Report

Biomass for Energy versus Food and Feed, Land Use Analyses and Water Supply

Svetlana Ladanai
Johan Vinterbäck

SLU, Institutionen för energi och teknik
Swedish University of Agricultural Sciences
Department of Energy and Technology

Report 022
ISSN 1654-9406
Uppsala 2010

SLU, Swedish University of Agricultural Science
Department of Energy and Technology

Biomass for Energy versus Food and Feed, Land Use Analyses and Water Supply

Svetlana Ladanai
Johan Vinterbäck

Rapport(Institutionen energi och teknik, SLU)
ISSN 1654-9406
2010:022

Uppsala 2010

Keywords: bioenergy, biomass, water, land use, food, feed, sustainability

EXECUTIVE SUMMARY

The global growth in energy demand continues, but the way of meeting rising energy needs is not sustainable. The use of biomass energy is a widely accepted strategy towards sustainable development that sees the fastest rate with the most of increase in power generation followed by strong rises in the consumption of biofuels for transport.

Agriculture, forestry and wood energy sector are the leading sources of biomass for bioenergy. However, to be acceptable, biomass feedstock must be produced sustainably. Bioenergy from sustainably managed systems could provide a renewable and carbon neutral source of energy.

Bioenergy systems can be relatively complex, intersectoral and site- and scale-specific. The environmental benefits of biomass-for-energy production systems can vary strongly, depending on site properties, climate, management system and input intensities. Bioenergy supply is closely linked to issues of water and land use. It is important to understand the effects of introducing it as well as it is necessary to promote integrated and synergic policies and approaches in the sectors of forestry, agriculture, energy, industry and environment.

Biofuels offer attractive solutions to reducing GHG emissions, addressing energy security concerns and have also other socio-economic advantages. Currently produced biofuels are classified as first-generation. Some first-generation biofuels, such as for example ethanol from corn possibly have a limited role in the future transport fuel mix, other ones such as ethanol from sugarcane or biodiesel made from oils extracted from rerennial crops, as well as non-food and industrial crops requiring minimal input and maintenance and offering several benefits over conventional annual crops for ethanol production.are promising. Sugarcane ethanol has greenhouse gas (GHG) emissions avoidance potential; can be produced sustainably; can be cost effective without governments support mechanisms, provide useful and valuable co-products; and, if carefully managed with due regard given to sustainable land use, can support the drive for sustainable development in many developing countries. Sugarcane ethanol - currently the most effective biofuel at displacing GHG emissions - is already mitigating GHGs in Brazil. *Jatropha curcas* L., a multipurpose, drought resistant, perennial plant has gained lot of importance for the production of biodiesel. However, it is important to point out that nearly all of studies have overstated the impacts of first-generation biofuels on global agricultural and land markets due to the fact that they have ignored the role of biofuel by-products. However, feed by-products of first-generation biofuels, such as dried distillers grains with soluble and oilseed meals are used in the livestock industry as protein and energy sources mitigates the price impacts of biofuel production as well as reduce the demand for cropland and moderate the indirect land use consequences.

The production of second generation biofuels is expected to start within a few years. Many of the problems associated with first-generation biofuels can be solved by the production of second generation biofuels manufactured from abundant ligno-cellulosic materials such as cereal straw, sugar cane bagasse, forest residues, wastes and dedicated feedstocks (purpose-grown vegetative grasses, short rotation forests and other energy crops). These feedstocks are not food competitive, do not require additional agricultural land and can be grown on marginal and wasteland. Depending on the feedstock choice and the cultivation technique, second-generation biofuel production has the potential to provide benefits such as consuming waste residues and making use of abandoned land.

As much as 97-98% of GHG emissions could be avoided by substituting a fossil fuel with wood fuel. Forest fertilization is an attractive option for increasing energy security and reducing net GHG emission. In addition to carbon dioxide the emissions of methane and nitrous oxides may be important factors in GHG balance of biofuels. Forest management rules, best practices for nitrogen fertilizer use and development of second generation technologies use reduce these emissions.

Soils have an important role in the global budget of greenhouse gases. However, the effects of biomass production on soil properties are entirely site and practice-specific and little is known about long-term impact. Soil biological systems are resilient and they do not show any lasting impacts due to intensive site management activities.

Land management practices can change dramatically the characteristic and gas exchange of an ecosystem. GHG benefits from biomass feedstock use are in some cases significantly lower if the effects of direct[1] or indirect (ILUC[2]) land use change are taken into account. LUC and ILUC can impact the GHG emission by affecting carbon balance in soil and thus ecosystem. To understand carbon fluxes in an ecosystem large ecosystem units and time scale are critical. Mitigation measures of the impact of land use change on greenhouse gas emissions include the use of residues as feedstock, cultivation of feedstock on abandoned arable land and use of feedstock by-products as substitutes for primary crops as animal feed. Cropping management is the other key factor in estimating GHG emissions associated with LUC and there is significant opportunity to reduce the potential carbon debt and GHG emissions through improved crop and soil management practices, including crop choice, intensity of inputs, harvesting strategy, and tilling practices. Also a system with whole trees harvesting with nutrient compensation is closely to being greenhouse-gas-neutral. Biochar applied to the soil offers a direct method for sequestrating C and generating bioenergy. However, the most recent studies showing that emissions resulting from ILUC are significant have not been systematically compared and summarized and current practices for estimating the effects of ILUC suffer from large uncertainties. Therefore, it seems to be delicate to include the ILUC effects in the GHG emission balance at a country level.

The land availability is an important factor in determining bioenergy sustainability. However, even though food and biofuel/biomass can compete for land, this is not inevitably the case. The pattern of completion competition will e.g. depend on whether food security policies are in place. Moreover, the great potential for uncomplicated biomass production lies in using residues and organic waste, introduction of second generation biofuels which are more efficient in use of land and bioresources as well as restoration of degraded and wasted areas. Agroforestry has high potential for simultaneously satisfying many important objectives at ecosystems, economic and social levels. For example, as a very flexible, but low-input system, alley cropping can supply biomass resources in a sustainable way and at the same time provide ecological benefits in Central Europe. A farming system that integrates woody crops with conventional agricultural crops/pasture can more fully utilize the basic resources of water, carbon dioxide, nutrients, and sunlight, thereby producing greater total biomass yield. Overall, whether food prices will rise in parallel to an increase in biofuel demand will depend,

[1] Direct land-use change occurs when feedstock for biofuels purposes (e.g. soybean for biodiesel) displace a prior land-use (e.g. forest), thereby generating possible changes in the carbon stock of that land.
[2] Indirect land-use change (ILUC) occurs when pressure on agriculture due to the displacement of previous activity or use of the biomass induces land-use changes on other lands.

more on trade barriers, subsidies, policies and limitations of marketing infrastructure than on lack of physical capacity.

There are plant species that provide not only biofuel resources but also has the potential to sequestrate carbon to soil. For example, reed canary grass (RCG, *Phalaris arundinacea L.*) indicates the potential as a carbon sink. Harvest residues are increasingly utilized to produce energy. Sweden developed a series of recommendations and good-practice guidelines (GPG) for whole tree harvesting practices.

Water has a multifarious relationship to energy. Biofuel production will have a relatively minor impact on the global water use. It is critically important to use low-quality water sources and to select the crops and countries that (*under current production circumstances*) produce bioenergy feedstock in the water-efficient way. However, local and regional impacts of biofuel production could be substantial. Knowledge of watershed characteristics, local hydrology and natural peak flow patterns coupled with site planning, location choice and species choice, are all factors that will determine whether or not this relationship is sustainable. For example, bioethanol`s water requirements can range from 5 to 2138 L per liter of ethanol depending on regional irrigation practices. Moreover, sugarcane in Brazil evaporates 2,200 liters for every liter of ethanol, but this demand is met by abundant rainfall.

Biomass production can have both positive and negative effects on species diversity. However, woodfuel production systems as well as agroforestry have the potential to increase biodiversity.

A regional energy planning could have an important role to play in order to achieve energy-efficient and cost-efficient energy systems. Closing the loop through the optimization of all resources is essential to minimize conflicts in resource requirements as a result of increased biomass feedstock production. A systems approach where the agricultural, forestry, energy, and environmental sectors are considered as components of a single system, and environmental liabilities are used as recoverable resources for biomass feedstock production has the potential to significantly improve the economic, social, and environmental sustainability of biofuels. The LCA (life cycle analysis) approach takes into account all the input and output flows occurring in biomass production systems. The source of biomass has a big impact on LCA outcomes and there is a broad agreement in the scientific community that LCA is one of the best methodologies for the GHG balance calculation of biomass systems.

Overall, maximizing benefits of bioenergy while minimizing negative impacts is most likely to occur in the presence of adequate knowledge and frameworks, such as for example certification systems, policy and guidelines. Criteria for achieving sustainability and best land use practices when producing biomass for energy must be established and adopted.

PREFACE

There are many benefits of bioenergy to society, the economy, and the environment. These include improving carbon balances, mitigating global climate change, the creation of jobs, increased economic development, reduction in energy cost, local energy security, debt reduction and the use of indigenous technology. Producing bioenergy is necessary. However, it could bring environmental and socio-economic problems if management of the source of bioenergy is carried out on an unsustainable basis. In order to contribute to the international debate on the relative impacts of production and processing of biomass for energy and through a review of existing literature, this report highlight some of the key environmental factors highly important to the sustainability of biomass-for-energy production systems. These factors are: soil, land, water, productivity, biodiversity and energy/carbon balance. The report more specifically present many contrasting examples of the complex interrelationships between water, food, energy and the environment and as such it is useful both to illustrate various synergies and potential conflicts and to indicate considerable implications for policy.

The "WORLD BIOENERGY ASSOCIATION PROJECT ON BIOENERGY, CERTIFICATION CRITERIA, QUANTIFYING AND SUSTAINABILITY CRITERIA & BIOENERGY VERSUS FOOD, LAND-USE, AND WATER SUPPLY" makes up the framework for this report. The project partners are the Swedish University of Agricultural Science, Department of Energy and Technology and the World Bioenergy Association. The original project structure was changed somewhat along the way in order to be more efficient. The upgraded project structure was agreed upon in a document dated October 9th, 2009[3]. The updated structure of the project encompasses three position papers and related background material. The three papers are entitled "Global potential of sustainable biomass for energy"; "Certification criteria for sustainable biomass for energy"; and "Biomass for energy versus food and feed, land use analyses and water supply".

Much of the improvement in this report has been the result of constructive discussions with Mr. Kent Nyström, President of WBA. Important comments on the manuscript have also helpfully been provided by other members of the WBA board, including Mr Andrew Lang, SMARTimbers Cooperative Ltd. The Wood Energy Group, Australia; Prof. S.C. Bhattacharya, International Energy Initiative, India; Mr Marcos Martin, AVEBIOM, Spain and Ms Karin Haara, Svebio, Sweden. We thank Ms Cecilia Sundberg, SLU, for her valuable comments on the final version of the manuscript.

Financing of the project has been gratefully acknowledged from the Swedish Board of Agriculture.

[3] Structure for the project "WBA Bioenergy Project on Criteria, Quantification and Land Use" – an agreement made between the partners

Contents

I. INTRODUCTION 9

II. BACKGROUND 9

1. Biomass energy 10

1.1. The term, overview, current status and global trends 10

1.2. Bioenergy is a widely accepted strategy towards sustainable development 10

2. Bioenergy technologies 11

3. Biomass resources 11

4. Effects of increasing bioenergy: general 12

III. OBJECTIVE 13

IV. METHODOLOGY 14

1. Quantitative overview of available literature on the bioenergy issue 14

2. Literature review 14

V. QUANTITATIVE OVERVIEW OF BIOENERGY LITERATURE 15

VI. BIOFUELS 16

1. First generation biofuels 16

2. Second generation biofuels 18

VII. ENERGY – FOOD/FEED/LAND - ENVIRONMENT DEBATE AND RESEARCH: STATE OF THE ART 20

1. Impacts on the environment: general 20

2. Sustainability is important 21

3. Climate change and bioenergy 24

3.1. Energy/carbon balance or impact on climate 24

3.2. Bioenergy and other important greenhouse gases 26

3.3. Greenhouse gas release from land use change 27

3.4. Other climate forcing effects 30

4. Land /Soil for Food versus Energy 31

4.1 Land availability 31

4.2 Agroforestry 35

4.3. Effects of biomass production systems on soil properties 35

5. Hydrology and renewable energy 39

5.1. General 39

5.2. Biomass production and water use 40

6. Biodiversity 43

7. Site productivity 44

8. Biofuels offer an attractive solution 45

8.1. Future biofuels demand *45*
8.2. Biofuels in the market *46*
8.3. Environmental benefits of biofuels *47*
9. Systems approach for sustainable biomass feedstock production 48
10. To sum up 51
VIII. CONCLUSIONS 51
REFERENCES 56

I. INTRODUCTION

The growth in world energy demand is likely to continue; the International Energy Agency predicts energy demand will increase by 40% between 2007 and 2030 (IEA, 2009a). However, global economy is dominated by the energy sector, which is dominated by oil and fossil fuels that are naturally unsustainable and the way in which the world's population currently meets its energy needs is thus not sustainable (e.g., Erbach and Wilhelm, 2009).

The intense and unsustainable use of fossil fuels was the background of the explosive population growth in the 20th century (from 1.65 billion in 1900 to 6.6 billion currently) (Koutsoyiannis et al., 2009). The acute population growth will exceed 10 billion by the year 2050 (Bilgen et al., 2004). Food production to sustain this population absolutely depends on energy use (Pfeiffer, 2004). Cheap energy, increased human population, economic development and the implied change of social and economic conditions resulted in sprawling urbanization with increasing global environmental impacts and consequences (e.g., Vlachos and Braga, 2001).

The argument against our continuing dependence on fossil fuels is further supported by the realization that widespread burning of fossil fuels damages the biosphere and presents increasing economic and security problems (Smil, 2005; 2006). The growing interest in renewable energy has been prompted by increasing concern over the resource depletion (e.g. Bilgen et al., 2004). The importance of energy issues and their linkages to climate have relatively recently started to be explored[4]. Since 1990 extensive funds have been spent on research in climate change, but at the same time, research was misleadingly focused more on the “symptom”, i.e. the emission of greenhouse gases, than on the “illness”, i.e. the unsustainability of fossil fuel-based energy production (Koutsoyiannis et. al., 2009).

All in all, rising energy prices, geopolitics as well as concerns over increasing oil prices, national security of supply, and the impacts of greenhouse gas emissions on global climate change are driving large-scale efforts to implement sustainable energy alternatives and have prompted countries to develop policies that promote alternative energy sources. Unless energy saving and use of renewable resources become the norm, the unsustainability of energy management will become the core problem of the next decades and will span all aspects of life, economy, society, demography and science (e.g., Koutsoyiannis et al., 2009). The time frame for conversion to an alternative energy system when the new technologies consume less energy than they produce or the energy payback is positive is typically/historically 75 to 100 years (Turner, 2004).

II. BACKGROUND

There are today general concerns over increasing oil prices, national security of supply, and the impacts of greenhouse gas emissions on global climate change. Adaptation to global change requires substantial energy saving and development of renewable energy sources. Numerous pilot projects undertaken over the years show that access to energy generated from locally or regionally available sources is a viable and sustainable option, but for this strategy to become reality, however, well-designed national policies and targeted international support for the implementation process are essential (e.g., Müller

[4] cf. the Panel Discussion on “Climate Changes and Energy Challenges” of the 2008 Council for the Landau Nobel Laureate Meetings, 2008

et al., 2008). According to the European Commission climate and energy plan a target of 20% of energy and a specific target of 10% of the energy in transport sector will come from renewable energy sources in 2020 (European Commission 2008). While the 20% target can be met by wind, solar, large-scale hydro power and bioenergy, the transport target seems to be more dependent on biofuels.

1. Biomass energy

1.1. ***The term, overview, current status and global trends***

The term biomass energy can refer to any source of energy produced from non-fossil biological materials. Biomass energy can e.g. come from ocean and freshwater habitats. However, only biomass energy from land is of interest in this report. In recent years there has been large increase in interest in bionergy or energy from biomass because it is seen as a solution to numerous problem facing society such as limited fossil fuel supplies (and energy security), low agricultural and forest commodity prices and climate change (Bird et. al., 2010). Biomass fuels[5] can contribute to climate change mitigation through substituting fossil fuels when sustainably produced (Best, 2006). Liquid biofuels in general, and biodiesel, in particular, have gained importance in the last years in many countries leading to many commercial projects.

The ability of biofuels[6] to meet the above mentioned goals makes them an attractive option to policymakers, offering solutions to a number of domestic challenges. However, although much of the recent biomass energy discussion has focused on ethanol, biodiesel and other liquid transportation fuels, the opportunities for biomass as a source for direct combustion fuel can be comparable or even larger (Field et al., 2007). Such kind of energy from biomass is widely used in cooking and heating in the developing world.

There is momentum, globally, to increase the use of biomass for the production of heat, power and liquid transport fuels (Rowe et al., 2009). Before the start of the industrial revolution, when energy demand was much lower than current demand, biomass energy dominated the supply of fuels. It is still important, accounting for roughly 10 % of world energy demand at present (IEA, 2008).

All energy scenarios show a shift toward an increased percentage of renewable energy sources, including biomass[7] (Gerbens-Leenes et al., 2009). The use of renewable energy, including biomass energy or bioenergy, sees the fastest rate with the most of increase in power generation followed by strong rises in the consumption of biofuels[8] for transport; developing Asian countries are the main drivers of this growth, followed by Middle East (e.g., IEA, 2009a).

1.2. ***Bioenergy is a widely accepted strategy towards sustainable development***

The application of biomass used to substitute fossil resources for the production of energy and fuels is a widely accepted strategy towards sustainable development (Weiss et al., 2007). Sustainability will be a strong factor in the regulatory environment and

[5] Biofuels are a wide range of fuels which are in some way derived from biomass.
[6] Biofuel in this chapter is liquid transportation fuel produced from biomass
[7] In this report, we define biomass as a sum of all organic products, which are used for energy production.
[8] Note that there is a difference between the broad term bioenergy (used in households, transport and industry) and the much more limited term biofuels, used as transport fuels for cars, buses and trucks.

investments in bioenergy and there is a strong societal need to evaluate and understand the sustainability of bioenergy, especially because of the significant increases in production mandated by many countries (e.g., Gopalakrishnan et al., 2009). Bioenergy from sustainably managed ecosystems could provide a renewable, carbon neutral source of energy throughout the world.

2. Bioenergy technologies

There are many ways to generate energy from biomass. Descriptions of different bioenergy technologies are given in Figure 1.

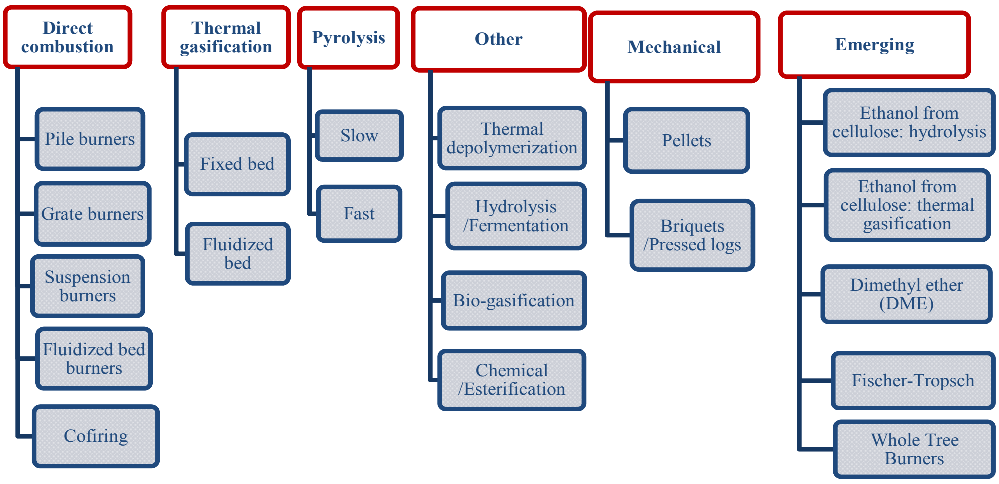


Figure 1. Bioenergy technologies (Source: based on website of Northeast Regional Biomass Program (NRBP), *http://www.nrbp.org/bioenergy/technology/index.htm*).

In addition, technologies such as plug-in hybrid electric vehicles (HEV) which can use both biofuel and biopower exist in near-commercial form, and biopower can be obtained from cogenerated heat and power (CHP) or electric-only power stations (IGCC) technologies which exist in fully commercial, economically viable form. A typical HEV reduces gasoline consumption by about 30% over a comparable conventional vehicle (Markel & Simpson, 2006) [9].

