editions Quae, 574 pages.

Arnalds, A. 2004. Carbon Sequestration and the Restoration of the Land Health an Example from Iceland. Climate Change 65: 333-346.

Baral, A and Guha, G.S. 2004. Trees for Carbon Sequestration or Fossil Fuel Substitution: the Issue of Cost vs. Carbon Benefit. Biomass and Bioenergy, Volume 27, Issue 1, 41-55. Published by Elsevier Ltd.

Bassam, N. 1998. Energy Plant Species: Their use and impact on environment and development. Published by Earthscan, 321 pages.

Baucum, L.E.Rice, R.W. and Schuneman, T.G. 2006. An Overview of Florida Sugarcane. Electronic Data Information Source (EDIS) SC032. Agronomy Department, University of Florida, Gainesville, FL. Available at: http://edis.ifas.ufl.edu/SC032. Cited on 10 September 2008.

Beeharry, R.P. 1996. Extended Sugarcane Biomass Utilization for Exportable Electricity Production in Mauritius. Biomass and Bioenergy, Volume 11, Issue 6, 441-449.

Beeharry, R.P. 2001. Carbon Balance of Sugarcane Bioenergy Systems. Biomass and Bioenergy, Volume 20, Issue 5, 361-370.

Blomqvist, L. 2007. Attractive Landscape and Biofuel Production – a possible Combination? Licentiate thesis. Department of Bioenergy, Uppsala, Sweden 2007.Rapport/Report No.15.ISSN 1651-0720.

Börjesson, P. 2006. Livscykelanalys a Salixproduktion. Lund University, Department of Technology and Society, Environment and Energy Systems Studies. Report no. 60. 21 pp. ISBN 91-88360-83-0. [In Swedish]. In Holmgren, K. Eriksson, E. Olsson, O. Olsson, M. Hillring, B and Parikka, M. 2007 .Biofuels and Climate Neutrality– System Analysis of Production and Utilization. Elforsk rapport 07:35.

Bouwman, A.F and Leemans, R. 1995. Role of Forest Soils in the Global Carbon Cycle. In; McFee, W.W., Kelly, J.M (eds) Carbon Forms and Functions in Forest Soils. Soils Science Society of America, Inc., Madison, Wisconsin USA. ; In Lemma, B. 2006. Impact of Exotic Tree Plantations on Carbon and Nutrient Dynamic in Abandoned Farmland Soils of Southerwesten Ethiopia. Doctoral Thesis No. 2006:108. Faculty of Natural Resources and Agricultural Science. Swedish University of Agricultural Science.

Broek, R. Burg, T. Wijk, A. and Turkenburg, W. 2000. Electricity generation from *Eucalyptus* and Bagasse by Sugar Mills in Nicaragua: A Comparison with Fuel Oil Electricity Generation on the Basis of Costs, Macro -economic Impacts and Environmental Emissions. Biomass and Bioenergy, Volume 19,311-335. Published by Elsevier Science Ltd.

Chikowo, R. Mapfumo, P. Nyamugafata P. and Giller, K.E. 2004. Woody legume fallow productivity, biological N2-fixation and residual benefits to two successive maize crops in Zimbabwe.Kluwer Academic.Publishers.Printed in the Netherlands. Plant and Soil 262: 303–315.

Cossalter, C and Smith, C.P. 2003. Fast –Wood Forestry: Myths and Realities. Centre for International Forestry Research, Bongor, Indonesia pp. 1-60.

Davidson, E.A and Ackerman, I.L. 1993. Changes in Soil Carbon Inventories Following Cultivation of Previously Untilled Soils. Biogeochemistry 20, 161-193. ; In Lemma, B. 2006. Impact of Exotic Tree Plantations on Carbon and Nutrient Dynamic in Abandoned Farmland Soils of Southerwesten Ethiopia. Doctoral Thesis No. 2006:108. Faculty of Natural Resources and Agricultural Science. Swedish University of Agricultural Science.

Eldridge, k. Davisson, J. Hardwood. Wyk, G. 1994. Eucalyptus Domestication and Breeding. Published by Oxford University Press, 288 pages.

Hall, D.O.and House, J.I. (2008). Biomass energy development and carbon dioxide mitigation options .Available at http://uneprisoe.org/CopenhagenConf/hall.htm.Cited on April 2008.