3. Biomass resources

To produce bioenergy, biomass has to be provided. This requires an analysis of existing and potential biomass resources. The resources for biomass use for energy come from a wide range of sources that can be divided into forest biomass, agriculture biomass, waste biomass and energy crops (e. g., Ladanai & Vinterbäck, 2009). However, in the present significant switch from a fossil fuel to a biofuel-based economy, agriculture and forestry are the leading sources of biomass for biofuels such as fuelwood, charcoal, wood pellets, bioethanol and biodiesel.. In 2007 the dominant sources of biomass based liquid transportation fuels were ethanol from corn or sugarcane and biodiesel from rapeseed, soy, or palm oil (e. g., Coyle, 2007).

[9] With additional improvements in aerodynamics and engine technology, hybrid vehicles today have demonstrated upwards of a 45% reduction in consumption as compared to a conventional vehicle.

However, one of the world´s major raw materials is wood and the use of wood for energy is important. About 53 percent of all wood consumed is used for home heating and cooking (Bowyer et al., 2003). In the future, forest fuels are still projected to be by far the dominating biomass energy source. The wood energy sector - an important share of the renewable energy sector - is currently strongly influenced and supported by energy policies and this is despite the economic downturn of the last years that has had severe effects on most sectors in the global economy (e.g., Hartkamp et al., 2009). There are many options that can be pursued to ensure sufficient supplies of wood-related biomass for energy. These include: intensifying forest management practices; increasing reliance on high productivity tree plantation; gaining renewed public support for wood production on public land; developing improved technologies for using forest residues; expanding of agroforestry practices globally; and using greater volumes of recycled wood materials such as for example wood construction and demolition residues (e.g., Bowyer et al., 2003). Increasing biomass production through forest fertilization is an attractive option for increasing energy security and reducing net GHG emission (e. g., Sathtre et al., 2010).

Biomass for energy potentials differ considerably among different regions. However, restoration of degraded areas is the greatest challenge on the way to a sustainable development and if done properly it will, for example, increase the fertility and water status of the adjacent agricultural lands (e.g., Metzger & Hüttermann, 2009), regenerate and stabilize sustainably the global and especially drinking water resources (Piao et al., 2007). During recent years a renewed interest in restoration of areas, that have been degraded and wasted in historical times by human activities everywhere in the world, has spurred increasing efforts for looking at these areas as possible sources of renewable energy (e.g. Borsari et al. 2009).

Possible future energy sources such as hydrogen from engineered microorganisms or electricity from photosynthetic cells could also be considered biomass energy, although these will have a different series of technical challenges than those for current biomass energy derived from terrestrial plants (Field et al., 2007). Hydrogen, the smallest biological substrate, has great potential as an alternative energy carrier (Das and Veziroglu, 2001). Microorganisms produce hydrogen via two main pathways: photosynthes and fermentation. However, compared with photosynthetic processes, fermentative hydrogen production generally yields two orders of magnitude higher rates, does not rely on the availability of light, utilizes a variety of carbon sources such as organic compounds, low-cost wastes, or insoluble cellulosic substrates, requires less energy, and is technically much simpler and more stable (Levin et al., 2006; Ust'ak et al., 2007).

4. Effects of increasing bioenergy: general

As the need for bioenergy increases and producing alternative fuels is necessary, it is important to understand the various effects of introducing fuels based upon feedstocks other than petroleum. The choice of the fuel biomass is guided by environmental, economic and technical considerations. The utilization of untapped residues and the establishment of energy crops can address environmental concerns. Thus, annual energy crops can allow diversification and expansion of crop rotations, with benefits in terms of water, soil and inputs management while deforested, degraded or marginal lands could be rehabilitated as bioenergy plantations which could combat desertification and increase food production (Best, 2006). Biomass feedstock production is also an important contributor to social impacts from bioenergy.

However, though it may seem beneficial to use renewable plant materials for biofuel, the use of crop and forest residues as well as other biomass for fuels raises many environmental and ethical concerns (e.g., Pimentel, 2006). There is a view that biofuels cannot provide a solution to our energy needs. Thus, as land resources for arable substitution of transport fuels on the scale required are not available without further extensive deforestation, which would cause massive carbon dioxide emissions and demand for forest land to provide biomass for burning or gasification would need to be on a similarly large scale to meet emissions reductions targets, it is becoming increasingly clear that the risks associated with these land-use changes may outweigh any
benefits (e.g., Righelato and Spracklen 2007). Undesired impacts on food prices have also become a topic of discussion (Doornbosch and Steenblik 2007). In addition, greenhouse gas reductions from switching to biofuel use may be negated by other factors, especially when forests needs to be cleared to make way for energy crops (Fargione et al. 2008, Searchinger et al. 2008). Increasing attention to biological concerns has focused attention on the desirability of leaving coarse residues on the forest floor for wildlife habitat, erosion control and nutrient recycling. Overall, it is important to avoid possible negative environmental impacts associated with biomass for energy systems such as loss of biodiversity, organic depletion in soils, water depletion and possible negative energy or carbon balances.

However, bioenergy systems can be relatively complex, intersectoral and site- and scale-specific. For example, the carbon balance between restoring forests and producing biofuels is site-specific and depends on biomass productivity, the efficiency with which harvested material is used, the initial state of the surface vegetation, and the fossil fuel to be displaced (Marland & Schlamadinger, 1997). In many circumstances, biomass can produce greater carbon benefit than saving or restoring forests, particularly when forest products are used efficiently to displace carbon-intensive fossil fuels, and when productivity is high (e. g., Marland et al., 2007).

III. OBJECTIVE

While producing renewable energy from biomass is necessary (Blanco-Canqui & Lal, 2007), impacts of this production on environmental quality must be carefully assessed. However, environmental evaluation of production and processing of biomass for energy must take into account that these activities can have both positive and negative environmental effects. Based on a review of available literature, the objective of this report is to give insights into the environmental performance of bio-based production systems by assessing the opportunities and risks with increased biomass production.

IV. METHODOLOGY

1. Quantitative overview of available literature on the bioenergy issue

There is an earlier survey of the amount of scientific information on bioenergy (Ladanai & Vinterbäck, 2009). However, there is a rapid development in many bioenergy issues. How much has the amount of scientific information on bioenergy increased with time? A renewed survey could be compared with the previous one to reveal and quantify the growing interest in bioenergy.

In order to minimize negative impacts while maximizing benefits, knowledge of potential "critical" issues is a key to the design of bioenergy production systems. Among possible challenges to the bioenergy development that have received considerable media attention are its effects on food/feed, water, land occupation and carbon balance. How well are these different issues represented within scientific literature?

In order to answer the above mentioned questions, we used the ISI Web of Knowledge All Databases (ISIWOKAD) – a high-quality research database. We have followed standard search rules when creating search queries. Queries were arranged as subject categories and can be traced via Topic index. Subject categories were: food, water, feed, land and bioenergy.

2. Literature review

A literature review - a description of the literature relevant to a particular topic or field - is not in itself primary research, but rather it reports on other findings. The literature review is important for the understanding of the topic, of what has already been done, how the topic has been researched and what the key issues are.

Our literature review is partly descriptive and therefore seeks to describe the content of primary information and to give an overview of the key writers. Moreover, the review summarises, evaluates, clarifies and/or integrates the content of primary information in these topics. As such, it provides a critical assessment of the available literature in the bioenergy fields, giving an overview of what has been said, contrasting the views of particular authors and raising questions.

The review uses as its database different written documents such as reports, published articles, books as well as web-pages. Based on the review, the report draws some conclusions about the food/feed, soil, land and water implications of bioenergy production for, in particular, policies formulation.

As verbal codes must exist at some level simply because we can transmit and receive verbally encoded messages, similarly visual codes are necessary to account for our visual capacities. However, verbal and visual information are processed in different ways. For example, words are not needed to think about the shape of a car. On the other hand, different concepts and ideas can be represented visually to maintain an overview of them and to keep context in mind at the same time when switching to abstract analyses of problems. In order to make written information easier to understand the reviewed ideas and concepts were visualized.

V. QUANTITATIVE OVERVIEW OF BIOENERGY LITERATURE

This section gives a quantitative overview of the literature available on the bioenergy issue. The growing interest in bioenergy is reflected in the large number of articles published as well as in an increase in the amount of articles during rather short time. Thus, we found that the number of recent papers indexed in ISIWOKAD with the word "renewable bioenergy" in their topic amounted to 5762 at 2009-11-23 (Figure 5). When this new survey was compared with an earlier one to quantify the development in the bioenergy issues, we found that the amount of records was 17 % higher compared to only four months earlier (Figure 5).

How well are food/feed, water, land and other subject categories represented within scientific literature on renewable bioenergy? Refining the previous bioenergy records using these subject categories revealed that food, water and feed are topics which figure prominently in existing literature on bioenergy. These topics are among the potential issues that may be critical for bioenergy production systems. Knowledge of potential issues is a key to the design of bioenergy production systems that minimizes negative impacts to ecosystems while maximizing benefits. Thus, as food, water and feed – categories within the bioenergy Topic - are connected with soil and water resources and properties, these resources/properties are the ecosystem attributes that may be affected by bioenergy production systems. However, these ecosystem attributes are site-specific in nature. Consequently, the results of the information survey identified a strategic issue: We need site-specific information of environmental impacts of bioenergy production systems.

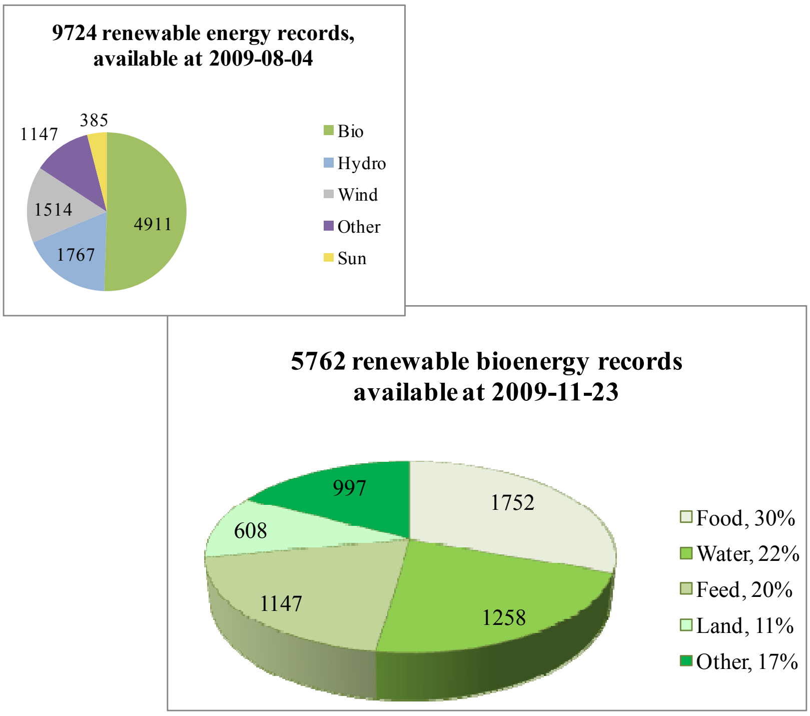


Figure 5. Relative distribution of records of different subject categories (these are food, water, feed, land and other) within 5762 renewable bioenergy records available from ISI WEB of Knowledge All Databases (ISIWOKAD) at 2009-11-23. For comparison, the amount of 4911 renewable bioenergy records available at ISIWOKAD about four months earlier are given in the upper left part of the figure (Source: renewable energy Topic[a] in all databases of ISIWOKAD refined by bioenergy Topic[b] and different subject categories Topics[c]).

[a] renewable energy Topic: Topic=(renew* SAME energ*)
[b] bioenergy Topic: Topic=(bio*)
[c] different subject categories Topics: Topic=(food*) OR Topic=(water*) OR Topic=(feed*) OR Topic=(land*)

VI. BIOFUELS

Two types of liquid biofuels are commonly distinguished. Thus, first-generation are produced from food crops like sugar, maize, and oil crops to produce bioethanol and biodiesel while second-generation biofuels are produced from the fibrous material (lignocellulosic and woody biomass) from a variety of plants such as corn stalks and wheat straw, native grasses, and forest trimmings. Liquid biofuels offer an attractive solution to reducing the carbon intensity of the transport sector and addressing energy security concerns and are therefore given particular attention in this report.

1. First generation biofuels

The feedstock for producing first- generation biofuels either consists of sugar, starch and oil bearing crops or animal fats that in most cases can also be used as food and feed or consists of food residues (IEA Bioenergy, 2009). First-generation biofuels are produced in two ways. One way is through the fermentation of either a starch-based or a sugar-based product. The other way is by processing vegetable oils into biodiesel, a nonpetroleum-based diesel fuel. First-generation biofuels are the land-using biofuels which are on the market in considerable amounts today. The typical representatives of first-generation biofuels are: biodiesel, bio-ethanol, vegetable oil and biogas. The demand for first-generation biofuels, produced mainly from agricultural crops traditionally grown for food and animal feed purposes as well as their production, continues to grow strongly (e.g., IEA, 2008a). The main liquid and gaseous first-generation biofuels on the market today produced from different biomass feedstocks are shown in Figure 2.

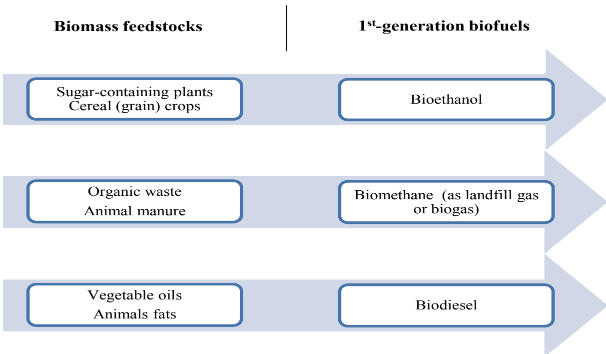


Figure 2. The main liquid and gaseous first-generation biofuels on the market today (Source: based on IEA, 2008a).

By far the largest volume of biofuel production comes from ethanol, produced from a wide range of feedstocks but with 80% coming from corn (maize, mainly produced in the US) and sugarcane (mainly produced in Brazil). It is increasingly understood that most first-generation biofuels, with the exception of sugar cane ethanol, will likely have a limited role in the future transport fuel mix (IEA, 2010). Perennial crops, as well as non-food and industrial crops offer several benefits over conventional annual crops for ethanol production. These crops require minimal input and maintenance, whereas annual crops such as maize require high input energy costs for planting, cultivation, and fertilization (e.g., Sivakumar et al., 2010). For example, *Jatropha curcas* L., a multipurpose, drought resistant, perennial plant belonging to the Euphorbiaceae family has gained lot of importance for the production of biodiesel. The properties of Jatropha and its oil have persuaded investors, policy makers and clean development mechanism (CDM) project developers to consider this crop as a substitute for fossil fuels to reduce greenhouse gas emissions.Biodiesel can be made from oils extracted from rapeseed, sunflower, soybean, palm oil, linseed, canola, castor, hemp, beef tallow and even algae or from used frying oil. Increasing the use of biodiesel could also lead to improved economic development and poverty alleviation, especially in rural areas, since it attracts investment in new jobs and business opportunities for small- and medium-sized enterprises in the fields of production, preparation, transportation, trade and use (Best, 2006). Sugarcane ethanol has greenhouse gas (GHG) emissions avoidance potential; is produced sustainably; can be cost effective without governments support mechanisms, provide useful and valuable co-products; and, if carefully managed with due regard given to sustainable land use, can support the drive for sustainable development in many developing countries (IEA, 2008a). One example is sugarcane ethanol produced currently in Brazil without subsidies following strong supporting policies (IEA, 2008a).

Today the production routes of the first generation biofuels give rise to several issues, such as competition with food and feed industries for raw materials and fertile land, potential availability limitation by soil fertility and per-hectare yields, limitation of the effective savings of CO_2 emissions and fossil energy consumption by the high energy input required for crop cultivation and conversion, which simultaneously burden other environmental impact categories such as eutrophication and acidification (e.g., Cherubini et al., 2009; Zah et al., 2007). Due to an improved understanding of total greenhouse gas (GHG) emissions as a result of detailed life cycle analyses, and related direct (LUC) and indirect[10] land use change (ILUC) issues, the perceived environmental benefits of first-generation biofuels have more recently been brought into question (IEA, 2008a).

It is an important challenge to develop new technologies to be able to convert the chemical energy stored in biomass, and in fossil fuels as well, to electrical energy much more efficiently, avoiding the transformation to thermal energy (Metzger & Hüttermann, 2009). For example, the Direct Methanol Fuel Cell has a theoretical efficiency close to 97%, although presently still performs well below their theoretical potential (Olah et al. 2006). However, it is important to point out that nearly all of studies have overstated the impacts of first-generation biofuels on global agricultural and land markets due to the fact that they have ignored the role of biofuel by-products. Feed by-products of first-generation biofuels, such as dried distillers grains with solubles and oilseed meals are used in the livestock industry as protein and energy sources, their presence mitigates the price impacts of biofuel production as well as they reduce the demand for cropland and moderate the indirect land use consequences of first-generation biofuels (e. g., Taheripour et al., 2010).

[10] The effect when biofuels production on current land and use of biomass in a given region can induce displacement of activities and land-use changes elsewhere is known as indirect land-use change (ILUC).

2. **Second generation biofuels**

The increasing criticism of the sustainability of many first-generation biofuels has raised attention to the potential of so-called second-generation biofuels[11]. Many of the problems associated with first-generation biofuels can be addressed by the production of biofuels manufactured from ligno-cellulosic feedstock materials. These include by-products (cereal straw, sugar cane bagasse, forest residues), wastes (organic components of municipal solid wastes), and dedicated feedstocks (purpose-grown vegetative grasses, short rotation forests and other energy crops). Such low-value agricultural and forest crops and residues as well as non-food crop feedstocks makes the CO_2 performance of second-generation biofuels better than those of first-generation. Depending on the feedstock choice (e.g., ligno-cellulosic, agricultural, forest, energy crops, genetically modified crops) and the cultivation technique, second-generation biofuel production has the potential to provide benefits such as consuming waste residues and making use of abandoned land. In this way, the new fuels could offer considerable potential to promote rural development and improve economic conditions in emerging and developing regions (IEA, 2010).

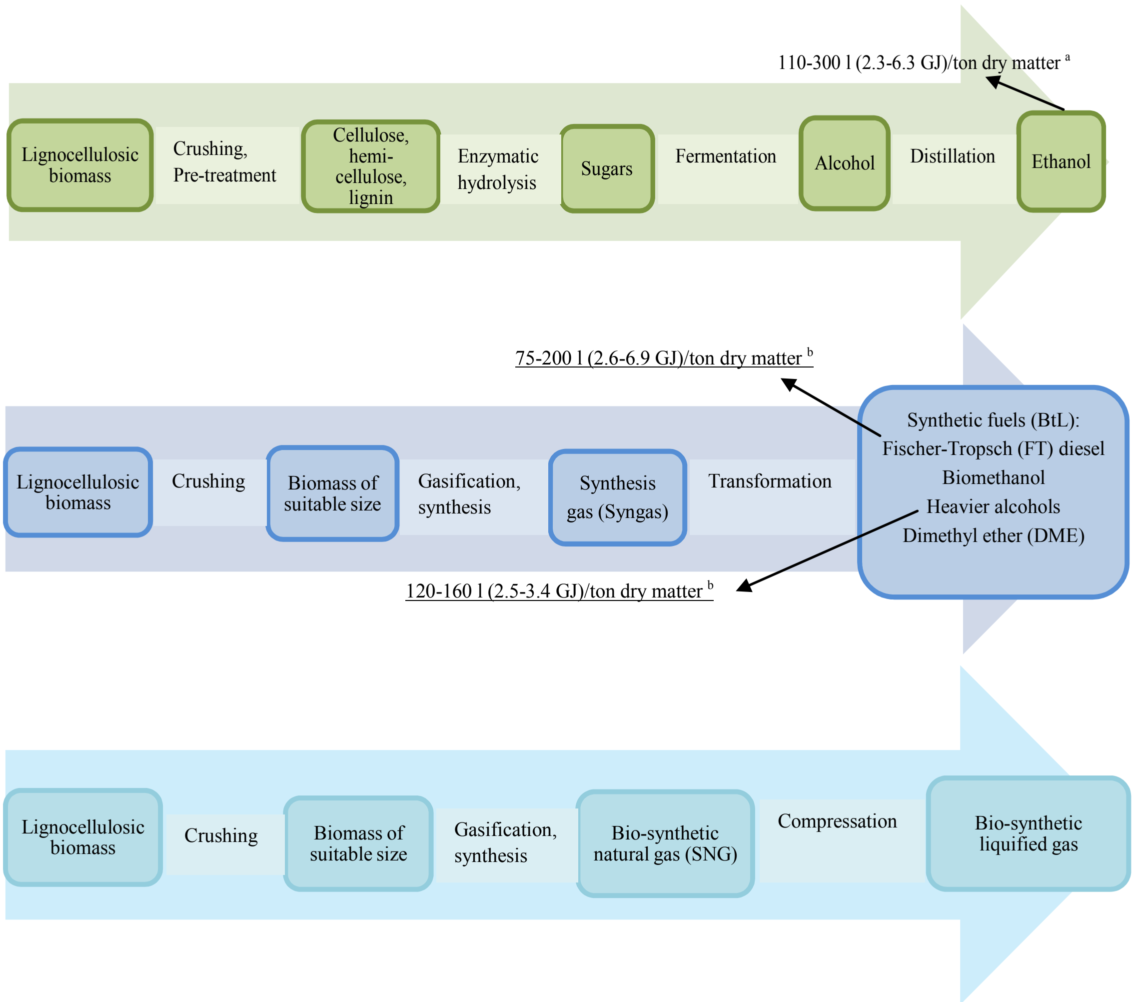
The production of second-generation biofuels from ligno-cellulosic feedstocks can be achieved through two very different processing routes: biochemical and thermochemical also known as biomass-to-liquids, BTL (Figure 3). Enzymes and microorganisms are used to convert cellulose and hemicelluloses components of the feedstocks to sugar prior to their fermentation to produce ethanol through biochemical passway. In contrast to the biochemical approach, the thermochemical route for biofuel production is largely based on existing technologies that have been in operation for a number of decades (IEA, 2008a). Thus, in the thermochemical process, pyrolysis/gasification technologies produce a synthesis gas from which a wide range of long carbon chain biofuels, for example synthetic diesel, can be reformed. There is currently no clear commercial or technical advantage between the biochemical (green colored area) and thermochemical pathways, both sets are under continual development and evaluation (e. g., Sims et al., 2010). On the other hand, while thermochemical processing offers a higher degree of control over product formation and a nearly complete conversion of biomass into usable products, the main drawback is its large energy requirement. Moreover, although both routes have similar potential yields in energy terms, different yields, in terms of liters per tonne of feedstock, occur in practice (Figure 3) (Sims et al., 2010).

These two pathways are not the only second generation biofuels pathways; several variations and alternatives are under evaluation in research laboratories and pilot-plants. As the main issue here is the resistance of lignin to enzymatic degradation that can vary between species, individuals and cell types, the main goal is therefore to increase the availability of soluble polysaccharides from cell wall while decreasing cell wall crystallinity and increasing accessibility to enzymes (e.g., Sivakumar et al., 2010). Sacharification and fermentation are processes that mainly act on cell wall polysaccharides (Sivacumar et al., 2010). Pyrolysis may therefore prove useful for converting residual biomass to energy (Johnson et al., 2007; Gomez et al., 2008).

---

[11] Second generation biofuels are produced from cellulose, hemicellulose or lignin.
2nd-generation biofuels can either be blended with petroleum-based fuels combusted in existing internal combustion engines, and distributed through existing infrastructure or is dedicated for the use in slightly adapted vehicles with internal combustion engines (*e.g.* vehicles for DME). Examples of 2nd-generation biofuels are cellulosic ethanol and Fischer-Tropsch fuels (IEA Bioenergy, 2009).

However, although second generation cellulosic technologies that derive energy from crop residues have the clear potential to augment biofuel production, these technologies are not yet available on a fully commercial scale and are expected to enter the market in the coming five to ten years (IEA, 2010) or probably 10–20 years away from commercial reality (Hellegers et al., 2008). It seems obvious that second-generation biofuel technologies (i.e., using biomass consisting of the residual non-food parts of crops as well as bio-energy crops) must be promoted.



Notes: [a] Mabee et al., 2006
[b] Putsche, 1999.

Figure 3. Classification of second-generation biofuels from lignocellulosic feedstock, their biochemical (green colored area) and thermo-chemical (blue colored area) conversion routes and some biofuel and energy yield ranges per dry tonne of feedstock (Sources: based on Ehring & Dallos, 2009 and IEA, 2008a).

The typical representatives of second-generation biofuels are ligno-cellulosic ethanol, Biomass to Liquid (BtL), bio-synthetic natural gas (SNG) and bio-synthetic liquefied gas (Figure 3).

VII. ENERGY – FOOD/FEED/LAND - ENVIRONMENT DEBATE AND RESEARCH: STATE OF THE ART

1. Impacts on the environment: general

Development of bioenergy has the potential to offset substantial use of fossil fuels and to generate positive economic and environmental benefits. Many studies have proven the great potential of bio-based energy, fuels and materials for reducing both non-renewable energy consumption and fossil carbon dioxide (CO_2) emissions (e.g., Weiss et al., 2007; Dornburg et al., 2004; Patel et al., 2003; Reinhardt and Zamanek, 2000; Wihersaari, 2005). There are other environmental issues that are ultimately important in making choices between fossil fuels and biofuels such as soil, water and air quality, land availability, biodiversity and productivity. Thus, development of bioenergy sources has the potential to threaten conservation areas, pollute or relocate water resources, cause negative equity impacts and create distributional problems (e.g., McCornick et al., 2008; Field et al., 2008; Hellegers et al., 2008). Impacts of harvesting of residues remaining in the field following the harvest of agricultural crops and forests on soil organic carbon (SOC) sequestration, agricultural and forest productivity, and environmental quality must be carefully and objectively assessed. Apart from this, as food and biofuels can depend on the same resources for production such as land, water, and energy, diverse conflicts exist in the use of land, water, energy and other environmental resources for food and biofuel production (Pimentel et al., 2009).

However, the interrelationships that exist in different facets of the energy-food/feed/land-environment interface are complex and sensitive (e.g., McCornick et al., 2008; de Fraiture et al., 2008; Müller et al., 2008). Biofuels present new conflicts in this interface. On the other hand, such conflicts also exist in modern intensive and unsustainable agriculture (e.g., Pfeiffer, 2004). Thus, during the past 50 years, agricultural activities where external inputs of pesticides, herbicides, including plant hormone, inorganic fertilizer and animal feedstuffs is a means to increase food production, have tended to substitute for natural processes and resources, rendering them more vulnerable (e.g., Pretty, 2008b). Technologically-enhanced agriculture has eroded soil, polluted and overdrawn groundwater and surface water, and even (largely due to increased pesticide use) caused serious public health and environmental problems. More hydrocarbon-based products are needed to combat these problems, for example irrigation water requires more energy to pump.

The ecological evaluation of production of biomass for energy is complicated by the fact that this process can have both positive and negative environmental effects. Moreover, regional variations in the environmental impacts of biomass production are significant (Kim & Dale, 2009). However, the emphasis is often driven by a global perspective and disregards environmental impacts relevant on a regional level, for example such as eutrophication or acidification (Weiss et al., 2007). Water availability and pollution are the other examples of the scale issue, where only growing biomass using ill-advised species, or scale or design not appropriate to the site or region would pollute and potentially reduce local availability of water.

An analysis of available information on the relative environmental impacts of production of biomass for energy that is consisting in most cases of a mixture of scientific knowledge, assumptions and subjective value judgments can be used for assisting the decision making process (e.g., Weiss et al., 2007). The same author pointed out that comparing and evaluating different environmental impacts is, moreover, by no means straightforward because scientific knowledge and subjective value judgments have to be combined in order to develop transparent evaluation criteria. The future of biomass energy is dependent on the complex interplay of a number of several potential environmental factors highly important to the sustainability of biomass-for-energy production such as soil, water, land, biodiversity, productivity, and energy/carbon balance. These factors must be effectively integrated to maximize the benefits and minimize the ecosystem and societal costs of biomass energy production.

The decision process in favor of or against comparable product alternatives often involves weighing different environmental impact categories within a sustainability framework (Kaenzig et al., 2004). Weighing of different environmental impacts, therefore, always requires decisions regarding the priorities of impact assessment in order to evaluate the overall environmental performance of a particular product (Weiss et al., 2007). In particular, constraints owing to ecosystem characteristics, competition from alternative land use and offsite impacts can lead to practical or desirable level of biomass energy production that are much smaller than theoretical potential levels and a clear picture of these constraints can be an important asset in encouraging rational development of the biomass energy industry (Field et al., 2007).

This chapter provides a list of known environmental impacts that should be assessed and used to inform the creation of sustainable management of biomass-for-energy production systems. Thus, with focus on constraints owing to ecosystem characteristics, but rather than examine the entire range of relevant environmental impact categories in different biomass-for-energy production systems, we asses soil, land-for-food/feed, water, biodiversity, productivity and energy/carbon balance as issues highly important to the sustainability of these systems. In each of the issues there are potential benefits and risks to be considered. These issues will be discussed in turn.

2. Sustainability is important

Policy developments in the European Union (e.g., RED[12]), the US (e.g., CSBP[13], LCFS[14]) and other countries reflect policy makers' growing efforts to ensure sustainable biomass production. Important focus points of the policy discussions are the effects included in economic, social and environmental standards. Diagrammatic visualization of sustainability of biomass for energy production with a wide range of potential environmental, economic and social impacts is given in Figure 6.

[12] EU Renewable Energy Directive (RED) is Directive 2009/28/EC of the Council of the European Union on the promotion of the use of energy from renewable sources. The aim of this legislative act is to achieve by 2020 a 20% share of energy from renewable sources in the EU's final consumption of energy and a 10% share of energy from renewable sources in each member state's transport energy consumption2

[13] The Council for Sustainable Biomass Production (CSBP) was initiated to develop a voluntary sustainability standard for biomass growers and bioenergy producers and bioenergy companies on sustainable production methods for biomass-based bioenergy in the United States

[14] The Low Carbon Fuel Standard (LCFS) (issued on January 18, 2007) is a rule that calls for a reduction of at least 10 percent in the carbon intensity of California's transportation fuels by 2020.

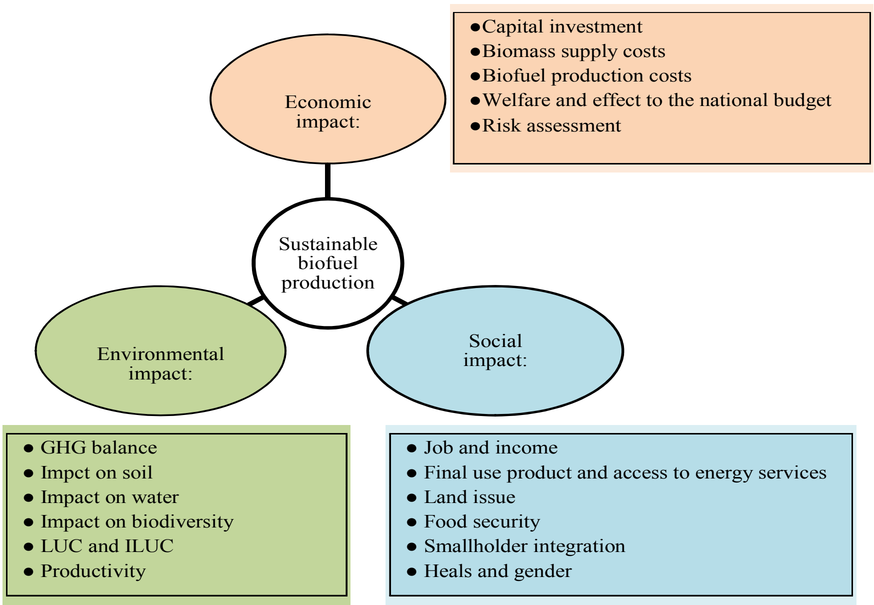


Figure 6. Diagrammatic visualization of sustainability of biofuel feedstocks production with a wide range of potential environmental, economic and social impacts (Source: based on IEA, 2010).

According to the differentiation between sustainable and unsustainable or renewable and non-renewable biomass (e. g., Jürgens et al., 2006), a renewable and sustainable source of biomass would be one where the carbon stocks are not declining over time due to over-exploitation. There are international efforts underway to find ways to regulate the production and trade of bioenergy by establishing sustainability criteria (e.g., Palmujoki, 2009). A set of sustainability criteria for biofuels was included under the Renewable Energy Directive (RES Directive 2009/28/EC, 2009). The Decision Support Tool ToSIA (Tool for Sustainability Impact Assessment) has been developed in the European Commission (FP6) funded project EFORWOOD (Sustainability Impact Assessment of the Forestry-Wood-Chain) to assess impact on different parts of the Forestry Wood Chain (FWC) for a broad range of drivers, and to cover up to 80 percent of the wood flows within Europe. ToSIA is the product of EFORWOOD and represents a dynamic sustainability impact assessment model that analyses environmental, economic, and social impacts of changes in forestry-wood production chains, using a consistent and harmonized framework from the forest to the end-of-life of final products. The difference between ToSIA and other similar, already existing, tools is that none of the latter addresses all three sustainability dimensions (environmental, economical and social) along the whole European FWC in a balanced way.

However, sustainability is a term that has by now many possible meanings. The most widely quoted definition of sustainability and sustainable development is that of the Brundtland Commission of the United Nations on March 20, 1987: “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987). Sustainability - a highly promoted principle in the last two decades - is a relative equilibrium among social and natural subsystems, an equilibrium that is challenged to reach. The natural and social subsystems is of great value because they provide the context or the constitutional basis for personal and group identity, and for the formation of the preferences that would give rise to a given conception of well being (Pretty, 2008). The sustainable development debate is based on the assumption that societies need to manage three type of capital: economic, social and natural.

Sustainability`s original meaning in the modern environmental debate is linked to a steady state economy (Daly, 1995; Hueting and Reinders, 1998). Sustainable use of biomass defined in that way is a type of use that can be continued indefinitely without an increase in negative impact due to pollution while maintaining natural resources and beneficial functions of living nature relevant to mankind over millions of years, the common lifespan of a mammalian species (Reijnders, 2006). The other way to define sustainability is that wastes irretrievably lost should not substantially exceed the small addition to the stock by geological processes (Reijnders, 2006). Although in the relation with living nature sustainability is harder to define, a further reduction of the useful functions of living nature, also called ecosystem services, would seem to violate sustainability (Reijnders, 2003). Thus, sustainability can be defined in terms of the carrying capacity of an ecosystem. Carbon neutral and climate neutral can be the specifications of sustainability in line with the requirement that environmental pollution should not increase. Regenerative and resource-conserving technologies and practices can bring both environmental and economic benefits for farmers, communities and nations (Pretty, 2008b). Overall, strategies that combine biological and technological approaches, which conserve soil organic matter and nutrients, and which utilize organic wastes will have the greatest chance of attaining sustainability (e.g., Kimmins, 1997).

The philosophical and conceptual richness of the sustainability concept can be viewed as problematic (e.g., Jamieson, 1998). According to the social science definition, sustainability is outcome of the collective decision making that arises from interaction among stakeholders, identified in this case as natural resource users and managers (e.g., Woodhill, 1993; Röling, 1988; Röling and Wagemakers, 2008). The formulation of sustainability in this manner implies that the definition is part of the problem that stakeholders have to resolve (Pretty, 1995). Unfortunatelly, during 1990s-early 2000s the social and institutional conditions for spread of for example agricultural sustainability were less well understood and the political conditions for the emergence of supportive policies were the least well established (e.g., Pretty, 2008a). However, the concept of sustainability is highly valued as the sheer complexity of sustainability weighs against its use as an idea that can mobilize mass political movements (e.g., Pretty, 2008).

However, securing agreement on what people shall take sustainability to mean for a given environment, is half the job of getting there (Röling and Wagemakers, 2008). The shift to sustainable development is not only technological fix, nor a matter of only new financial investment, but is also an ethical shift (e.g., Kothari, 1994). Thus, while much of sustainability issue focuses on how to increase the supply of basic staples (Figure 6), Stokstad (2010) in contrast examines one idea for reducing demand: eating less meat. Moreover, all important questions in the field of sustainable development have a very strong demographic component. Ecological theory maintains that there is always a sustainable level for a given species in a given area. The sustainability capacity of the habitat derives from the natural limitation of the resources of the habitat. All populations are limited in their development by the sustainability of their environment, for example, food and energy resources, and the extent of pollution. However, the global population continues to increase in size and resource consumption. Thus, there are still a lot of countries with annual growth rates of 2% or more in contrast to all industrial countries with averaged annual growth rates of 0,2% (e.g., Nentwig, 1999). Projections for human population growth suggest that by 2050, more than 9 billion people will inhabit the earth

(US Census Bureau, 2009). However, the limits of sustainability have already been questioned with the 6 billion humans alive today (e.g., Nentwig, 1999). Moreover, recent evidence suggests that the current human population is utilizing natural and industrial systems at levels that are not biologically or energetically sustainable (Wackernagel et al., 2002). Therefore, the most important issue facing the human race is its seemingly unstoppable population growth (Farrell, 2009).

3. Climate change and bioenergy

Climate change appears to be caused by the present increase of anthropogenic greenhouse gas emissions. The reduction of energy-based greenhouse gases emissions is a goal worldwide. Promising approaches to reducing anthropogenic greenhouse gas (GHG) emissions include energy generation from climate neutral biomass resources. Only land-based or "terrestrial" carbon sequestration offers the possibility today of large-scale removal of greenhouse gases from the atmosphere, through plant photosynthesis and no strategy for mitigating global climate change can be complete or successful without reducing emissions from agriculture, forestry, and other land uses (Scherr & Sthapit, 2010).

3.1. Energy/carbon balance or impact on climate

Carbon released as carbon dioxide when burning fossil fuels is the major part of the anthropogenic greenhouse gas emissions. Increased change over to bioenergy could result in net emission savings of greenhouse gases. Biofuels use is an alternative to oil consumption that reduces greenhouse gas (GHG) emissions (Pacala & Socolow, 2004). Moreover, the ability of biofuels to mitigate GHG emissions is a key facet of their environmental sustainability and is the main reason for renewable energy identified to play an important role in mitigating climate change. Calculations show that in a favourable situation as much as 97-98% of the greenhouse gas emissions could be avoided by substituting a fossil fuel with wood fuel, but even in an unfavourable situation the amount avoided should be higher than 75% (e. g., Wihersaari, 2005).

The net effect of biomass energy production on climate forcing needs to include changes in the carbon content of the site. Generally, carbon content measurement is widely used because stocks in biomass and soil are measurable at low costs. Eliminating inputs of fossil fuels and maintaining carbon stocks in soils and above-ground biomass are important elements in balancing of atmospheric carbon.

Adsorption of carbon dioxide by the growing biomass is one of the environmental benefits of renewable fuels. Thus, there are e.g. results suggesting that increased stock of forest biomass and thereby increased carbon sequestration as a result of forest fertilization is an attractive option for reducing net GHG emission (Sathre et al, 2010). Willow biomass crops can be sustainable from an energy balance perspective and can contribute additional environmental benefits. Thus, generating electricity from willow biomass crops could produce 11 units of electricity per unit of fossil energy consumed, assuming reasonable biomass transportation distance and energy conversion efficiencies (Heller et al., 2003). Moreover, substituting inorganic N fertilizer with sewage sludge biosolids increases the net energy ratio of the willow biomass crop production system (ibid.).

Soils have an important role in the global budgets and emissions of the greenhouse gases. The other main option for greenhouse-gas mitigation is the sequestration of carbon in soils. Thus, in terms of the biomass feedstock, the crops are carbon neutral and can be carbon negative as a result of increased carbon sequestration in the soil and root biomass (Hill et al., 2006; Lemus and Lai, 2005; Huo et al., 2009*).* There are plant species that provide not only renewable biofuel resources but also has the potential to sequestrate carbon due to its high C input to soil, especially through the turnover of roots and rhizomes. For example, reed canary grass (RCG, *Phalaris arundinacea L.*) is of special interest in this respect and indicates the potential as a carbon sink (e.g., Xiong Shao & Katterer, 2010; McLaughlin & Walsh, 1998; Tolbert, 1998). Temporal variation in carbon stocks and fluxes is an additional factor to consider when assessing the full impact of individual bioenergy production systems on carbon budgets.

Land management practices have the potential to change dramatically the characteristics and gas exchange of an ecosystem. Thus, while deforestation typically releases a large fraction of the tree and soil carbon to the atmosphere (Houghton et al., 1983), establishing biomass energy production on land degraded by agriculture, grazing, or erosion can have the opposite effect of deforestation, increasing ecosystem carbon stocks as a consequence of consistent inputs of root and shoot litter (e.g., Tilman et al, 2006). For lands currently in agricultural production and not severely degraded, the carbon consequences of a transition to biomass energy will depend on the cropping system, the management practices and the inputs (Field et al., 2007). Thus, the cropping of willows on agricultural land may also lead to the net sequestration of carbon in soil (Heller et al., 2003). There is also work that further substantiates the environmental benefits associated with renewable fuels and demonstrates that with proper management, the integration of livestock manures in biofuel cropping systems can enhance GHG remediation (Thelen et al., 2010).

Sugarcane-based ethanol - currently the most effective biofuel at displacing GHG emissions (Sagar and Kartha, 2007) - in Brazil is already mitigating GHGs and that even with a harvested area of 14.0 Mha by 2039, it should be possible to fulfill 20% of one of the seven wedges[15] proposed by Pacala and Socolow (2004) (Pacca & Moreira, 2009). A 70 Mha[16] global harvested area of sugar cane for energy use (which corresponds to 4.7% of all agriculture/ cultivated land for food and feed in 2005 (Hoogwijk et al., 2005) and a sugar cane sector performance similar with the one in Brazil, would be enough to mitigate 1Gt C (100% of one Pacala and Socolow wedge) or 20.4%[17] of all GHG emissions required to stabilize CO_2 atmospheric concentrations by 2039, as predicted by Pacala and Socolow (2004) (Pacca & Moreira, 2009). However, the authors pointed out that sugar cane plantation implemented only over tropical forests does not contribute to

[15] Pacala and Socolow estimated each wedge based on1 Gt of carbon mitigation required by 2054. They assumed a linear contribution of each wedge along a 50 year period till 2054. Thus, by 2039 each wedge corresponds to 0.7 GtC or 2.57 Gt CO_2 (cited in Pacca & Moreira, 2009).