Heineman, A.M. Otieno, H.J.O. Mengich, E.K. and Amadalo, B.A. 1997. Growth and Yield of Eight Agroforestry Tree Species in Line Plantings in Western Kenya and their Effect on Maize Yields and Soil Properties. Forest Ecology and Management 91, 103-135.

Harmand, J.M .and Njiti, C.F. 2004. Aboveground and Belowground Biomass, Productivity and Nutrient Accumulation in Tree Improved Fallows in the Dry Tropics of Cameroon. Forest Ecology and Management 188, 249-265. Published by Elsevier Ltd.Science Direct.

Holmgren, K. Eriksson, E. Olsson, O. Olsson, M. Hillring, B and Parikka, M. 2007 .Biofuels and Climate Neutrality– System Analysis of Production and Utilization. Elforsk rapport 07:35.

Hunter, I. 2001. Above ground Biomass and Nutrient Uptake of Three Tree Species (*Eucalyptus camaldulensis, Eucalyptus grandis and Dalbergia sissoo*) as Affected by Irrigation and Fertilizer, at 3 Years of Age, in Southern India. Forest Ecology and Management, Volume 144. 189-199.

FAO 2008. Biofuels: Prospects Risks and Opportunities. Food and Agriculture Organization of the United Nations, Rome, Italy.

Jonson, F. and Roman, M 2008. Biofuels sustainability Criteria: Relevant issues to the proposed directive on the promotion of the use of energy from renewable sources (COM (2008) Final). The European Parliament‘s Committtee on Environment, Public Health and Food safety, 37 pages.

Jonsson, K. 1995. Agro forestry in Dry Savanna Areas in Africa: Interactions between Trees, Soils and Crops .Dissertation Umea. SLU.

Kamara, C.S. and Maghembe, J.A. 1994. Performance of Multipurpose Tree and Shrub Species 28 Months after Planting at Chalimbana, Zambia. Forest Ecology and Management 64, 145-151 p.

Karachi, M. Lema, N. Sabas, E. and. Shirima, D. 1994. Growth, biomass production and plant mortality of seven *Sesbania sesban* var. *nubica* and three *Sesbania macrantha* accessions at Tumbi, Tanzania. Forest Ecology and Management, 64. 153-159.

Karekezi, S. 2002. ‘Renewables in Africa – Meeting the Energy Needs of the Poor’, Energy Policy, Vol. 30 Nos. 11-12, Special Issue – Africa: Improving Modern Energy Services for the Poor. Oxford: Elsevier Science Limited.

Kauzeni, A.S. Masao, H.P. Sawe, E.N. and Shechambo, F.C. 1998. Bioenergy Options: Multidisciplinary Participatory Method for Assessing Bioenergy Options for Rural Villages in Tanzania. Stockholm Environment Institute (SEI). 89 pages.

Koh, K. and Ghazoul, J. 2008. Biofuels, biodiversity, and people: Understanding the conflicts and finding opportunities. Biological Conservation 1 4 1; 2450-2460.

KSLA 2007. Tilting Forest Industries from North to South, a summary from seminar arranged by the Royal Swedish Academy of Agriculture and Forestry and the Engineering Science Academy on the 26 of April 2007.

Kwesiga, F. and Baxter, J. 1998. Sesbania Fallows for increased Maize Production in Zambia. ICRAF, 265-268 p. Bucles, D. Ateka, A. Osiname, O. Galiba, M. and Galiano, M. (ed_s).Cover crops in West Africa Contributing Sustainable Agriculture.Published by IDRC, 291.

Kwesiga, F. and Coe, R. 1994. The Effect of Short Rotation *Sesbania sesban* Planted Fallows on Maize Yield. Forest Ecology and Management ,Volume 64, Issues 2-3, 199-208.

Lemma, B. 2006. Impact of Exotic Tree Plantations on Carbon and Nutrient Dynamic in Abandoned Farmland Soils of Southerwesten Ethiopia. Doctoral Thesis No. 2006:108. Faculty of Natural Resources and Agricultural Science. Swedish University of Agricultural Science.

Macedo, I.C.1992. The Sugar cane Agro-Industry-its Contribution to Reducing CO_2, Emissions in Brazil. Biomass and Bioenergy, Vol. 3, No. 2. 77-80 .Pergamon Press Ltd.

Macedo, I.C.2004. Assessment of Greenhouse Gas Emissions in the Production and Use of Fuel Ethanol in Brazil .Government of the State of São Paulo.