[16] Presently, global sugar cane harvested area for energy and food use is around 24 Mha (FAOSTAT, 2009). Thus, the sugar cane area for 2039, for food and energy use, should be just under 100 Mha, assuming that sugar demand for food and beverage is increasing at a rate of 1% per year, while average sugarcane productivity is evolving at 0.73% per year (based on data for the last 40 years) (FAOSTAT, 2009)). The 100 M ha should be compared with areas used for wheat and corn all over the world, respectively 230 and 170 M ha (cited in Pacca & Moreira, 2009).

[17] Pacala and Socolow estimated each wedge based on1 Gt of carbon mitigation required by 2054. They assumed a linear contribution of each wedge along a 50 year period till 2054. Thus, by 2039 each wedge corresponds to 0.7 GtC or 2.57 Gt CO_2 (cited in Pacca & Moreira, 2009).

C mitigation and should be avoided due its negative carbon balance and other impacts caused to the environment.

In an idealized case biomass energy does not contribute to the forcing of climate change with greenhouse gases, but real production systems can differ from this ideal in some important ways. Thus, modern bioenergy chains are to some extent associated with burning fossil fuels which is not carbon neutral. The production of biomass energy almost always entails the use of fossil energy for the farming, transportation and manufacturing stages of the process (e.g., Hill et al., 2006). Thus, while CO_2 emitted in combusting dedicated biomass is balanced by CO_2 adsorbed in the growing biomass, production process contributes to the system´s net global warming potential (Heller et al., 2003). The substitution of bioelectricity for fossil fuel- based electricity can mitigate carbon emissions. However, the full realization of the bioelectricity potential when substituting bioelectricity for fossil fuel- based electricity, the implementation of CO_2 sequestration during fermentation of sugarcane's juice, and the adoption of the best available technologies are crucial to enhance the potential of the sugar cane system as a substantial mitigation option (Pacca & Moreira, 2009).

3.2. Bioenergy and other important greenhouse gases

There are many greenhouse gases in the atmosphere that affect our climate. Thus, in addition to carbon dioxide (CO_2), the emissions of methane (CH_4) - the most important greenhouse gas next to CO_2 (e. g., Langeveld et al., 1997) as well the emissions of nitrous oxide (N_2O) (e. g., Bouwman et al., 2010) - may be important factors in the greenhouse gas balance of biofuels. There are a lot of discussions on the availability of different biomass sources for bioenergy applications and on the reduction of greenhouse gas emissions compared to conventional fossil fuels. Emissions from cropland are high compared to grassland due to the fact that cropland (including energy crops) is generally located in areas with good soils and climatic conditions, while a major part of the global grassland area is in less favorable areas (Bouwman et al., 2010). There is much less discussion on the other effects of biomass such as the acceleration of the nitrogen cycle through increased fertilizer use resulting in losses to the environment and additional emissions of oxidized nitrogen (Erisman et al., 2010). A complete account of all the greenhouse gases emitted and lost in other ways is therefore required to asses this balance and determine if biofuels have a net negative or positive impact on the global warming potential of fuel consumption.

Soils have an important role in the global budgets of greenhouse gases and understanding nitrous oxide (N_2O) and methane (CH_4) fluxes from agricultural soils is necessary to fully assess greenhouse gas emissions from bioenergy cropping systems. Crutzen et al. (2008) and Smeets et al. (2008) addressed nitrous oxide (N_2O) emission as part of the greenhouse gas budget of biofuels from crops. However, soil greenhouse gas fluxes from bioenergy crop production in semi-arid regions are likely to have less influence on the net global warming potential of biofuel production than in temperate climates (Barton et al., 2010). Further, while tropical seasonally-dry ecosystems both in natural and managed conditions represent a significant source of N_2O (4.4 T[18]g N_2O year $^{-1}$) and a potential CH_4 sink of 5.17 Tg CH_4 year $^{-1}$ on a global scale and as a consequence of the large area they occupy, the limited information on fluxes from

[18] $T = 10^{12}$

Mediterranean ecosystems does not allow a meaningful scaling up (e. g., Castaldi et al., 2006).

In an overview of the state of knowledge on nitrogen and biofuels (Erisman et al., 2010) it has been proposed that optimization of the nitrogen use efficiency and the development of second generation technologies will help fulfill the sustainability biomass use. Linked economic and terrestrial biogeochemistry model examining direct and indirect effects of possible land-use changes from increasing production of biofuels predict that indirect land use will be responsible for substantially more carbon loss (up to twice as much) than direct land use; however, because of predicted increases in fertilizer use, nitrous oxide emissions will be more important than carbon losses themselves in terms of warming potential (e. g., Melillo et al., 2009). However, a global greenhouse gas emissions policy that protects forests and encourages best practices for nitrogen fertilizer use can dramatically reduce emissions associated with biofuels production (Melillo et al., 2009).

3.3. Greenhouse gas release from land use change

There is a relationship between land use and climate change. Thus, future changes in the climate affect land use decisions, but there is also feedbacks from land use change to the global climate system through GHG fluxes.

Increased demand for biofuels is expected to produce changes in the present land-use configuration. Biomass production will lead to intense pressures on land supply and can increase greenhouse gas emissions from land-use changes. By recent estimates land use activities account for approximately 31 % of global emissions of carbon dioxide equivalents (Scherr & Sthapit, 2009). Greenhouse gas release from land use change (the so called "carbon debt") has been identified as a potentially significant contributor to the environmental profile of biofuels (Kim et al., 2009).

Land-use change is associated with a change in land cover and an associated change in carbon stocks. Houghton (1991) assessed seven types of land-use change for carbon stock changes (Figure C).

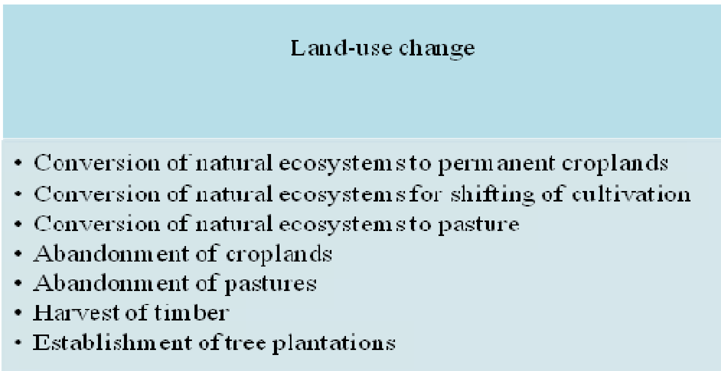


Figure C. Types of land-use change for carbon stock changes (Source: based on Houghton 1991)

According to a lot of academic literature on the subject (e.g., Geist et al., 2002; Lambin et al., 2003), land use change (LUC) is driven by three primary forces: timber harvest, infrastructure development (e.g., road building), and agricultural expansion. However, as any one of these variables taken alone explains less than 20% of documented land use changes worldwide, but taken together, they explain over 90% of observed cases of land use change, it is arbitrary and unreasonable to assume that all land use change worldwide is driven primarily by agricultural expansion (e.g., Kim et al., 2009). Both grassland and forest may be involved in land use conversion, but we do not know in what relative amounts (Kim et al., 2009).

The environmental effects of indirect land-use change (ILUC) is the result of an action occurring in a system that induces effects, indirectly, outside the system boundaries but that can be attributed to the action occurring in the system (Gnansounou et al., 2008). A certain amount of feedstock obtained by biomass use substitution, crop area expansion and shortening the rotation length in order to meet a given demand of biofuels, may result in indirect land-use effects (e.g., Gnansounou et al., 2008). Recent studies have suggested that GHG benefits from biomass feedstock would be significantly lower if the effects of direct[19] or indirect (ILUC[20]) land use change are taken into account (e.g., Righelato and Spracklen, 2007; Fargione et al., 2008; Searchinger et al., 2008). GHG emissions from ILUC are claimed to be more important than emissions from direct land-use change (e.g., Farrell & O'Hare, 2008; Searchinger et al., 2008). Model simulation of EU biofuels policy and global biofuels implementation indicate that the greenhouse gas emissions associated with ILUC are very significant and generally amount to 20-60 g CO_2–eq/MJ biofuels, equivalent to 25-75% of the carbon emissions per MJ of the petrol or diesel being substituted (Croezen et al., 2010).

However, the impact of land use change on greenhouse gas emissions can be mitigated through agro-economic mechanisms or technical developments. Mitigation measures include the use of residues as feedstock, cultivation of feedstock on abandoned arable land and use of feedstock by-products as substitutes for primary crops as animal feed (Croezen et al., 2010). Gnansounou et al. (2008) reviewing impacts of ILUC on GHG balance of biofuels, conclude that while ILUC may impact the GHG emission balance by affecting carbon balance in soils and in the biomass produced on that land, these effects are not necessarily negative. Thus, cropland established on highly disturbed and sparsely vegetated lands and some grasslands can result in a net gain in both soil and biomass carbon. Moreover, moving from a long-term cultivated system to a shifting cultivation when the land is set-aside to recover from intense agricultural use, can reduce the loss of carbon. Furthermore, it is also worth to point out that changes in the carbon stock can take place even if the land-use does not change. Thus, temporal variation in carbon stocks and fluxes is an additional factor to consider when assessing the full impact of individual bioenergy production systems on carbon budgets. Moreover, changes in the carbon stock results from complex interactions and feedbacks among plant productivity, decomposition, climate, soil properties, and human activities. To comprehensively understand the causes and magnitudes of ecosystem carbon fluxes and carbon storage, it is critical to study the systems in meaningfully large units and over sufficiently large time scales (e. g., Zhao et al., 2010).

Both direct and indirect LUC analyses depend on a number of variables and assumptions. One of the most significant sources of GHG emissions in LUC is from soil organic carbon (SOC). Cropping management is the key factor in estimating GHG emissions associated with LUC and there is significant opportunity to reduce the potential carbon debt and GHG emissions through improved crop and soil management

[19] Direct land-use change occurs when feedstock for biofuels purposes (e.g. soybean for biodiesel) displace a prior land-use (e.g. forest), thereby generating possible changes in the carbon stock of that land.
[20] Indirect land-use change (ILUC) occurs when pressure on agriculture due to the displacement of previous activity or use of the biomass induces land-use changes on other lands (Gnansounou et al., 2008).

practices, including crop choice, intensity of inputs and harvesting strategy (e.g., Kim et al., 2009). Thus, for example, no-tillage practice or the use of winter cover crops can improve soil organic carbon levels and increase carbon sequestration rates in comparison to plow tillage (Bruce et al., 1999; Smith et al., 2008). Moreover, no-tillage practice combined with the use of winter cover crops is the best cropland management practice in reducing the GHG emissions associated with direct and indirect LUC considered in order to maximize cumulative GHG benefits of the biofuel (e. g., Kim et al., 2009). However, as the benefits of no tillage practice may or may not be observed if the whole soil profile (1 m depth) is analyzed (Blanco-Canqui et al., 2008; Angers et al., 2008) the further investigations of the effects of soil depth on carbon accumulation with tillage practices are therefore needed (Kim et al., 2009). Unfortunately, according to Kim et al. (2009) some existing studies (Searchinger et al, 2008; Fargione et al., 2008) did not take into account the effects of different tillage methods when analyzing LUC. Crop choice is the other key factor in reducing potential carbon debt and GHG emissions. Thus, compared to sugarcane and corn that are currently used for biofuel production in the world, sweet sorghum has been shown to be more suitable for this because it has higher tolerance to salt and drought, much lower water and fertilizer requirements and high fermentable sugar content which makes it to be more suitable for fermentation to ethanol (e. g., Almodares & Hadi, 2010).

Land use is an important factor in carbon sequestration changes and therefore cannot be ignored. Different land use types vary in the amount of carbon stored in soil and vegetation. Forest ecosystems represent the largest terrestrial storage of carbon and there is increasing evidence that human activities are controlling the carbon cycle in forests at the global scale through direct and indirect effects (Magnani et al., 2007). Thus, management effects on the carbon cycle in forests are considerable and the impacts of forest management on atmosphere and climate is therefore a key issue of the sustainability of the forestry wood chain (Loustau & Klimo, 2006). Not harvesting any biomass from the forest will in a landscape perspective increase the carbon stock in the ecosystem because the phases after clear-cuts with low tree biomasses are avoided, but on the other hand, the forests will then not provide any climate benefit by biofuels or other renewable forest wood products (Ågren et al., 2010). Forest SOC stocks tend to be higher than pasture or cropland SOC stocks and conversion of forest to pasture or cropland is found to decrease SOC stocks, the opposite conversions usually lead to increased SOC stocks (e g., Falloon et al., 2006). A system with whole tree harvesting with nutrient compensation is closely to being greenhouse-gas-neutral (G. Ågren, personal communication (cited in Levin and Eriksson, 2010)). Land use changes including arable land to/from forest or Salix plantation indicate that no major changes in soil carbon stocks are to be expected (Ågren et al., 2010).

The debate about biofuels and ILUC effects continues. There is a growing concern about the effect of land-use change on GHG emissions, biodiversity, food supply, soil and water quality. However, it is argued that the most recent ranges of studies, showing that emissions resulting from ILUC are significant, have not been systematically compared and summarized (Croezen et al., 2010). Moreover, current practices for estimating the effects of indirect land use changes suffer from large uncertainties (Kim & Dale, 2009). Thus, it is argued that indirect land use change effects are too diffuse and subject to too many arbitrary assumptions to be useful for rule-making, and that the use of direct and controllable measures, such as building statements of origin of biofuels into the contracts that regulate the sale of such commodities, would secure better results (Mathews &Tan, 2009). At present, due to the lack of a robust methodology carbon reporting initiatives do not consider ILUC. EU governments recommend using idle land for biofuels production in order to avoid indirect effects (Gnansounou et al., 2008). It seems that even if ILUC effects should be known and a causal relationship should be established, the consequences (GHG emissions) are particularly difficult to be accurately attributed to the expansion of biofuels production in a given country and consequently it would be delicate to include them in the GHG emission balance at a country level (Gnansounou et al., 2008). More research and consensus about system boundaries and allocation issues are needed to reduce uncertainties related to the effects of indirect land use changes (Kim & Dale, 2009).

3.4. Other climate forcing effects

One of the potentially negative impacts of biomass use on climate includes the effects of soot and trace gases that are emitted into the atmosphere during combustion. Slash and burn farming procedures, and deforestation, can also result in large amounts of smoke and soot production. Soot particles in the atmosphere can originate from burning both fossil fuels and biomass. However, the contribution of wood burning to atmospheric particulate carbon is regarded as a major source (e. g., Freeman & Cattell, 1990; Fine et al., 2001).

It has been established that combustion generated particulates have an important impact on climate and rainfall (Ramanathan et al., 2001; Graf, 2004). However, the nature and extent of the emissions produced by the combustion of biomass depends on the combustion conditions. Thus, in order to efficiently use biomass fuels as a source of heat, stoves are needed. However, in contrast to combustion of pulverised biomass in power stations with controlled combustion where very much smaller quantities of soot are produced, the majority of anthropogenic biomass derived black carbon is a result of cooking in small scale appliances, slash and burn farming procedures, and deforestation, all of which result in large amounts of smoke and soot production (Fitzpatrick et al., 2007).

The flue gases from the stoves can cause serious health problems and environmental air pollution (e.g., Bhattacharya et al., 2002; EPA, 2001). However, the flue gas emissions have different values depending on the characteristics of biomass fuels and stoves thermal efficiency. Thus, biochar - the stable, carbon rich charcoal that results from pyrolysis[21] of biomass materials - is the most appropriate biomass fuel for use in the space-heating biomass stoves (an improved space-heating biomass stove) because its combustion emits less smoke and the thermal efficiency of a particular stove is approximately 46% (Koyuncu & Pinar, 2006). Moreover, biochar applied to soil offers a direct method for sequestering C and generating bioenergy (e.g., Lehmann, 2007; Gaunt & Lehmann, 2008; Roberts et al., 2010) and may at present be financially viable as a distributed system using waste biomass (Roberts et al., 2010.). Furthermore, used as a soil amendment, biochar can improve soil health and fertility, soil structure, nutrient availability, and soil-water retention capacity (Rondon et al., 2007; Kimetu et al., 2008; Lehmann et al., 2003; Steiner et al., 2007), and is also a mechanism for long term C storage in soils (Roberts et al., 2010).

The effect on climate forcing involves also the balance between absorption and reflection of solar energy at the surface of the earth (Schaeffer et al., 2006). In general,

[21] Pyrolysis is the thermal decomposition of organic material in the absence of oxygen, and is also an initial stage in both combustion and gasification processes (Bridgwater et al., 2008).

the overall balance is that while at high latitudes, forests (particularly evergreen forests) tend to warm the climate because they are darker than grasslands and crops, the pattern is the opposite in the tropics because forests increase evapotranspiration and cloud cover, which produces a cooling effect through reflection of solar energy (e. g., Bala et al., 2007).

4. Land /Soil for Food versus Energy

There are sets of criteria that are crucial in determining the overall consequences of expanding biomass for energy production. However, land comes first.

4.1. Land availability

Renewable energy systems such as wind, solar and biomass are significantly more land intensive than traditional fossil fuels. Thus, the overall potential yield of biomass energy depends on the land area allocated to producing it. Expanding the biomass energy industry involves the possibility that new production of biomass for energy will occupy land needed for growing food, feed and for conservation. Scenarios developed for the USA and the EU indicate that while short-term targets of up to a 13 percent displacement of petroleum-based fuels with liquid biofuels (bioethanol and biodiesel) appear feasible on available cropland, more ambitious targets will have to be fulfilled with imports (Best, 2006).

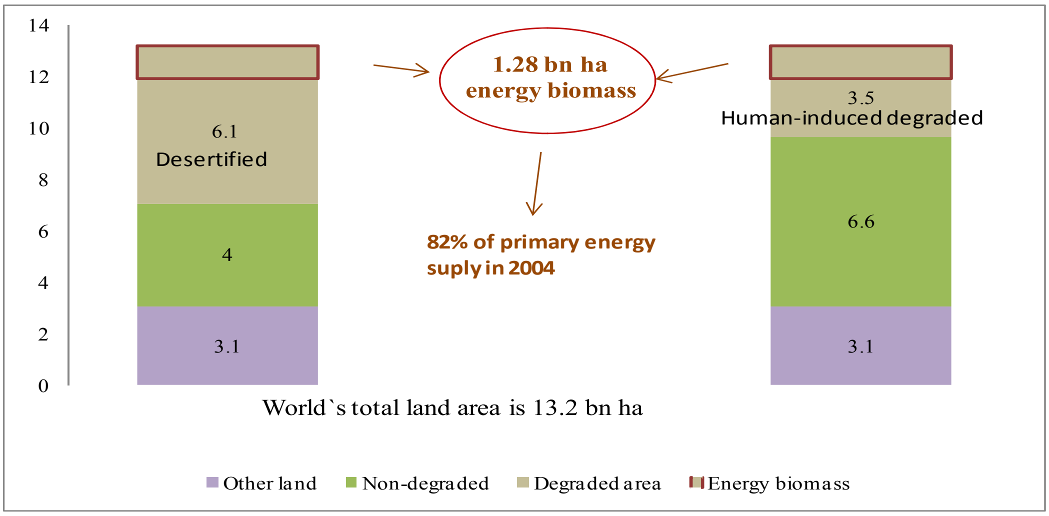
The role of agriculture as a source of energy resources is gaining in importance. As mentioned in Croezen (Croezen et al. 2010) significant volumes of biofuels require significant areas of arable land, but there already appears to be little chance of the world`s current arable acreage being sufficient to produce enough food and feed to meet rising future demand and therefore additional crop demand for biofuel is likely to require extra arable land that must be created by land use change. Many of the international assessments of future food supply project a global expansion of crop area for food production, with particularly high rates in Africa and South America (e.g., Bruinsma, 2003; Rosegrant et al., 2001). While bioenergy systems based on forest and agriculture residues require no additional land resources as the land is used for timber or food production regardless of how the residues are used, dedicated energy crops on the other hand require land which is often a limited resource (Schlamadinger et al., 1997).

However, even if food and biofuels/biomass can compete for land, this is not inevitably the case. Thus, firstly, the greatest potential for biofuel production within the present agricultural system lies in using residues and organic waste, e.g., mold attacked matter and crops of inferior quality. Secondly, the expansion of biomass energy agriculture could be limited through regulations to surplus and abandoned areas. Despite that the uncertainty for the abandoned area estimate can be substantial (probably 50% or more) and even more uncertain is the estimate of the amount of marginal land that has never been used for agriculture but that is potentially available for biomass energy production (e.g., Field et al., 2007), agriculture for biomass energy can move into abandoned agricultural land, degraded land and other marginal land that does not have competing uses (e.g., Tilman et al., 2006; Hoogwijk et al. 2005; Hoogwijk et al. 2003). Moreover, degraded and marginal land could be rehabilitated by bioenergy plantations which could combat desertification and increase food production (Best, 2006). However, the main factor for the large biomass potentials is the availability of surplus agricultural land, which could be made available through more intensive agriculture (IEA, 2010). Thus, biomass energy modeling studies project that additional areas beyond degraded, abandoned and marginal lands will become available as agricultural land is abandoned in response to surplus food supplies (Hoogwijk et al. 2005; Hoogwijk et al. 2003; Wolf et al., 2003).

Thirdly, second generation biofuels, are often seen as a prominent candidate for realizing not only reduced emissions and lowered oil dependency but also more efficient use of land and bioresourses (e.g., IEA, 2010). Sustainability of many first-generation biofuels – which are produced primarily from food crops such as grains, sugar cane and vegetable oils – has been increasingly questioned over concerns such as reported displacement of food-crops (IEA, 2010). However, second-generation biofuels produced from agricultural or forestry residues do not require cultivation of additional land (IEA, 2010). The use of second generation biofuels shows a more efficient use of land and bioresources (Campbell et al., 2009; Ohlrogge et al., 2009). The existing forests, especially primary forests and forest areas designated for conservation of biodiversity, may be used only partially for energy supply because of economical, ecological, and social reasons (FAO, 2005). Pastures, especially poor pastures, may possibly be used for afforestation depending on the conditions in the respective country and considering the fact that a substitute fodder has to be supplied (Metzger & Hüttermann, 2009). The production of lignocellulosic biomass and fodder for ruminants can be combined by, e.g., using white rot fungi (Hüttermann et al., 2000). In addition, poorer quality land could possibly be utilized. If the ligno-cellulosic feedstock is to be produced from dedicated energy crops grown on arable land, energy yields (in terms of GJ/ha) are likely to be higher than if crops grown for first-generation biofuels (and co-products) are produced on the same land, even if several concerns remain over competing land use.

However, there are the concerns, particularly present in many developing countries regarding the identification of suitable land for sustainable feedstock production (e.g., IEA, 2010). Mankind has been degrading in historical times some billion hectares of areas originally forested and covered with vegetation, respectively (Williams, 2003; Lal, 2004). Global energy supply may be provided from biomass grown on degraded and wasted areas. Thus, deforestation has many and varied (economic, agricultural, demographic and cultural) causes. Endangered biodiversity, destroyed and infertile soils, affected water cycle and global warming are the consequences of deforestation at the local and the global levels (e.g., Karsenty, A., 2010). An additional historical consequence of degradation of forest areas was increasing the global river runoff significantly during the twentieth century (Labat et al, 2004) and producing widespread watershed degradation (UN, 2006). Afforestation of degraded areas is the greatest challenge on the way to a sustainable development (Metzger & Hüttermann, 2009). Terrastat database (FAO, 2003) gives a global area of 0.8 Gha of very severe and of 2.7 Gha of severe human-induced degradation (FAO, 2000a, b). The IPCC study estimated that 1.28 Gha of land should be available for energy biomass production giving a primary energy potential of 9,216 Mtoe (IPCC, 2001), about 82% of the primary energy supply of the year 2004(Metzger & Hüttermann, 2009). This estimated land available corresponds to only less than 30% of the global degraded area of 3.5 Gha shown in Figure 7. The other consequence of reforestation may be regeneration and stabilization of the global water and especially drinking water resources (Piao et al., 2007) as well as reduction of the frequency and severity of flood-related catastrophes (Bradshaw et al., 2007). Reforestation will slowly stop these processes. Furthermore, deforestation resulted in increased sediment loads, with various impacts on downstream and coastline habitats (UN, 2006). It can be expected that reforestation will slowly stop this process.

Land occupation is one of the most controversial issues. Current land use data are in many cases not accurate enough to classify land as "degraded" or "unused" (IEA, 2010) Distribution of degraded/non-degraded area in world`s total land area is given in Figure 7.



Notes: [a]Other land: Land not included in FAO land use categories

[b]Degraded area: Global degraded area as a sum of 0.8 bn ha of very severe (FAO, 2003) and of 2.7 bn ha of severe human-induced degradation (FAO, 2000a,b).

[c]Non-degraded area as a difference in areas between world`s total and the sum of other and non-degraded land.

[d]Land area that could be available for energy biomass production giving about 82% ot the primary energy supply of the year 2004 (IPCC, 2001)

Figure 7. Distribution of degraded/non-degraded area in world's total land area (Source: based on Metzger & Hüttermann, 2009).

Cultivation on degraded arable lands is presently an uncertain, expensive and probably unlikely option, but this may change if policies (including biofuel policies) substantially support the use of degraded land (e. g., Croezen et al., 2010). Arable areas are required to produce food for the global population and have been thought to be not or only most limited available (IPCC, 2001; see also Moreira, 2006); see, however, the discussion by Smeets et al. (2004) and by Hoogwijk et al. (2005)). Recently, based on the approach where the estimated available land was combined with climatological NPP[22], to estimate the potential for new biomass energy production that does not reduce food security, remove forests, or endanger conservation lands, it was argued that increasing the area beyond the 386 Mha[23] used for the calculation runs the risk of threatening food security, damaging conservation areas, or increasing deforestation (Field et al., 2007). There is considerable agreement that increasing yields on existing agricultural land, especially cropland, is a key component for minimizing further expansion (Tilman et al., 2002; Evans, 2003; Lee et al., 2006). There are, however, limitations and negative aspects of further intensification of the use of cropland (Wirsenius et. al., 2010). Thus, increasing yield per hectare does not seem to be option because even with substantial external inputs, NPP for major food crops – whether destined for food or biomass energy uses – will probably remain below native NPP over several decades at least (e. g., Field et al., 2007). Also, high crop yields depend on larger inputs of nutrients, fresh? water, and

[22] Net Primary Production
[23] 386 Mha equals 0.386 bn ha

pesticides and contribute to negative ecosystem effects, such as eutrophication (Tilman et al., 2002).

However, it is still uncertain how much arable land is required. Thus, for example, while some studies give a picture where arable land is expanding (e. g., Croezen et al. 2010), there are alternatives indicating that the future development could result in a more limited requirement for extra arable land caused by less rapid increase in food demand in the future than in the past due to slowing of global population growth (e. g., Morris 2009). Moreover, investment in agricultural research is rarely mentioned as a mitigation strategy, but agricultural intensification and investment in yield improvements could result in a more limited requirement for extra arable land. Furthermore, there is substantial scope for land-minimizing growth of world food supply by efficiency improvements in the food-chain, particularly in animal food production, and dietary changes towards less land-demanding food (e. g., Wirsenius et al., 2010).

The pattern of competition between fuel and food crops is not clear yet, and this will depend, among others, on whether food security policies are in place (Hellegers et al., 2008). Until 2008/2009, biofuels were considered among the best alternatives to oil consumption in a captive market such as transport fuels but social and political consensus about biofuels decreased sharply when their ability to strongly decrease overall GHG emissions was questioned, and mainly when they were blamed of being responsible for the 2007-2008 food-price increase (Ninni, 2010). In July 2008, the Farm Foundation published “What’s Driving Food Prices?” reviewing over two dozen substantive reports and studies on the subject, all published in either 2007 or early 2008 (Abbott et al., 2008). Much of the public discussion of the food price crisis has focused on the sharply increased use of food commodities for biofuel production, framing debate in simple food versus fuel terms (Dewbre et al., 2008). Food sovereignty, including a moratorium on agrofuels, was argued to offer the best option for managing the crisis (e. g., Rosset, 2009).

However, when biofuels were examined in the context of the world food price crisis and when both short- and long-term causes of the crisis were assessed, biofuels were not a prime causal factor. There were multiple forces that drove food prices to high levels. Thus, the degree to which the price of traded food commodities and the price of food are related depends on a long list of factors, most of which operate to dampen price transmission and it was found that the distinction between high world prices for food commodities and the consumer costs of food is an important one to make (Dewbre et al., 2008). Moreover, the long-run behaviour of prices is not well understood, the issue of which are the main drivers of booms and slumps remains controversial and little is known on the frequency, magnitude and persistence of price spikes such as one in 2007–08 (e. g., FAO, 2010). Recently, In the European Union, biofuels policy is supported through a new Directive approved on April 23rd, 2009, including the request for various certifications to prove the environmental sustainability of biofuels (Ninni, 2010). Whether food prices will rise owing to an increase in biofuel demand will depend, according to de Fraiture et al. (2008) more on trade barriers, subsidies, policies and limitations of marketing infrastructure than on lack of physical capacity. The new food strategy is quite unique in both its policy scope and spatial scale, reintroducing national and international food security — defined as having enough food, in the right place, at the right time — as a key concern both nationally and internationally (Marsden, 2010).

4.2. Agroforestry

Sustainable combined production of food and biomass is possible on the same field. Thus, agroforestry and "farm forestry" are synonymous terms for land use practice, in which both trees and agricultural crops or livestock are combined on the same field. The idea of agroforestry systems is to grow trees or shrubs in strips between crops to produce an energy crop in addition to the food crop.

Agroforestry is an integrated natural resource management option (e.g., Nuberg & Brendan, 2009). Simultaneously, especially in marginal areas, the ecological function of the landscape can be improved. Since the 1980s there has been a rapidly growing community awareness of the need to integrate trees with agriculture to address natural resources degradation in Australia (Inions, 1995). Thus, a farming system that integrates woody crops with conventional agricultural crops/pasture can more fully utilize the basic resources of water, carbon dioxide, nutrients, and sunlight, thereby producing greater total biomass yield (Sanchez, 1995). The potential of agroforestry in meeting the deficit of demand and supply in timber, fodder supply, bioenergy sector through tree biomass and meeting the food/fruit security has been enumerated and the direct benefits like employment generation and indirect ones like carbon sequestration and environment restoration have been emphasized in respect of various agroforestry systems (e.g., Dhyani et al., 2009). Careful development of on and off-farm benefits of bioenergy crops may demonstrate that conflict with food production is minimal; that the overall cost of bioenergy from woody biomass feedstocks is quite competitive with other renewables; that bioenergy can make major contribution to a more productive and sustainable agriculture; and that a wide range of environmental benefits may be delivered by the proposed systems (Bartle & Abadi, 2010).

Agroforestry can be advantageous over conventional agricultural and forest production methods through increased productivity, economic benefits, social outcomes and the ecological goods and services provided. The benefits can include better catchment management, the multiplier effects of incomes spent in regional communities derived from processing activities, improved farm income, and the social impacts of increased rural employment and associated opportunities (e.g., Race & Curtis, 1996). For example, as a very flexible, but low-input system, alley cropping can supply biomass resources in a sustainable way and at the same time provide ecological benefits in Central Europe (Quinkenstein et al., 2009). A wide range of species may be used, including conventional forestry species (for sawn timber or pulp) or short cycle coppice for wood products and bioenergy (Dickmann, 2006).

Overall, agroforestry has high potential for simultaneously satisfying many important objectives: protecting and stabilizing the ecosystems; producing a high level of output of economic goods; improving income and basic materials to rural population; conserving natural resources through various systems in different agroclimatic regions (e.g., Dhyani et al., 2009). In a Summary Report of the XXIII IUFRO World Congress the development of agroforestry has been described as an approach for: poverty alleviation;; food security; carbon sequestration; combating deforestation and desertification; fodder and fuel-wood supply; and environmental protection (IUFRO, 2010).

4.3. Effects of biomass production systems on soil properties

Biomass production systems can alter soil chemical, physical and biological properties. Adequate amounts of soil organic matter (SOM) are important for maintenance of these properties (e.g., Burger, 2002; Scott et al., 2004). Thus, soil organic matter is an important reserve for plant nutrients; it improves soil structure and water holding capacity (Kahle et al., 2002) as well as limits erosion (Troeh et al., 1980). Maintenance of high level of SOM is one important factor in maintaining high biomass productivity (e.g., Vance 2000). Accurate prediction of the amount of added N retained in the ecosystem seems to be one of the key issues for estimating enhanced SOM (e. g., Eliasson & Ågren, 2010).

Replacing current conventional agricultural and forestry systems with biomass for energy systems will alter the balance between organic matter inputs and losses from the soil carbon pool and is thus likely to affect soil carbon. Thus, when a higher proportion of the organic matter and nutrients are removed from the site of biomass production system compared with conventional grain and timber production systems there is a risk of depletion of soil carbon stocks. However, in general, environmental and management factors govern the magnitude and direction of changes in an ecosystem. For example, the degree to which biomass production systems affect SOM is dependent on how much biomass is removed and how soil climate is altered. Bioenergy systems such as coppiced willow, switchgrass, or long-rotation timber+biomass plantations are likely to enhance soil carbon where these replace conventional cropping, as intensively cropped soils are generally depleted in soil C (Cowie et al., 2006).

Biomass residues are often regarded as a free source of energy. Appropriation of crop and forestry residues for biofuels implies that such residues will no longer be returned to crop and forestry lands, meaning that nutrients or organic matter previously recycled through these sources must be replaced (presumably through fossil fuel-based processes) if soil productivity and hydraulic properties are to be maintained (Varvel et al., 2008). Residue retention is an important issue in evaluating the sustainability of forest biomass-for energy production. Bioenergy from the forests is regarded as a possible replacement for fossil fuels and logging residues are increasingly being used as a source of bioenergy. There are studies aimed to measure the influence of various residues as well as site management treatments on the plant nutrition status, nutrient contents in soil and the biomass yield of the second-rotation stands. Thus, for some soils it has been recommended to retain both harvest residues and forest floor materials for the maintenance of soil C stocks in plantation forests (Jones et al. 2008). However, long-term impacts of such retention have not been studied extensively, especially in sub-tropical environments (Tutua et al., 2008). The importance of the selection of the modelling approach when projecting the potential effects of forest management practices on forest carbon balance has been underlined. Thus, using modelling approach, little difference in the soil carbon stock has been observed between different harvesting intensities, but this result is uncertain (e.g., Ågren et al., 2010). Detection of residue management impacts on C stocks in soils may require additional analysis.

The effect of intensified biomass extraction on forests is a timely question since harvest residues are increasingly utilized to produce energy. However, the impacts of the changed management practices are not always well understood. Thus, while whole tree harvesting (WTH) including foliage increased nutrient exports by 70-150% and fertilizers are likely to be required to compensate for the additional removal of nutrients and to maintain site productivity in the next rotation, intensive harvesting including removal of log residues and branches for biofuels but leaving foliage on site increased in contrast nutrient exports by approximately 30% but did not exceed accession of nutrients over 30 years except for N (Hopmans & Elms, 2009). Although along with the growing interest in WTH, concerns have been raised about potential ecological risks associated with this type of biomass harvesting such as nutrient depletion, loss of the acid neutralization capacity of soil, negative effects on biodiversity and soil carbon balance, effects on water chemistry, and decreases in future site productivity (Egnell et al. 2006, Olsson 2008) the other works suggest negligible effects of debris manipulation on soil productivity (e.g., Harrington & Schoenholtz, 2010). The effect of thinning on the soil or foliar nutrient status is poorly documented (Jonard et al., 2006).

The degradation of long-term site productivity after WTH is one of the concerns that have been widely discussed (e. g., Rosenberg and Jacobson 2004). However, the review of available studies regarding the effects of different harvesting intensities on SOM reveal in agreement with other (e. g., Grigal, 2000) that differences in harvesting intensity and the amount of debris remaining on-site generally have little effect on SOM in the long-term perspective, for example after 15 years. The removal of stumps[24] for bioenergy production may markedly affect the nutrient status and nutrient cycling of boreal forests (Palviainen et al., 2010) but the long-term effects of stump harvesting for energy on SOM and soil C are not yet well known (Lattimore et al., 2009). Long-term stem growth data will be needed to achieve a more comprehensive understanding of the effects of WTH on the site nutrient status and productivity (Luiro et al., 2010). Overall, although there may be some decline in soil carbon associated with biomass production, this is negligible in comparison with the contribution of bioenergy systems towards greenhouse mitigation through avoided fossil fuel emissions (Cowie et al., 2006).

In order to maximize the ecological sustainability and integrity of harvested sites, and to ensure that ecosystem services and biodiversity are maintained, it is necessary to have guidelines or legislated policies governing harvesting and site restoration practices (Levin & Eriksson, 2010). Sweden developed a series of recommendations and good-practice guidelines (GPG) for WTH that are based on various scientific studies and include prescriptions and mandates to minimize environmental damage caused by whole tree harvesting for bioenergy (e.g., Levin & Eriksson, 2010). Thus, Sweden's new 2008 GPG and regulations include a directive that if WTH is to be undertaken, ash recycling, first of all, should be used to restore acid neutralization capacity and nutrients to harvested sites (Swedish Forest Agency, 2008). Secondly, WTH operations should leave snags in place, leave slash from less common tree species, and leave at least 20 % of the slash from harvesting operations on site, but should not be permitted where endangered species might be negatively affected (Swedish Forest Agency, 2008). However, scientific uncertainty still exists. For example, the importance of carbon removal from harvested sites and the effects of WTH on long-term nutrient budgets and runoff water quality are still being discussed and investigated. This suggests that dedicated feedstock production will be required to provide most of the biomass needed to fulfill sustainable production goals and, by extension, that future water resource impacts can be justifiably estimated from land use changes required for this additional dedicated production (Evans and Cohen, 2009).

Soil biological properties also have a direct impact on SOM concentrations, soil C storage, nutrient cycling and soil hydrology. There are concerns that residue removal can change soil biological properties by removing substrate for soil microorganisms (e.g., Lattimore et al., 2009; Karlen et al., 1994; Salinas-Garcia et al., 2001). However, soil

---

[24] After a tree has been cut and felled, the stump or tree stump is usually a small remaining portion of the trunk with the roots still in the ground. Stumps are the largest coarse woody debris component in managed forests.

biological systems tend to be very resilient and studies have not yet shown any lasting impacts due to whole tree harvesting or other intensive forest management activities (Grigal, 2000). On the other hand, forest floor microbial communities composition appeared to be strongly influenced by topographic position rather than stand related differences and structural differences in microbial communities observed between sites at higher and lower elevations appear to be linked to seasonal patterns in moisture (e.g., Swallow et al., 2009). Genomic-related microbial research generates massive amounts of data; one challenge still facing microbial ecology is the ability to link microbial composition and function (Langenheder et al., 2005; Ahlgren et al., 2006). Overall, the effects of harvesting on the structure of forest soil microbial communities and the functional consequences warrant more comprehensive investigation.

Sustainable enhancement of biomass production can be achieved if there are ways to increase nutrient availability indefinitely (Vance, 2000). There are studies indicating that removal of biomass nitrogen may increase the long-term retention of nitrogen (e.g., Goodale and Aber, 2001). On the other hand, the potential for biofuel production systems to cause nutrient deficiencies is an issue of particular concern. That is, response in nutrient retention/losses to biomass harvest intensity is a function of pre-existing site conditions and data on soil nutrients demonstrate a mixed pattern of accumulation and depletion, depending on plot, farmer and location (e.g., Toulmin and Scoones, 2008). However, nutrients present in ashes should be recycled to biomass production systems. While this is not a major problem for nutrients such as Mg, K and Ca, because these elements are relatively abundant, the element P is geochemically scarce. Indefinitely increased availability of P in soils is critically dependent limiting losses due to erosion/runoff and leaching and on high efficiency recycling of P present in biomass, while keeping soil concentrations of hazardous compounds below critical levels (Kvarnström and Nilsson, 1999). Moreover, strict control of the fate of elements such as N, S, As and heavy metals and of relatively toxic organic compounds is necessary to fit a steady state economy and the substance flows of such compounds to the environment should be kept low. Meeting such conditions for sustainability requires a major effort (Reijnders, 2006). Overall, while much is known about how forest management activities contribute to nutrient removals on a variety of sites, little is known about how these removals affect long-term forest productivity (Burger, 2002).

A detailed understanding of local soil types and how they respond to specific treatments is other key to sustainable production (Lattimore et al., 2009). According to literature on the subject (e. g., Vitousek and Melillo, 1979; Hakkila, 2002; Lattimore et al., 2009) the effects of biomass production systems on soil nutrient levels and base captions saturation are entirely site and practice-specific. Predicting stand productivity from soil properties seems difficult (e.g., Ladanai et al., 2010). Once site-specific issues are identified, practices can be designed to mitigate losses in soil nutrients and productivity (Hakkila, 2002). Potential measures may include: avoiding production on sensitive sites; choosing an appropriate time of year for harvesting; leaving materials on site to dry; and applying wood ash, lime or gypsum, where necessary (Lattimore et al., 2009).