Malca, J. and Freire, F. (2006). Renewability and Life-cycle Energy Efficiency of Bioethanol and Bio-ethyl Tertiary butyl ether (bio-ETBE):Assessing the Implications of Allocation. Energy 31, 3362–3380.

Mrini, M. Senhaji, F. and Pimentel, D. 2001. Energy Analysis of Sugarcane Production in Morocco. Environment, Development and Sustainability, Volume 3, 109-126.

Mohee, R. and Beeharry, R.P.1999. Life Cycle Analysis of Compost incorporated Sugarcane Bioenergy Systems in Mauritius.Biomass and Bioenergy, Volume17.73-83

Montagnini, F and Porras, C. 1998. Evaluating the Role of Plantations as Carbon Sinks: An example of an integrative approach from the humid tropics. Environmental Management 22, 459- 470. ; In Lemma, B. 2006. Impact of Exotic Tree Plantations on Carbon and Nutrient Dynamic in Abandoned Farmland Soils of Southerwesten Ethiopia. Doctoral Thesis No. 2006:108. Faculty of Natural Resources and Agricultural Science. Swedish University of Agricultural Science.

Oliveira, M.E.D.O. Burton, E.V. Edward, J. and Rykiel, J.R. 2005. Ethanol as Fuel: Energy, Carbon Dioxide Balances, and Ecological Footprint. BioScience, Volume 55, Issue 7. 593–602.

Palm, O.Weerakoon, W.L.Silva, M.A.P. and Rosswall, T. 1988. Nitrogen mineralization of *Sesbania sesban* used as green manure for lowland rice in Sri Lanka. Plant and Soil 108, 201-209. Kluwer Academic Publishers.

Patzek, T.W. and Pimentel, D. 2006 .Thermodynamics of Energy Production from Biomass. Plant Sciences, 24(5-6), 327-364.

Perera, K.K.C.K. Rathnasiri, P.G. Senarath, S.A.S. Sugathapala, A.G.T. Bhattacharya, S.C. and Abdul Salam, P. 2005. Assessment of sustainable energy potential of non-plantation biomass resources in Sri Lanka. Biomass and Bioenergy, Volume 29 .199-213.

Petersen Raymer, A.K. 2006. A comparison of avoided greenhouse gas emissions when using different kinds of wood energy. Biomass & Bioenergy, 30: 605-617.

Ranasinghe, D.M.S.H.K. and Mayhead, G.J., 1991. Dry matter content and its distribution in an age series of *Eucalyptus camaldulensis* (Dehn.) plantations in Sri Lanka. Forest Ecology and Management, Volume 41. 137-142.

Rao, D.L.N. and Gill, H.S. 2000. Residual Effects of *Sebania sesban* Forestry on Yield and Nitrogen Uptake by Rice and Wheat in a Reclaimed Alkalil Soil in Haryana. Page 139.148 in Long-term Soil Fertility Experiments in Rice-Wheat Cropping Systems (Abrol, I.P., Bronson, K. F., Duxbury, J. M. and Gupta, R. K. eds.). Rice-Wheat Consortium Paper Series 6. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Rao, D.L.N. Gill, H.S.and Abrol, I.P. 1989. Regional Experience with Perennial *Sesbania* in India 189-198; In Perennial *Sesbania* Species in Agroforestry Systems. Proceeding of a Workshop Sponsored by ICRAF and NFTA .Held on March 27-31, 1989, ICRAF, Nairobi, Kenya.

Sarah C. Davis. Kristina J. Anderson-Teixeira. and Evan H. DeLucia. 2008 .Life-Cycle Analysis and the Ecology of Biofuels. Elsevier Ltd ,Trends in Plant Science Vol.14 No.3.

Schlamadinger, B. and Marland, G. 1996. The Role of Forest and Bioenergy Strategies in the Global Carbon Cycle. Biomass and Bioenergy, Volume 10. 275-300.

Smith, K.R. Kaltschmitt, M. and Thrän, D. 2001. Renewable Energy from Biomass. Contribution for the Encyclopedia of Physical Science and Technology. Academic Press, San Diego, California, USA.

Sotomayor, A. and Pitman, W. 2000. Tropical Forage plants :Development and Use. Published by CRC Press, 391 pages.

Ståhl, L. 2005. Planted Tree Fallows and Their Influence on Soil Fertility and Maize Production in East Africa .Nitrogen Fixation and Soil Nitrogen Dynamics .Faculty of Forest Sciences Department of Forest Ecology. Umea Doctoral Thesis. Swedish University of Agricultural Sciences, Umeå 2005. Acta Universitatis Agriculturae Sueciae.2005: 109.