While the effects of changes in soil chemical and biological properties on long-term site productivity are still relatively ambiguous, the effects of physical site disturbances (e.g., soil erosion and compaction) are better known (Lattimore et al., 2009). Thus, production of annual and perennial crops as well as forest harvesting practices can give rise to net loss of land caused by soil erosion. There may be competition between the use of plant residues for combustion and for combating erosion (Reijnders, 2006). Resource conservation requires that loss due to erosion should be balanced by soil formation due to such processes as natural weathering (Riksen et al., 2003). However, there are the other measures that can reduce erosion. These include judicious planting and harvesting practices, conservation tillage, controlling drainage, terracing, planting windbreaks (to reduce wind erosion) and using hedging and buffer strips to catch sediments (Pimentel et al., 1997; Nisbet, 2001; Smolikowski et al., 2001; Mrabet, 2002; Nordstrom and Hotta, 2004). Site productivity can decline by 10% as a direct result of physical disturbances including erosion and decreased aeration, water infiltration and root growth caused by soil compaction after machinery use can last for ten years, and may be irreversible (Grigal, 2000). Thus, the reviewed literature shows that changes in soil compaction due to residues removal can be small in clayey soils and that complete removal of residues has greater adverse impacts than partial removal (Blanco-Canqui & Lal, 2009b). The greater the amount of residue mulch cover, the greater is its capacity to buffer the soil against compaction. However, vulnerability to compaction varies from site-to-site, and careful planning can help reduce its occurrence (Lattimore et al., 2009).

Overall, soil chemical, physical and biological properties are often altered in response to management practices, but the effects of these alterations on soil productivity are still largely unclear. Thus, a great deal is known about short-term effects of forest management practices on soil productivity, but much less is known about long-term impacts. The combined effect of biomass harvest regime and site specific conditions may influence several processes, which exert important controls on nutrient retention and loss. Magnitude of impacts of crop residue removal on soil structural properties is most probably governed by differences in soil type (texture and mineralogy), cropping system, climate, and drainage conditions (Blanco-Canqui, 2009a). Moreover, data on the impacts of crop residue removal on soil properties at the aggregate or micro-scale level are few because most of the studies on residue removal have primarily focused on macro-scale soil properties (Lal et al., 1980; Karlen et al., 1994; Sharratt et al., 2006; Singh and Malhi, 2006). However, microaggregates differ in their properties from the whole soil due to the differences in the mechanisms of their formation and turnover. For example, microaggregates may, unlike the whole soil, remain undisturbed during plowing (Horn, 1990).

Taken as a whole, given the diversity of local context and the complex dynamics of soil-fertility change, the options to support more sustainable soil management when producing biomass for energy must combine different elements: technical choices, strategies for intervention and a range of policy measures. Unfortunately, soil-fertility management itself has rarely been the main target of such policies; rather, soil quality has been considered not as a policy objective in itself, but as an input into achieving other policy objectives (e.g., Toulmin and Scoones, 2008). However, soil degradation and nutrient losses are unlikely to prompt changes in farmer behavior until and unless the decision by farmers to invest effort and capital in improving the soil and productivity of their farmland will depend, in part, on pressures to do so, the perception that changes are necessary and the lack of other options (e.g., Toulmin and Scoones, 2008).

5. Hydrology and renewable energy

5.1. General

Water is an essential ecosystem component and has a multifarious relationship to energy, food and environment. Freshwater supports the very survival of plant and animal on the earth, but adequate quantities of it are in short supply in many regions of the world. Water plays an important role in producing renewable energy sources both directly in the form of hydropower and indirectly in the form of biomass. That is, both hydropower and biomass require substantial amounts of water. The new energy pursuit is likely to increase the stress on existing water resources as well as current patterns of water allocation. Disturbances from biomass management can subsequently affect natural processes, including hydrologic flows and physical, chemical, and biological properties of waterways. The water stress is particularly serious in parts of Asia that are already water short or have difficulty in meeting existing water demand, and also in sub-Saharan Africa which is known for increasing population coupled with under-investment in water infrastructure. As a result, the water sector in these areas is likely to face major conflicts between its energy and environmental goals on the one hand and food and livelihood goals on the other. The issue of how to resolve these conflicts with acceptable tradeoffs is going to be, therefore, a major policy concern in the Asian and African regions in particular and other developing regions in general (de Fraiture, 2008).

Hydropower is largely a nonconsuming water user though there are some consumption losses through evaporation from reservoirs and timing of releases may conflict with other consuming uses (de Fraiture et al., 2008). As theory predicts (Zilberman et al., 2008) a classic conflict between those who want to use the water in the dam strictly for hydropower generation and those who want to divert some of it for industrial and agricultural needs might be positive synergies when water first generates hydropower and then provides agricultural benefits, as is the case in the lower Krishna Basin. However, that biofuels/biomass competes for water is not inevitably the case. Thus, afforestation, reforestation and agroforestry practices where dispersed wide belts of trees integrated into conventional agriculture, can reduce wind erosion, improve shelter, reduce dryland salinity, increase water status of adjacent agricultural lands, regenerate and stabilize water resources and – if properly sited, designed and smart species selection used – having no significant impact on catchment flows.

5.2. Biomass production and water use

The increased demand of energy worldwide will reflect directly and indirectly on water-dependent systems (Hellegers et al., 2008). The production of biomass is a consumptive use of water that may compete directly with food crop production for water and land resources (Berndes, 2002; de Fraiture et al., 2008). However, among the possible challenges to biofuel development that may not have received appropriate attention are its effects on water resources. Water is required for both growing the feedstock crop and in many cases processing biofuels at the production facility. However, water needed to process biomass into biofuel or bioenergy is negligible compared with the amounts required to grow it.

There are reports that warn that large-scale production of biomass may pose significant threats to both water supply and water quality. Thus, in October 2007, an expert panel on the issue for the US National Academies' National Research Council (NRC) released a report on the issue: Water Implications of Biofuels Production in the United States (NRC, 2007). The report predicted that a serious hike in corn ethanol capacity could trigger local water shortages, along with soil erosion and worrying rises in fertiliser run-off. A a primary concern is that irrigation demands for feedstock production will promote unsustainable exploitation of surface and ground water, resulting in aquatic ecosystem degradation and reduced future agricultural potential (NRC, 2007). However, high-energy demand of irrigation could be reduced by a factor 3 (24%) if surface water is used for irrigation instead of water pumped from a depth (e.g., Cavalaris et al., 2008). Irrigation can also pose issues related to water yield (e.g., Baker et al., 2000). However, changes in water yields will vary in scale and intensity from site-to-site, depending on local climate, soils, and management practices. Thus, in dry climates, or areas with high water demands, energy plantations requiring irrigation may be more likely to contribute to groundwater depletion than similar practices in areas with plentiful rainfall or low overall extraction; alternatively, intensive irrigation can raise local groundwater tables and increase soil salinity (e.g., Australia) (Baker et al., 2000). A combination of factors related to climate, vegetation and watershed characteristics can lead to a 21-280 % increase in water yield as well as increases in peak flow of up to 1,400%, causing potential danger for humans, wildlife, property and livestock; conversely, some regions show no increase in peak flow at all (Neary, 2002). Overall, knowledge of local hydrology, coupled with site planning, location choice and species choice, are all factors that will determine whether or not irrigation is sustainable (Lattimore et al, 2009).

From a water perspective it makes a large difference whether for example biofuel is made from fully irrigated or rain-fed crops. In contrast to 80% rain-fed agricultural systems that produce 60% of world food (Schoengold and Zilberman, 2007), irrigated systems constitute 20% of agricultural land and produce 40% of agricultural output by volume (Zilberman et al., 2008). Biomass production goes hand in hand with large water requirements. However, there is result indicating that bioethanol's water requirements can range from 5 to 2,138 L per liter of ethanol depending on regional irrigation practices (e.g., Chiu et al., 2009). This result highlights the need to take regional specifics into account when implementing biofuel mandates. Putting this result in the context of the consumer (in liters of water consumed/withdrawn per km traveled), the difference in water intensity of various transportation fuels between irrigated and non-irrigated biofuel feedstock (up to 3 orders of magnitude in liters per km) shows the need to properly plan for their incorporation (e.g., King and Webber, 2008).

Theoretically, all crops can be used for energy and water use for a specific crop does not depend on whether the crop is for energy or for food. However, in the shift towards a larger contribution from bioenergy to total energy, it seems to be promising to select the crops, tree species and countries that (under current production circumstances) produce bioenergy in the most water-efficient way. The multiple benefits of Jatropha, a typical energy crop, as well as its suitability under e.g. Egypt's climate and scarce water conditions (Abou Kheira et al., 2009), means that Jatropha can survive and produce full yield with high quality seeds under minimum water requirements compared to other crops. The ethical discussion on whether food crops can be used for energy should be extended to a discussion on whether we should use our limited water resource base for food or for energy (Gerbens-Leenes et al., 2009). On the other hand, Jatropha is the least water efficient for both electricity generation and biodiesel production, compared to many other crops (e.g., Gerbens-Leenes et al., 2009). However, rising energy price will make the extraction and conveyance of water more costly and will be likely to encourage reform of water policy to more efficient systems (Zilberman et al., 2008).

From a global overview of the water footprints (WFs[25]) of bioenergy from 12 crops it was concluded that the WF of bioenergy is large when compared to other forms of energy (Gerbens-Leenes et al., 2009). However, WF does not take into account that we are effectively in a closed system for water, and there is no "loss" of water from the

[25] A concept for the calculation of water needs for consumer products is the water footprint (WF) (Hoekstra and Chapagain, 2007), defined as the total annual volume of fresh water used to produce goods and services for consumption. In this study the WF is assumed per unit of bioenergy [m^3/gigajoule (GJ)].

system which means that in every case the water involved is almost entirely transpired or passed and returns to the atmosphere as water vapour. Thus, sugarcane in Brazil evaporates 2,200 liters for every liter of ethanol, but this demand is met by abundant rainfall (Hellegers et al., 2008). Moreover, the WF of bioenergy shows large variation, depending on 3 factors: (*i*) the crop used, (*ii*) the climate at the location of production, and (*iii*) the agricultural practice (Gerbens-Leenes et al., 2009).

Soil hydrology and management practices of biomass production systems are related. However, while in some studies negative effects have been widely documented for example of crop residue removal on soil water retention (e.g., Blanco-Canqui & Lai, 2007), in contrast, in the other studies no differences was observed in water retention and plant available water content between soils with 0% and 100% residue removal (Morachan *et al.*1972; Karlen *et al.* (1994). That is, available data show that crop residue removal impacts on soil water retention can be large in some soils and small on others, depending on soil texture, terrain, drainage, and climate. Moreover, stover removal may impact soil hydrology differently because such residues as wheat and soybean residues are less coarse and more decomposable than stover, which remains longer on the soil surface (Blanco-Canqui et al. 2009b). Reported in the literature impacts of residue mulch on water infiltration is inconsistent and published data highlight the complexity of the impact of residue mulch and the large variability of water infiltration characteristics (e.g., Blanco-Canqui et al. 2009a). Even physical properties of water can be changed by increased sedimentation from runoff and by temperature changes from the clearance of streamside vegetation (Jordan, 2006; Holopainen and Huttunen, 1992).

Woodfuel production systems can also have a range of impacts on hydrological processes and water quality, especially during harvesting and site preparation. Thus, a high level of N (and especially nitrates) is an indicator of reduced water quality and consequently site disturbance. Forest harvesting, slash removals (e.g., Neary, 2002) as well as forest applications of wood ash from bioenergy conversion plants (e.g., Aronsson and Ekelund, 2004) can lead to leaching of nitrogen or heavy metals into streams or groundwater. However, while removal of all or some trees has an impact on the water flow in general, it has been observed that thinning of up to 60 % keep the plant uptake function intact and without any increase in nitrogen leaching (e g., Knight et al., 1991). Moreover, in general, levels of N significant enough to threaten human health or to harm aquatic ecosystems have not been found in streams draining harvested sites (Lattimore et al., 2009). Overall, the main concerns are that groundwater and aquatic ecosystems in and around woodfuel production sites could be subject to: changes in water yield and peak flow; changes in stream temperature and light infiltration; increased turbidity and sedimentation; increased concentration of N and other nutrients; and accumulation of toxic substances (e.g., Burger, 2002; Dyck and Mees, 1990; Neary, 2002).

Water has a new integrative and regulating role to pay (Koutsoyiannis et al., 2009). Thus, with increasing water demands to satisfy a growing population requiring more food, fuel, and water, it will be critically important to use a low-quality water source, such as for example, saline or reclaimed water (King and Webber, 2008), livestock wastewater (e.g., Cantrell et al., 2009;) and secondary treated effluent (Sugiura et al., 2008) as a valuable water resource in biomass production systems. For example, irrigation with swine effluent by increasing K, Ca, and Na in the bermudagrass hay, may have positive implications on future thermochemical conversion processes by promoting combustible gas formation (e.g., Cantrell et al., 2009). Overall, the water resource implications of biofuel production are less well-studied than other environmental factors

(Giampietro et al., 1997; NRC, 2007). However, knowledge of watershed characteristics, hydrological processes and natural peak flow patterns can help to determine likely effects on a particular site (Lattimore et al., 2009).

De Fraiture et al. (2008), using the WATERSIM model to give a global overview of the land and water implications of increased biofuel production, conclude that biofuel production will have a relatively minor impact on the global food system and water use. However, local and regional impacts could be substantial. Thus, the strain on water resources would be such in China and India that it is unlikely that policy makers will pursue biofuel options, at least those based on traditional field crops.

Overall, as water resources have already been stressed in many regions, the long-term sustainability of water resources used for biofuel feedstocks is a key issue to consider. Policies designed to conserve water and prevent the unsustainable withdrawal of water from depleted aquifers should be formulated. Thus, from a water quality perspective, it is important to prevent an increase in total loadings of nutrient to waters. Cellulosic feedstocks, which have a lower expected impact on water quality in most cases could be an important alternative to pursue, keeping in mind that there are many uncertainties regarding the large-scale production of these crops.

6. Biodiversity

Healthy ecosystems are relatively stable and the diversity of the organisms they contain enables them to adapt to changing circumstances. The complex diversity of animals, plants and microorganisms, their interactions with each other and with the environments in which they have developed, keep life on earth in balance. This diversity provides us with food, shelter and other material goods. We have always found ways of manipulating our environment and the biodiversity they contain to satisfy our needs. However, in doing so we have had an enormous impact on the world's ecosystems and in many places they can no longer cope with the demands made on them or the speed of change (Amalu, 2008).

Biomass for energy production can have both positive and negative effects on species diversity. Woodfuel production systems as well as agroforestry have the potential to increase biodiversity. Thus, afforestation of former agricultural lands will create new habitat for some species, while thinning or replacement of degraded stands can improve forest structure for other species (Lattimore et al., 2009).

However, effects can occur at a number of levels, including landscapes (e.g., Egnell and Valinger, 2003; Sanchez et al., 2006), ecosystems (e.g., Rosén, 1986; Egnell et al., 1998), habitats, species (e.g., Röser et al., 2008) and genes (e.g., Egnell and Valinger, 2003); this greatly increases the complexity of planning at a landscape level. For example, while a decline in diversity can be expected on whole tree harvested sites (e.g., Jonsell 2007), leaving a portion of slash on site, leaving old dead standing wood (snags), and leaving slash of less common tree species are measures that can be taken to protect biodiversity (e.g., Egnell et al. 1998, Jonsell 2007). Retention of sufficient mature trees might be more important for biodiversity (e.g., Raulund-Rasmussen et al., 2006). Extraction of logging residues may have negative effects on saproxylic organisms, both because it reduces the amount of available habitats and because saproxylic insects can get trapped in the wood. However, in many types of stands these effects are probably negligible and the benefits of using forest fuels could be considered larger than the negative effects (Jonsell, 2008). Overall, the positive effects – i.e. the main gain of decreased extinction risks – of care taken during forest operation may differ between regions, even when the structure of the stand and tree species composition ect. are similar (ibid). However, maximizing benefits to biodiversity while minimizing negative impacts is most likely to occur in the presence of adequate knowledge and frameworks (e.g., certification systems, policy, guidelines) (e.g., Lattimore et al., 2009).

7. Site productivity

A renewed interest in the intensive harvesting of biomass as a source of bioenergy raises concerns about the impacts that this practice may have on the maintenance of site productivity. Site productivity is the production that can be realized at a certain site with a given genotype and a specified management regime. Site productivity depends both on natural factors inherent to the site and on management-related factors.

Wood sources are expected to contribute a greater portion of energy in the future. It has been suggested that much of the feedstock would come from the improved use of woody materials remaining in the forest after harvest (e.g., woody debris, stumps, and other logging residues), non-merchantable biomass (e.g., small trees and noncommercial species), and waste from the creation or disposal of wood products (e.g., mill residues and municipal wood waste) (e. g., Perlack et al., 2005). Additional material may also come from short-rotation woody crops of trees grown specifically for bioenergy (Janowiak & Webster, 2010).

Many factors contribute to forest productivity, including site conditions, soil characteristics, vegetative cover, and management history (Grigal, 2000). However, soil organic matter is essential for tree growth. Research regarding the sustainability of forest productivity emphasizes the importance of preserving soil quality by maintaining organic matter and soil nutrients (Vance, 2000; Burger, 2002).

Several short- and long-term studies have been conducted to assess the impacts of residue removal on crop yields (Morachan *et al.*, 1972; Wilhelm *et al.*, 1986; Karlen *et al.*, 1994; Sow *et al.*, 1997; Linden *et al.*, 2000). The reviewed literature shows that impacts of residue removal on crop yields are highly variable, and depend on the tillage method, cropping systems, duration of tillage and crop management, soil-specific characteristics (e.g., texture and drainage), topography, and climate during the growing season. Thus, as the year-to-year variability in weather conditions (e.g., precipitation amount) can mask the impacts of residue removal on crop yields and crop residue removal can, thus, increase, decrease, or have no effect on crop yields depending on site-specific conditions (Blanco-Canqui and Lai, 2009a). However, even if in some soils, a small fraction of crop residues may be available for removal without causing serious adverse impacts on the environment (Lindstrom *et al.*, 1979; Nelson, 2002; Kim and Dale, 2004; Graham *et al.*, 2007), but harvesting a small fraction of crop residues is neither logistically feasible nor economically viable. To produce large volumes of bioenergy and other renewable energy feedstocks must therefore be developed as possible alternatives. Results from agricultural studies indicate that maintenance of long-term soil productivity may be possible in short rotation, intensively managed forest systems (Vance, 2000). Thus, a shift from crop residues to dedicated energy crops (e.g.,warm-season grasses and short-rotation woody crops) is needed to produce alternative sources of biofuel feedstocks without adversely affecting soil and environmental quality and agronomic production (Blanco-Canqui and Lai, 2009a).

Likely, the potential environmental impacts of forest residue harvesting on site productivity, as indicated by tree growth response, depend also on site properties (e.g., Scott & Dean, 2006; Egnell et al., 2006). It is therefore not surprising that the site-specific differences that drive site productivity, plus different reforestation practices, can lead to a range of responses after intensive biomass removals (Lattimore et al., 2009), from decreased (Egnell and Valinger, 2003) to no difference (Sanchez et al., 2006) and even to increased tree growth (Proe et al., 2001). Caution must be used in interpreting short-term results (Sanchez et al., 2006; Proe et al., 2001).

However, site and soil productivity are not necessarily synonymous; for example, use of genetically improved stock, appropriate planting density and other site-specific reforestation techniques may result in increased tree growth compared to the previous rotation and thus mask detrimental soil impacts that would otherwise have led to reduced growth (Lattimore et al., 2009). While reduced tree growth is indicative of reduced site productivity, lack of apparent negative impacts on growth (or even improved growth) does not necessarily indicate a lack of negative impacts on soils and soils-related biodiversity (Sanchez et al., 2006).

8. Biofuels offer an attractive solution

8.1. Future biofuels demand

There is a steady increase of global primary biomass-for-energy consumption (e. g. IEA, 2010). In order to model future bioenergy demand, the IEA provides different scenarios, based on different assumptions and time spans. Projections are based on Reference Scenarios that models how global energy markets evolve if there is no change to the existing policies, technology and measures. Overall, projections see a rapid increase in second-generation biofuels demand.

However, projections for global biomass demand in the scenarios differ. Thus, the *World Energy Outlook 2009* (IEA, 2009a) *450 Scenario*[26] projects biofuels to provide 9% (11.7 EJ) of the total transport fuel demand (126 EJ) in 2030 (Figure 4). In the most ambitious scenario- the *Blue Map Scenario*[27] of *Energy Technology Perspectives 2008* (IEA, 2008b) - that extends analysis until 2050, biofuels provide 26% (29 EJ) of total transportation fuel (112 EJ) in 2050, with second-generation biofuels accounting for roughly 90% of all biofuels. This makes biofuels, together with electrification of the vehicle fleet, the second largest contributor to CO_2 reductions (17%) in the transportation sector, right after end use efficiency (52%) (IEA, 2010). More than half of the second-generation biofuel production in the *Blue Map Scenario* is projected to occur in non-OECD countries, with China and India accounting for 19% of the total production (IEA, 2010).