Sultan, M. I. Gill, M. A. Anwar, M. M. and Athar, M. (2007).Evaluation of soil physical properties as influenced by various green manuring legumes and phosphorus fertilization under rain fed conditions. Int. J. Environ. Sci. Tech., 4 (1): 109-118.

Tarimo, A.J.P.and Takamura, Y.T. 1998. Sugarcane Production, Processing and Marketing in Tanzania. African Study Monographs, 19(1): 1-11.

Wahlund, B. Jinyue, Y. and Mats, W. 2004. Increasing Biomass Utilization in Energy Systems: A comparative study of CO_2 reduction and cost for different bioenergy processing options. Biomass and Bioenergy, Volume 26, Issue 6, 531-544.

Wihersaari, M. 2005a. Greenhouse gas emissions from final harvest fuel chip production in Finland. Biomass & Bioenergy, 28: 435-443.; In Holmgren, K., Eriksson, E., Olsson, O., Olsson, M., Hillring, B. and Parikka, M. 2007.Biofuels and Climate Neutrality–System Analysis of Production and Utilization. Elforsk rapport 07:35.

Wikipedia 2008. Processing. Milling. Available at http://en.wikipedia.org/wiki/Sugarcane. Cited on 27 November 2008.

World Agroforestry Centre (WAC) .Transforming Lives Landscapes. Agroforestry Database Species Identity .Available on http://www.worldagroforestrycentre.org/Sites/TreeDBS/aft/speciesPrinterFriendly.asp?Id=760 .Cited on 18 August 2008.

World Energy Council.2004.Comparison of Energy Systems Using Life Cycle Assessment: A Special Report of the World Energy Council.

Zewdie, M. 2008. Temporal Changes of Biomass Production, Soil Properties and Ground Flora in *Eucalyptus globulus* Plantations in the Central Highlands of Ethiopia. Doctoral Thesis No. 2008:8. Faculty of Natural Resources and Agricultural Science. Uppsala 2008. Swedish University of Agricultural.

Publications from
The Department of Forest Products, SLU, Uppsala

Rapporter/Reports

1. Ingemarson, F. 2007. De skogliga tjänstemännens syn på arbetet i Gudruns spår. Institutionen för skogens produkter, SLU, Uppsala
2. Lönnstedt, L. 2007. *Financial analysis of the U.S. based forest industry*. Department of Forest Products, SLU, Uppsala
4. Stendahl, M. 2007. *Product development in the Swedish and Finnish wood industry.* Department of Forest Products, SLU, Uppsala
5. Nylund, J-E. & Ingemarson, F. 2007. *Forest tenure in Sweden – a historical perspective.* Department of Forest Products, SLU, Uppsala
6. Lönnstedt, L. 2008. *Forest industrial product companies – A comparison between Japan, Sweden and the U.S.* Department of Forest Products, SLU, Uppsala
7. Axelsson, R. 2008. Forest policy, continuous tree cover forest and uneven-aged forest management in Sweden's boreal forest. Licentiate thesis. Department of Forest Products, SLU, Uppsala
8. Johansson, K-E.V. & Nylund, J-E. 2008. NGO Policy Change in Relation to Donor Discourse. Department of Forest Products, SLU, Uppsala
9. Uetimane Junior, E. 2008. Anatomical and Drying Features of Lesser Known Wood Species from Mozambique. Licentiate thesis. Department of Forest Products, SLU, Uppsala
10. Eriksson, L., Gullberg, T. & Woxblom, L. 2008. Skogsbruksmetoder för privatskogs-brukaren. *Forest treatment methods for the private forest owner.* Institutionen för skogens produkter, SLU, Uppsala
11. Eriksson, L. 2008. Åtgärdsbeslut i privatskogsbruket. *Treatment decisions in privately owned forestry.* Institutionen för skogens produkter, SLU, Uppsala
12. Lönnstedt, L. 2009. *The Republic of South Africa's Forets Sector.* Department of Forest Products, SLU, Uppsala
13. Blicharska, M. 2009. *Planning processes for transport and ecological infrastructures in Poland – actors' attitudes and conflict.* Licentiate thesis. Department of Forest Products, SLU, Uppsala
14. Nylund, J-E. 2009. *Forestry legislation in Sweden*. Department of Forest Products, SLU, Uppsala