Overall, biofuels, together with electric-vehicles, are seen as an important technology and second-generation fuels will play a major role after 2020. On the other hand, there is

[26] This scenario models future energy demand in light of a global long-term CO_2 concentration in the atmosphere of 450 parts per million (ppm), which would require global emissions to peak by 2020 and reach 26 Gt CO_2-equivalent in 2030, 10% less than 2007 levels.

[27] This scenario models future energy demand until 2050, under the same target as the WEO 450-Scenario (i.e. a long-term concentration of 450ppm CO_2 in the atmosphere).

the suggestion that the biofuel target of 10% in 2020 should be reconsidered (e. g., Eickhout et al. 2008).

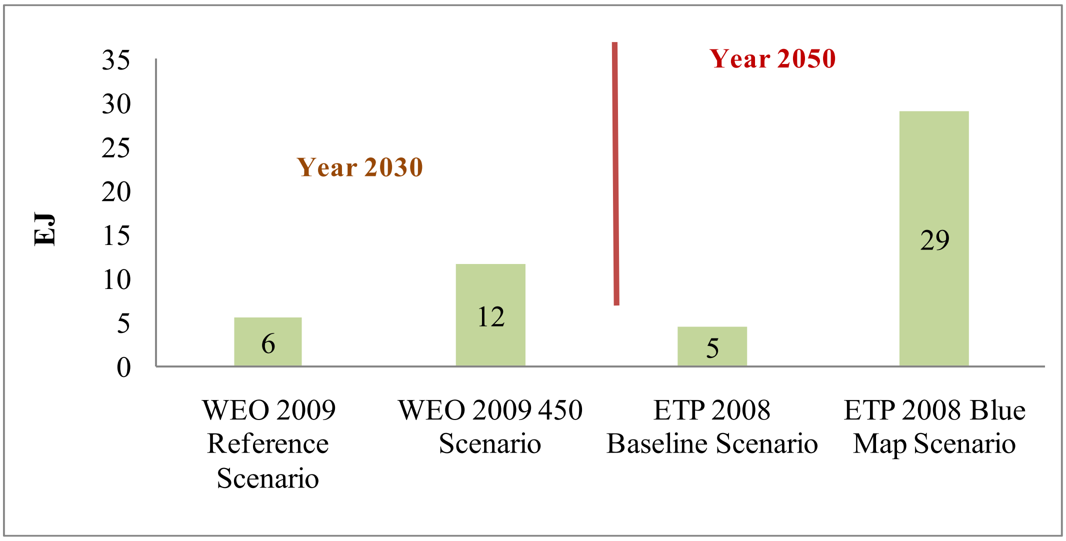


Figure 4. Modeled future transport biofuel demand (according to different scenarios provided by the IEA and based on different assumptions and time spans). Source: based on IEA, 2010.

8.2. Biofuels in the market

Biofuel production has been increasing steadily over the last years and the most common end use is the transport sector. Liquid biofuels in general, and biodiesel, in particular, have gained importance in the last years in more than 21 countries leading to commercial projects in Austria, the Czech Republic, France, Germany, Italy, Malaysia, Nicaragua, Sweden and the USA (Best, 2006).

However, virtually all currently produced biofuel can be classified as first-generation, whereas second generation biofuel production is in the demonstration stage with the first commercial plants expected to start production within a few years (IEA, 2010). Currently, cellulosic ethanol production exists only at pilot and commercial demonstration-scales, because the technologies for breaking down the fibers into fuel on a commercial scale are still being developed and may be five or more years in the future. Research-and-development activities on second-generation biofuels so far have been undertaken only in a number of developed countries and in some large emerging economies like Brazil, China and India (IEA, 2010).

Some companies have reported the start of commercial production of 2nd-generation biofuels within the coming years, but they will still depend on subsidies to be economically viable for some years to come (IEA, 2010). The *WEO 2009 450 Scenario* projects that 2nd-generation biofuels will not penetrate the market on a fully commercial scale earlier than 2015 (IEA, 2009a).The US and EU mandates could become important drivers for the global development of 2nd-generation biofuels, since current IEA analysis sees a shortfall in domestic production in both the US and EU that would need to be met with imports (IEA, 2009b).

8.3. Environmental benefits of biofuels

Biofuels represent one of the most prominent technical options in replacing the fossil fuels and especially oil by renewable and more sustainable fuels due to possibility of blending with fossil fuels and using in the existing cars without significant adaptations (Gnansounou, 2010). However, to be acceptable, biofuel feedstock should be produced sustainably. There is widespread concern that the production of biofuels will increase demand for new agricultural land at the expense of natural ecosystems. Hence, the big global issues will be the impact on the environment, biodiversity, land and other constrained resources. On the other hand, the negative environmental implications from this resource perspective also need to be considered in the light of the potentially possible positive environmental benefits of biofuels, for example, from the perspective of pollution reduction (e.g., CO_2 mitigation).

The first generation of commercially available biofuels suffers from their reliance on food crops and their eventual wide scale development raises concerns about direct and indirect effects on land use (e. g., Gnansounou, 2010). In this respect, the sustainable production of bioethanol from lignocellulosic biomass is expected to become one of the most credible alternatives within a few years (Gnansounou, 2010). Non-food or lignocellulosic biomass is considered as feedstock for second generation biodiesel (Figure A).

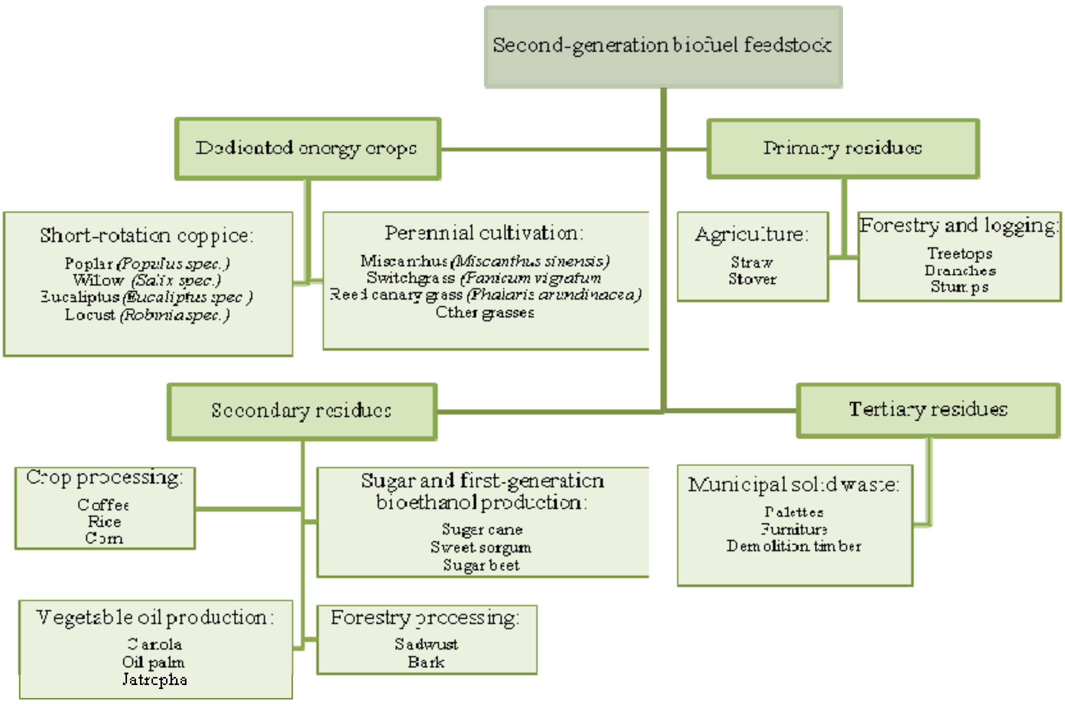


Figure A. Potential lignocellulosic feedstocks for second-generation biofuels (Sources: based on IEA, 2007; Rosillo-Calle et al., 2006; Faaij et al., 1997; Bassam, 1998 (cited in IEA, 2010))

Lignocellulosic biomass is everywhere around the globe and represents a much more abundant feedstock for biofuel production (Figure A). These feedstocks have the advantage of not affecting the human food chain by them being diverted to make fuel (Figure B).

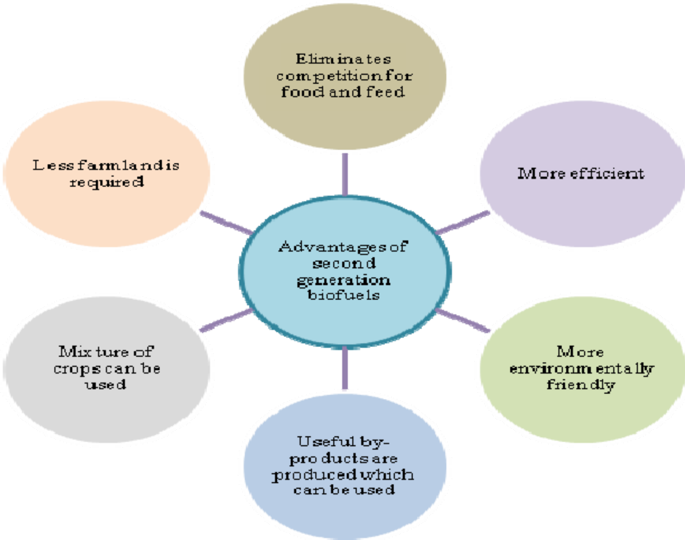


Figure B. Visualization of the advantages of second-generation biofuels (Source: based on the AltProfits website http://www.altprofits.com/ref/se/re/bio/sgb/sgb.html)

The most of feedstocks belonging to the second generation are no food competitive, do not require additional land and can be grown in marginal and wastelands.

Galbe et al. (2007) identified the key drivers for reducing the production cost of lignocellulosic ethanol, i.e. improvement of the ethanol yield, high ethanol concentration during fermentation, improvement of pre-treatment techniques, enhancement of saccharification step as well as production of cheaper and more effective enzymes and achievement of process integration. However, the policy instruments should explicitly reward the higher value of lignocellulosic ethanol compared to first the generation ethanol and gasoline (Gnansounou, 2010). The transition to an integrated first- and 2nd generation biofuel landscape is therefore most likely to encompass the next one to two decades (Sims et al., 2010).

9. Systems approach for sustainable biomass feedstock production

Bioenergy can be produced in different forms and ways and in so many different locations in the world, and so conditions vary widely. That is, bioenergy systems can be relatively complex. For example, as ethanol production dependent upon the structures of the individual systems it is not possible to state generally whether ethanol is good or bad as regards the climate (e. g., Börjesson, 2009). Recently a number of objections have been raised against the use of ethanol produced from agricultural products such as maize, sugarcane, wheat or sugar beets as a replacement for gasoline. However, while current production of Swedish ethanol from wheat can be seen as ‘‘good” ethanol, reducing GHG emissions by some 80% compared to petrol and while ethanol based on sugarcane from Brazil leads to a reduction of – on average – 85%, ethanol from maize in the USA leads to a reduction of only 20% on average (Börjesson, 2009). Ethanol from sugarcane, as produced in Brazil, is the preferred option for the production of fuel not only in terms of cost but also as a favourable energy balance (e.g., Goldemberg & Guardabassi, 2009) and the reason for this is that fossil coal accounts, on average, for 25% of the fuel used in ethanol plants in the US, and natural gas for the remaining 75% (Wang et al., 2007). There is also the possibility of expanding ethanol production to other sugar-producing countries.

Approaches to improving the sustainability of bioenergy have typically focused on single issues. However, to assess the bioenergy utilization prospects for their environmental quality more system research is needed. Thus, for example, even if a reduction in GHG emissions is achieved, it should not be disregarded that additional environmental impacts (like acidification and eutrophication) may be caused and this aspect cannot be ignored by policy makers, even if they have climate change mitigation objectives as main goal (Cherubini & Jungmeier, 2010). Another example could be that sitting biomass feedstock on marginally productive lands rather than highly productive croplands would minimize competition with food production (Campbell et al., 2008), but marginal lands often require significant inputs of nutrients and water to maintain productivity (Schmer et al., 2008). In this case, a systems approach where the agricultural, energy, and environmental sectors are considered as components of a single system has the potential to significantly improve the economic, social, and environmental sustainability of biofuels. Thus, the inclusion of marginal land could contribute significantly to feedstock production for bioenergy and if the crops grown on these lands are irrigated and fertilized using degraded water resources, feedstock production could be further increased with concomitant environmental benefits obtained through the reuse and restoration of these resources (e.g., Gopalakrishnan et al., 2009). Studies indicating that water and nutrient requirements can be met through the use of municipal wastewater to grow short-rotation woody bioenergy crops (Börjesson and Berndes, 2006) suggest that closing the loop through the optimization of all resources is essential to minimize conflicts in resource requirements as a result of increased biomass feedstock production. Other benefits of implementing this strategy include feedstock intensification to decrease biomass transportation costs, restoration of contaminated water resources, and mitigation of greenhouse gas emissions with quantification of the carbon and nitrogen cycles at the field scale, especially nitrous oxide emissions as an important area of future research (e.g., Gopalakrishnan et al., 2009). Moreover, in the future the co-benefits of bioenergy production will need to be optimized and methods will need to be developed to extract and refine high-value products from feedstock before it is used for energy production (Sims et al., 2006)

A Life- Cycle Assessment (LCA) - investigation and evaluation of the environmental impacts of a given product or service – is a methodology able to reveal the validity if bioenergy to reduce greenhouse gas emissions and dependence on fossil fuels. LCA approach takes into account all the input and output flows occurring in biomass production systems. A fundamental role is played by biomass supply, because the source of biomass has a big impact on LCA outcomes (Cherubini et al., 2009). However, LCA results may differ even for apparently similar biomass production systems. Differences are due to several reasons: type and managements of raw materials, conversion technologies, end-use technologies, system boundaries and reference energy system with which the bioenergy chain is compared (Cherubini et al., 2009). Moreover, emissions from fields vary depending on soil type, climate, crop, tillage method, and fertilizer application rates (Larson 2005). LCA is promising because an important variable in LCA studies is the contribution to net GHG emissions of N_2O, which evolves from nitrogen fertilizer application and organic matter decomposition in soil (Stehfest & Bouwman, 2006). Overall, there is a broad agreement in the scientific community that LCA is one of the best methodologies for the GHG balance calculation of biomass systems (e .g., Cherubini, 2010).

Various LCA studies demonstrate the great potential of bioenergy to reduce both the consumption of non-renewable energy resources and greenhouse gas emissions. Special attention is paid to the question of which alternative for biomass use (production of energy, fuels, or materials) is generally most favorable from an environmental point of view (e. g., Weiss et al., 2007). Weighing can be used as an additional step at the level of stakeholders aiming for decisions based on LCA results and various methods for weighing environmental impacts were developed within the LCA community. Thus, by applying distance-to-target weighing methodology and aggregating LCA results to one environmental index, it was shown that that the potential of bio-based products to reduce negative environmental impacts compared to their fossil counterparts strongly depends on the value assumptions (e .g., Weiss et al., 2007). These results are largely caused by the relative energy intensive conversion of plant oils into final fuel products. However, for the interpretation of the final environmental index values it is important to note that as energy and fuels can be produced from biomass by using largely conventional technologies, further reductions of negative environmental impacts of bioenergy and biofuels can be expected from technological improvements in the future (e.g., Weiss et al., 2007). Although the result reveals also that bio-energy and bio-materials offer significantly higher environmental benefits than bio-fuels, but given the uncertainties and controversies associated not only with distance-to-target methodologies in particular but also with weighing approaches in general, the authors strongly recommend using weighing for decision finding only as a supplementary tool separately from standardized LCA methodology (Weiss et al., 2007).

Ecologically sound development is possible when energy needs are integrated with the environmental concerns at the local and global levels. An analysis of the cost-effectiveness of different applications of biomass gasification suggest that goals of increasing renewable electricity production and at the same time increasing production of biofuels could to some extent be counteractive and therefore prioritizing between available options whether to produce green electricity or transport biofuels is necessary (Börjesson & Ahlgren, 2010). It is very important to point out that energy planning has an important role to play in order to achieve energy-efficient and cost-efficient energy systems (e.g., Hiremath et al., 2007; Börjesson & Ahlgren, 2010). Energy-planning involves finding a set of sources and conversion devices so as to meet the energy requirements/demands of all the tasks in an optimal manner (Hiremath et al., 2007). However, centralised electricity generating stations waste around two thirds of the energy in the fuels they use by throwing away waste heat in cooling water, up the cooling towers and then in the electricity transmission wires and 65% of the energy is lost before it even reaches consumers (Anon 2, 2007). Overall, according to Hiremath et al. (2007), centralized energy planning (CEP) ignores energy needs of rural areas and poor, has led to environmental degradation due to fossil fuel consumption and forest degradation and cannot pay attention to the variations in socio-economic and ecological factors of a region, which influence success of any intervention. In contrast, the central theme of the energy planning at decentralized level would be to prepare an area-based decentralized energy planning (DEP) to meet energy needs and development of alternate energy sources at least-cost to the economy and environment. Its use is already widespread and mainstream in many European countries, including Sweden since the late 1970s.

An important perspective for considering environmental risks and associated strategies to reduce them is weighing the environmental tradeoffs by asking how dedicating land to feedstock production will alter impacts from current land use. Thus, in terms of both energy replacement and the perspective of carbon emissions reductions, as well from the largely positive soil conservation attributes associated with production of switchgrass and other forage grasses, the switchgrass-to-ethanol cycle has significant advantages that should make it an environmentally valuable supplement to corn in future ethanol markets (e.g., McLaughlin and Walsh, 1998).

Overall, the environmental benefits of biomass-for-energy production systems vary strongly, depending on soil, climate, management system and input intensities. Therefore, in order to develop a tool that can be applied to assess opportunities and barriers in biomass-for-energy production systems, and to help to understand what practices make the biggest difference in any particular system, taking the circumstance on individual fields and farms or other type of biomass-for-energy systems into account is crucial. For example, minimum tillage can lead to overall GHG savings under one set of circumstances, but increase net emissions under another and practical advice in each circumstance would therefore be helpful. Criteria for achieving sustainability and best land use practices when producing biomass for energy should therefore be established and adopted.

10. To sum up

Overall, the pursuit of increasing the share of biofuels and other bio-energy sources in the global energy supply is occurring within the broad context of complex inter-linkages between energy, food, land, water and the environment as well as their economic, social and ecological implications. It is necessary to promote integrated policies and approaches in the sectors of agriculture, energy, industry, environment (Best, 2006) and forestry.

This report presents many contrasting examples of the complex interrelationships between energy, food, land, water, productivity, biodiversity and the environment. The literature overview and analysis presented in the report is a pooling of existing knowledge from international contexts with respect to bioenergy issues. And as such the report might be useful both to illustrating synergies and conflicts in the bioenergy-environment debate. As revealed in this report, management alternatives aimed at optimizing environment services when producing biomass for energy is not always unambiguous. In some cases biomass for energy sources may compete for important inputs to existing activities, particularly agricultural land and water resources. In other cases these sources may be complementary, and involve little competition for existing resources. However, changes of both kinds can be perceived as threatening local social or environmental values.

Carbon stocks and water resources are mostly highly resistant and resilient thus securing ecosystem functions in the future. However, as mature nature reserves did not sequester much carbon, the very intensive alternatives might be optimal if carbon sequestration has highest priority. On the other hand, such alternatives generally have lower carbon stocks in the system due to harvesting and other operations that might cause a rapid release of a part of the carbon stock. Negative impacts of the no-harvesting regime in areas with high nitrogen load such as leaching of nitrate and hence accelerated soil acidification (Ritter & Vesterdal, 2006) might be counteracted by biomass harvesting and fertilisation.

VIII. Conclusions

All scenarios show a shift toward an increased percentage of renewable energy, including biomass. The use of biomass energy is a widely accepted strategy towards sustainable development. The use of renewable energy, including bioenergy, sees the fastest rate with the most of increase in power generation followed by strong rises in the consumption of biofuels for transport. Developing Asian countries are the main drivers of this growth, followed by Middle East.

To produce bioenergy, considerable amounts of biomass have to be provided. Agriculture, forestry and wood energy sectors are the leading sources of biomass for bioenergy. However, as an adequate bioenergy supply is closely linked to adequate food, water and land, the production of biomass for energy raises many environmental concerns. Moreover, bioenergy systems can be relatively complex, interdisciplinary, intersectoral and site- and scale-specific. The interrelationships that exist in different facets of the energy-environment/food/feed/land interface are complex and sensitive but the future of biomass energy depends on the interplay of these factors which are highly important to the sustainability of biomass production. It is important to understand the effects of introducing fuels based upon feedstocks other than petroleum. The report reveals both benefits and uncertainty regarding how well biomass-for–energy production and in particular, next-generation biofuels will fare on different environmental and sustainability factors when produced on a commercial scale.