Examensarbeten/Master Thesis

1. Stangebye, J. 2007. Inventering och klassificering av kvarlämnad virkesvolym vid slutavverkning. *Inventory and classification of non-cut volumes at final cut operations.* Institutionen för skogens produkter, SLU, Uppsala
2. Rosenquist, B. 2007. Bidragsanalys av dimensioner och postningar – En studie vid Vida Alvesta. *Financial analysis of economic contribution from dimensions and sawing patterns – A study at Vida Alvesta.* Institutionen för skogens produkter, SLU, Uppsala
3. Ericsson, M. 2007. En lyckad affärsrelation? – Två fallstudier. *A successful business relation? – Two case studies.* Institutionen för skogens produkter, SLU, Uppsala
4. Ståhl, G. 2007. Distribution och försäljning av kvalitetsfuru – En fallstudie. *Distribution and sales of high quality pine lumber – A case study*. Institutionen för skogens produkter, SLU, Uppsala
5. Ekholm, A. 2007. Aspekter på flyttkostnader, fastighetsbildning och fastighetstorlekar. *Aspects on fixed harvest costs and the size and dividing up of forest estates.* Institutionen för skogens produkter, SLU, Uppsala
6. Gustafsson, F. 2007. Postningsoptimering vid sönderdelning av fura vid Säters Ångsåg. *Saw pattern optimising for sawing Scots pine at Säters Ångsåg*. Institutionen för skogens produkter, SLU, Uppsala
7. Götherström, M. 2007. Följdeffekter av olika användningssätt för vedråvara – en ekonomisk studie. *Consequences of different ways to utilize raw wood – an economic study*. Institutionen för skogens produkter, SLU, Uppsala
8. Nashr, F. 2007. *Profiling the strategies of Swedish sawmilling firms.* Department of Forest Products, SLU, Uppsala
9. Högsborn, G. 2007. Sveriges producenter och leverantörer av limträ – En studie om deras marknader och kundrelationer. *Swedish producers and suppliers of glulam – A study about their markets and customer relations.* Institutionen för skogens produkter, SLU, Uppsala

10. Andersson, H. 2007. *Establishment of pulp and paper production in Russia – Assessment of obstacles.* Etablering av pappers- och massaproduktion i Ryssland – bedömning av möjliga hinder. Department of Forest Products, SLU, Uppsala
11. Persson, F. 2007. Exponering av trägolv och lister i butik och på mässor – En jämförande studie mellan sport- och bygghandeln. Institutionen för skogens produkter, SLU, Uppsala
12. Lindström, E. 2008. En studie av utvecklingen av drivningsnettot i skogsbruket. *A study of the net conversion contribution in forestry.* Institutionen för skogens produkter, SLU, Uppsala
13. Karlhager, J. 2008. *The Swedish market for wood briquettes – Production and market development.* Department of Forest Products, SLU, Uppsala
14. Höglund, J. 2008. *The Swedish fuel pellets industry: Production, market and standardization*. Den Svenska bränslepelletsindustrin: Produktion, marknad och standardisering. Department of Forest Products, SLU, Uppsala
15. Trulson, M. 2008. Värmebehandlat trä – att inhämta synpunkter i produktutvecklingens tidiga fas. *Heat-treated wood – to obtain opinions in the early phase of product development.* Institutionen för skogens produkter, SLU, Uppsala
16. Nordlund, J. 2008. Beräkning av optimal batchstorlek på gavelspikningslinjer hos Vida Packaging i Hestra. *Calculation of optimal batch size on cable drum flanges lines at Vida Packaging in Hestra*. Institutionen för skogens produkter, SLU, Uppsala
17. Norberg, D. & Gustafsson, E. 2008. *Organizational exposure to risk of unethical behaviour – In Eastern European timber purchasing organizations.* Department of Forest Products, SLU, Uppsala
18. Bäckman, J. 2008. Kundrelationer – mellan Setragroup AB och bygghandeln. *Customer Relationsship – between Setragroup AB and the DIY-sector.* Institutionen för skogens produkter, SLU, Uppsala
19. Richnau, G. 2008. *Landscape approach to implement sustainability policies? - value profiles of forest owner groups in the Helgeå river basin, South Sweden.* Department of Forest Products, SLU, Uppsala
20. Sokolov, S. 2008. *Financial analysis of the Russian forest product companies.* Department of Forest Products, SLU, Uppsala
21. Färlin, A. 2008. *Analysis of chip quality and value at Norske Skog Pisa Mill, Brazil*. Department of Forest Products, SLU, Uppsala
22. Johansson. N. 2008. *An analysis of the North American market for wood scanners.* En analys över den Nordamerikanska marknaden för träscanners. Department of Forest Products, SLU, Uppsala
23. Terzieva, E. 2008. *The Russian birch plywood industry – Production, market and future prospects*. Den ryska björkplywoodindustrin – Produktion, marknad och framtida utsikter. Department of Forest Products, SLU, Uppsala
24. Hellberg, L. 2008. Kvalitativ analys av Holmen Skogs internprissättningsmodell. *A qualitative analysis of Holmen Skogs transfer pricing method.* Institutionen för skogens produkter, SLU, Uppsala
25. Skoglund, M. 2008. Kundrelationer på Internet – en utveckling av Skandias webbplats. *Customer relationships through the Internet – developing Skandia's homepages.* Institutionen för skogens produkter, SLU, Uppsala
26. Hesselman, J. 2009. Bedömning av kunders uppfattningar och konsekvenser för strategisk utveckling. *Assessing customer perceptions and their implications for strategy development.* Institutionen för skogens produkter, SLU, Uppsala
27. Fors, P-M. 2009. *The German, Swedish and UK wood based bio energy markets from an investment perspective, a comparative analysis.* Department of Forest Products, SLU, Uppsala
28. Andræ, E. 2009. *Liquid diesel biofuel production in Sweden – A study of producers using forestry- or agricultural sector feedstock.* Produktion av förnyelsebar diesel – en studie av producenter av biobränsle från skogs- eller jordbrukssektorn. Department of Forest Products, SLU, Uppsala
29. Barrstrand, T. 2009. Oberoende aktörer och Customer Perceptions of Value. *Independent actors and Customer Perception of Value.* Institutionen för skogens produkter, SLU, Uppsala
30. Fälldin, E. 2009. Påverkan på produktivitet och produktionskostnader vid ett minskat antal timmerlängder. *The effect on productivity and production cost due to a reduction of the number of timber lengths.* Institutionen för skogens produkter, SLU, Uppsala
31. Ekman, F. 2009. Stormskadornas ekonomiska konsekvenser – Hur ser försäkringsersättningsnivåerna ut inom familjeskogsbruket? *Storm damage's economic consequences – What are the levels of compensation for the family forestry?* Institutionen för skogens produkter, SLU, Uppsala
32. Larsson, F. 2009. Skogsmaskinföretagarnas kundrelationer, lönsamhet och produktivitet. *Customer relations, profitability and productivity from the forest contractors point of view.* Institutionen för skogens produkter, SLU, Uppsala

33. Lindgren, R. 2009. Analys av GPS Timber vid Rundviks sågverk. *An analysis of GPS Timber at Rundvik sawmill.* Institutionen för skogens produkter, SLU, Uppsala
34. Rådberg, J. & Svensson, J. 2009. Svensk skogsindustris framtida konkurrensfördelar – ett medarbetar-perspektiv. *The competitive advantage in future Swedish forest industry – a co-worker perspective.* Institutionen för skogens produkter, SLU, Uppsala
35. Franksson, E. 2009. Framtidens rekrytering sker i dag – en studie av ingenjörsstudenters uppfattningar om Södra. *The recruitment of the future occurs today – A study of engineering students' perceptions of Södra.* Institutionen för skogens produkter, SLU, Uppsala
36. Jonsson, J. 2009. *Automation of pulp wood measuring – An economical analysis.* Department of Forest Products, SLU, Uppsala
37. Hansson, P. 2009. *Investment in project preventing deforestation of the Brazilian Amazonas***.** Department of Forest Products, SLU, Uppsala
38. Abramsson, A. 2009. Sydsvenska köpsågverksstrategier vid stormtimmerlagring. *Strategies of storm timber storage at sawmills in Southern Sweden.* Institutionen för skogens produkter, SLU, Uppsala
39. Fransson, M. 2009. Spridning av innovationer av träprodukter i byggvaruhandeln. *Diffusion of innovations – contrasting adopters views with non adopters.* Institutionen för skogens produkter, SLU, Uppsala
40. Hassan, Z. 2009. *A Comparison of Three Bioenergy Production Systems Using Lifecycle Assessment.* Department of Forest Products, SLU, Uppsala