To be acceptable, biomass feedstock must be produced sustainably. Bionergy from sustainably managed ecosystems could provide a renewable, carbon neutral source of energy through the world and there is a strong societal need to evaluate the sustainability of bioenergy, especially because of the significant increases in production mandated by many countries.

Environmental impact categories in different biomass-for-energy production systems (soil, land, water, productivity, biodiversity and energy/carbon balance) are shown in Figure 8. A wide range of potential environmental responses related to biomass-for-energy systems have been identified (Figure 8).

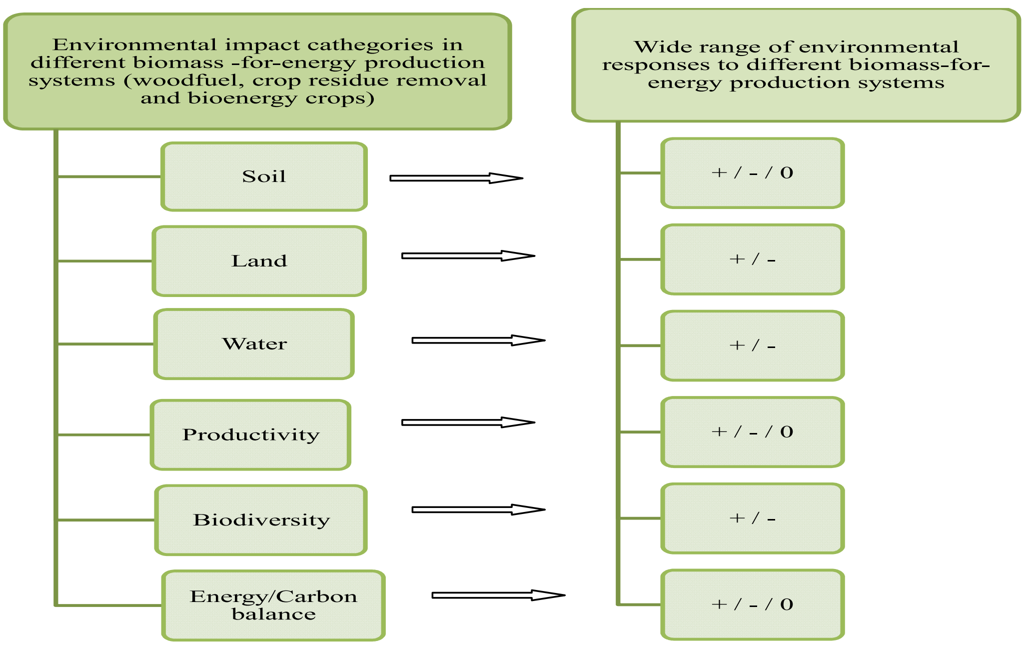


Figure 8. Environmental impact cathegories in different biomass-for-energy production systems. Environmental responses: 0 no effect; - negative influence; + posistive influence.

In general, environmental and management factors govern the magnitude and direction of changes in an ecosystem. Replacing current agricultural and forestry systems with biomass for energy systems is likely to alter the most of ecosystem properties. Although a huge number of experiments have been conducted aiming at quantification of impacts of biomass management operations on the ecosystems services several gaps still exist. There is the need to take regional specifics into account when implementing biofuel mandates.

The ability of bioenergy to mitigate greenhouse gas emissions by adsorption of carbon dioxide by growing biomass is a key facet of environmental sustainability and of environmental benefits. High biomass yields are extremely important in achieving high GHG emission savings. Soils have an important role in the budgets of greenhouse gasses. Understanding of nitrous oxide and methane fluxes from soils is necessary to fully assess greenhouse gas emissions from biomass production systems. Land management practices have the potential to change dramatically the gas exchange of an ecosystem, with proper management enhancing greenhouse gas remediation.

Land use is an important factor. Greenhouse gas release from land use change is a potential contributor to the environmental profile of bioenergy, but emissions have not been systematically compared and summarized. GHG emissions are particularly difficult to be accurately attributed to the expansion of biomass production in a given country and consequently it would be delicate to include them in the GHG emission balance at a country level. Existing land use change studies did not consider many of the potentially important alternative assumptions, scenarios and variables that might be important when quantifying GHG emissions of biofuels. Nevertheless, the impact of land use change on greenhouse gas emissions can be mitigated through agro-economic mechanisms or technical developments. Mitigation include the use of residues as feedstock, cultivation of feedstock on abandoned arable land and the use of feedstock by-products. Moreover, areas degraded and wasted in historical times by human activities are possible to use for biomass growing. Restoration of degraded areas, if done properly, will increase the fertility and water status of the adjacent agricultural land, stabilize sustainably the global and especially drinking water resources.

Biomass and food can compete for land, but this is not always the case and the pattern of competition between fuel and food is not clear yet, and depends on whether food security policies are in place. Abandoned agricultural land, degraded and other marginal land rehabilitated by bioenergy plantations, surplus agricultural land made available through more intensive agriculture are potentials for considerable biomass production. However, land occupation is one of the most controversial issues.

Agroforestry has a high potential for simultaneously satisfying many important objectives: protecting and stabilizing the ecosystems; producing a high level of output of economic goods; improving income and basic materials to rural population as well as conserving natural resources through various systems under different agroclimatic regions. Agroforestry and woodfuel production systems have the potential to increase biodiversity.

Soil chemical, physical and biological properties can be altered by biomass production systems. One of the main options for greenhouse-gas mitigation is the sequestration of carbon in soils. Each biomass system (especially dedicated energy crops) should avoid the depletion of carbon stocks or, at least, any decline in carbon stock of any pool should be taken into consideration in calculating the GHG mitigation benefits of the system. Perennial grasses like switchgrass and miscanthus can enhance carbon sequestration in soils and can thus increase the GHG savings of bioenergy systems. Also reed canary grass is of special interest in this respect and indicates the potential as a carbon sink. The effect of intensified biomass extraction on forest ecosystems is not always well understood. However, more sustainable soil management must combine technical choices, strategies for intervention and a range of policy measures. Sweden developed a series of recommendations and good-practice guidelines that include prescriptions and mandates to minimize environmental damage caused by whole tree harvesting for bioenergy.

Water has a multifarious relationship to energy, but it is not inevitably the case that biofuels/biomass compete for water. It is critically important to use low-quality water sources and it is promising to select the crops and countries that produce bioenergy feedstock in the most water-efficient way. However, water issues abound in every region having its own distinct challenges. Knowledge of watershed characteristics, local hydrology and natural peak flow pattern coupled with site planning, location choice and species choice, are all factors that will determine whether or not this relationship is sustainable.

Biofuels contribute to GHG mitigation strategies in the transport sector. All of currently produced biofuel is first generation; second generation biofuel production is still in the demonstration stage. Oil from Jatropha (*Jatropha curcas* L.) is considered as an interesting substitute for fossil fuels. Depending on the feedstock choice (e.g., ligno-cellulosic, agricultural, forest, energy crops, genetically modified crops, jatropha, switchgrass) and the cultivation technique, 2nd-generation biofuel production has the potential to provide benefits such as consuming waste residues and making use of abandoned land. Perennial crops, for example Jatropha , as well as non-food and industrial crops require minimal input and maintenance and therefore offer several benefits over conventional annual crops for biofuel production.

A systems approach where the agricultural, energy, and environmental sectors are considered as components of a single system has the potential to significantly improve the economic, social, and environmental sustainability of biofuels. Closing the loop through the optimization of all resources is essential to minimize conflicts in resource requirements as a result of increased biomass feedstock production. Moreover, most of the investigations and experiments rely on a reductionistic research approach whereas the impacts of the operations are on a system or a landscape level and should be assessed as such. LCA is one of the most promising methodologies for the emission calculation of biomass systems. The most fundamental problem for a systems approach is the short-term perspective of the experiments aiming at explaining effects that often have long-term impacts.

Regional energy planning could have an important role to play in order to achieve energy-efficient and cost-efficient energy systems. Moreover, adequate knowledge and frameworks, such as for example certification systems, policy and guidelines would be helpful for maximizing benefits of bioenergy while minimizing negative impacts. Figure 9 is a diagrammatic visualization of the sustainable biomass feedstock concept where feedstocks neither compete with food crops nor directly or indirectly cause land-clearing and that offer advantages in reducing greenhouse-gas emissions. A number of conditions have emerged for the sustainability of biomass-for-energy production. Practices should be such that levels of soil organic matter and nutrients in soils can be maintained indefinitely. Water usage and erosion should not exceed additions to water and soil stocks. Emissions related with burning biomass of persistent organics, acidifying compounds and heavy metals should be kept low and the bioenergy chain should be such that there is climate neutrality. Meeting these conditions requires major efforts as current or presumable future practices may well be different.

Based on the review of the available literature, this report suggests that as impacts are site-specific in nature, the net environmental effects of biomass-for–energy production depend on the relative magnitudes of their positive and negative effects, which can be reckoned appropriately only in local and regional contexts. As such, impacts will vary regionally and differ according to local ecological conditions and management practices. Moreover, practices that are profitable and sustainable in one place or in one period may result in substantial environmental damage under other conditions. Sensitive sites, such as those with shallow, coarse-textured, low-nutrient soils, are more susceptible to long-term losses in soil productivity from removal of all or most of the above-ground biomass than higher quality sites. Climate data and knowledge of local conditions and best practices will therefore determine which issues are most critical at different sites. Overall, we need site-specific surveys of environmental impacts of bioenergy production systems. However, the visualization of the sustainable biomass feedstock concept where feedstocks neither compete with food crops nor directly or indirectly cause land-clearing suggests that multiple uses of land to provide food and fiber while enhancing carbon stocks and producing energy may present further opportunities to reduce greenhouse gas concentrations with optimal use of resources (Figure 9).

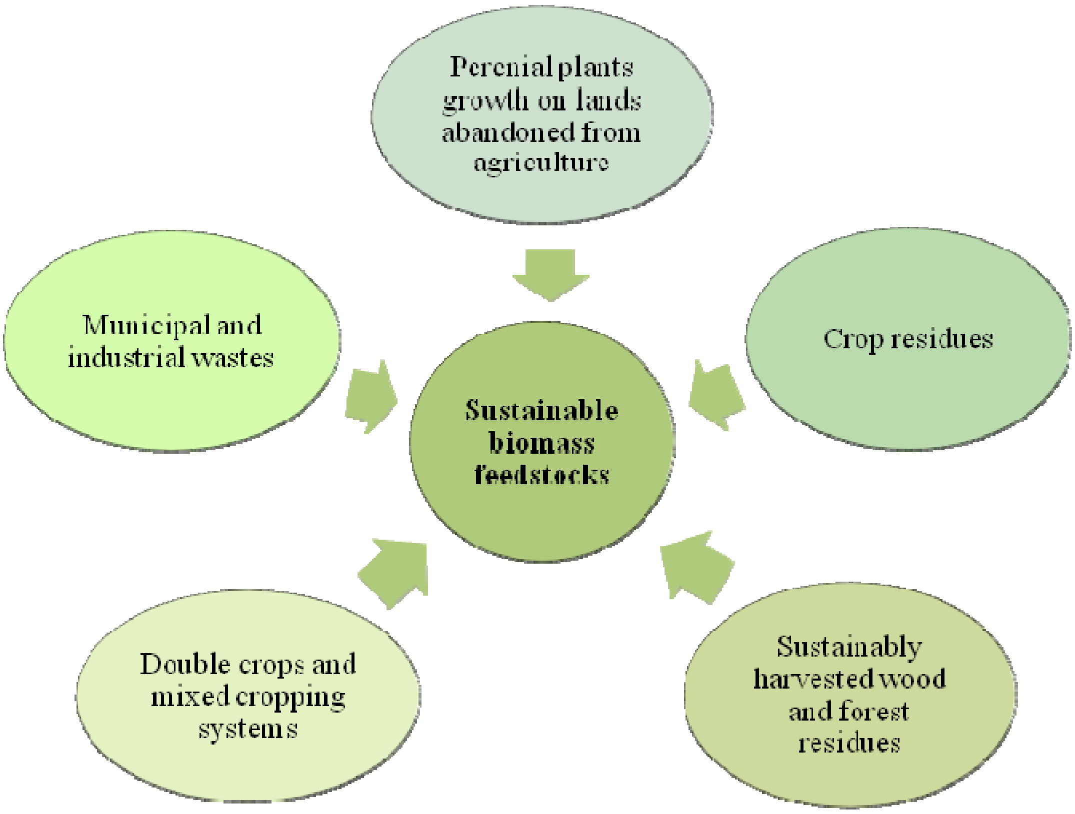


Figure 9. Visualization of the sustainable biomass feedstock concept where feedstocks neither compete with food crops nor directly or indirectly cause land-clearing.

REFERENCES

Abbott P., Hurt C., Tyner W., 2008. What's driving food prices? Farm Foundation Issue Report, http.//*www.farmfoundation.org* available online 2010-08-25.

Abou Kheira A.A. & Atta N.M.M. 2009. Response of Jatropha curcas L. to water deficits: Yield, water use efficiency and oilseed characteristics. *Biomass & Bioenergy* 33(10), 1343-1350.

Ahlgren N.A., Rocap G., Chisholm S.W. 2006. Measurement of Prochlorococcus ecotypes using real-time polymerase chain reaction reveals different abundances of genotypes with similar light physiologies. *Environmental Microbiology* 8, 441–454.

Almodares A. & Hadi M.R. 2010. Production of bioethanol from sweet sorghum: A review. African Journal of Agricultural Research 4(9), 772-780.

AltProfits. 2010-06-29. Second Generation Biofuels. Profiting from the Alternative Energy Revolution, *http://www.altprofits.com/ref/se/re/bio/sgb/sgb.html* 2010-06-20.

Amalu U.C. 2008. Ecological measures for sustainable agriculture in sub-saharan Africa. *Journal of Agriculture, Biotechnology and Ecology* 1(1), 3-25.

Angers D.A., Eriksen-Hamel N.S. 2008. Full-inversion tillage and organic carbon distribution in soil profiles: A Meta-Analysis. *Soil Science Society of America Journal* 72(5), 1370-1374.

Aronsson A.K. & Ekelund N.G.A. 2004. Biological effects of wood ash application on forest and aquatic systems. *Journal of Environmental Quality* 33, 1595-606. Atmospheric Chemistry and Physics 8, 389–395.

Baker T., Bartle J., Dickson R., Polglase P., Schuck S. 2000. Prospects for bioenergy from short rotation crops in Australia. In: Christersson L. & Wright L. (eds). Short-Rotation Crops for Bioenergy. *Proceedings of the Third Meeting of IEA, Bioenergy, Task 17 in Auburn, Alabama, U.S.A., September 6-9, 1999.*

Bala G., Caldeira K., Wickett M., Phillips T.J., Lobell D.B., Delire C., Mirin A. 2007. Combined climate and carbon-cycle effects of large-scale deforestation. *Proceedings of the National Academy of Sciences of the United States of America* 104, 6550–6555.

Bartle J.R & Abadi A. 2010. Toward Sustainable Production of Second Generation Bioenergy Feedstocks. *Energy & Fuels* 24, 2-9.

Barton L., Murphy D.V., Kiese R., Butterbach-Bahl K. 2010. Soil nitrous oxide and methane fluxes are low from a bioenergy crop (canola) grown in a semi-arid climate. Global Change Biology Bioenergy 2(1), 1-15.

Bassam N.El. 1998. *Energy Plant Species. Their Use and Impact on Environment and Development.* Earthscan Publications Ltd., London.

Berndes G. 2002. Bioenergy and water – the implications of a large-scale bioenergy production for water use and supply. *Global Environmental Change* 12, 253-271.

Best G. 2006. Alternative energy crops for agricultural machinery biofuels – Focus on biodiesel. *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development*. Invited overview. No.13. Vol. VIII.

Bhattacharya S.C., Albina D.O., Salam P.A. 2002. Emission factors of wood and charcoal-fired cookstoves. *Biomass and Bioenergy* 23, 453–69.

Bilgen S., Kaygusuz K., Sari A. 2004. Renewable energy for a clean and sustainable future. *Energy sources* 26(12), 1119-1129.

Blanco-Canqui H. & Lai R. 2007. Soil and crop response to harvesting corn residues for biofuel production. *Geoderma* 141(3-4), 355-362.

Blanco-Canqui H. & Lal R. 2008. No-tillage and soil-profile carbon sequestration: An on-farm assessment. *Soil Science Society of America Journal* 72(3), 693-701.
Blanco-Canqui H. & Lal R. 2009a. Crop Residue Removal Impacts on Soil Productivity and Environmental Quality. *Critical Review in Plant Science* 28, 139-163.
Blanco-Canqui H. & Lal R. 2009b. Corn Stover Removal for Expanded Uses Reduces Soil Fertility and Structural Stability. *Soil Science Society of America Journal* 73(2), 418-426.
Borsari B., Onwueme I., Kreidermacher E., Terril T. 2009. Renewable energy from restored prairie plots in southeastern Minnesota, USA. In: Brebbia C.A., Mammoli A.A (eds) *Energy and sustainability II. Book Series: WIT Transactions on Ecology and the Environment* 121, 137-145.
Bouwman F., van Grinsven J.J.M., Eickhout B. 2010. Consequences of the cultivation of energy crops for the global nitrogen cycle. Ecological Applications 20(1), 101-109.
Bowyer J.L., Shmulsky R., Haygreen J.G. 2003. *Forest products and wood science. An Introduction*. *Fourth Edition*. Iowa State Press, Blackwell Publishing, Iowa.
Bradshaw C.J.A., Sodhi N.S., Peh K.S.H., Brook B.W. 2007. Global evidence that deforestation amplifies flood risk and severity in the developing world. *Global Change Biology* 13(11), 2379-2395.
Bridgwater A.V., Czernik S., Piskorz J. 2008. The status of biomass fast pyrolysis. In: Bridgwater A.V (ed) *Fast Pyrolysis of Biomass: A Handbook*. CPL Press Liberty House, Newbury, UK 2, 1-22.
Bruce J.P., Frome M., Haites E., Janzen H., Lal R., Paustiain K. 1999. Carbon Sequestration in Soils. *Journal of Soil and Water Conservation 54*(1), 382–389.
Bruinsma J. 2003. *World Agriculture: Towards 2015/2030. An FAO Perspective*. Earthscan Publications Ltd; London; UK, pp. 432.
Brundtland G.H. 1987. *World Commisison on Environment and Development: Our Common Future.* Oxford University Press, pp. 147.
Burger . 2002. Soil and long-term site productivity values. In: (eds) Richardson J., Bjorheden R., Hakkila P., Lowe A.T., Smith C.T. *Bioenergy from sustainable forestry: guiding principles and practice.* Kluwer Academic Publishers, Dordrecht, Netherlands, pp. 165-190.
Börjesson P. 2009. Good or bad bioethanol from a greenhouse gas perspective - What determines this? *Applied Energy* 86(5), 589-594.
Börjesson M. & Ahlgren E.O. 2010 Biomass gasification in cost-optimized district heating systems-A regional modelling analysis. *Energy Policy* 38(1), 168-180.
Börjesson P. & Berndes G. 2006. The prospects of willow plantations for wastewater treatment in Sweden. *Biomass & Bioenergy* 30, 428-438.
Campbell J.E., Lobel D.B., Field C.B. 2009. Greater transportation energy and GHG offsets from bioelectricity than ethanol. *Science* 324(5930), 1055-1057.
Campbell J.E., Lobell D.B., Genova R.C., Field C.B. 2008. The global potential of bioenergy on abandoned agricultural lands. *Environmental Science and . Technology 4*2(15), 5791–5794.
Cantrell K.B., Stone K.C., Hunt P.G., Ro K.S., Vanotti M.B., Burns J.C. 2009. Bioenergy from Coastal bermudagrass receiving subsurface drip irrigation with advance-treated swine wastewater. *Bioresource Technology* 100(13), 3285-3292.
Castaldi S., Ermice A., Strumia S. 2006. Fluxes of N2O and CH4 from soils of savannas and seasonally-dry ecosystems. Journal of Biogeography 33(3), 401-415.
Cavalaris C., Karamoutis C., Fountas S., Gemtos T.A. 2008. Sunflower oil energy budget for in-farm oil production under four tillage systems. *Agricultural and*

biosystems engineering for a sustainable world. International Conference on Agricultural Engineering, Hersonissos, Crete, Greece, 23-25 June, 2008, p. 165. changes in soil C from mineral soils at 1-km resolution in the UK. *Soil Use and*

Cherubini F. & Jungmeier G. 2010. LCA of a biorefinery concept producing bioethanol, bioenergy, and chemicals from switchgrass. International Journal of Life Cycle Assessment 15(1), 53-66.

Cherubini F. 2010. GHG balances of bioenergy systems - Overview of key steps in the production chain and methodological concerns. Renewable Energy 35(7), 1565-1573.

Cherubini F., Bird N.D., Cowie A., Jungmeier G., Schlamadinger B., Woess-Gallasch S. 2009. Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. *Resource Conservation and Recycling* 53(8), 434–447.

Chiu Y.W., Walseth B., Suh S. 2009. Water Embodied in Bioethanol in the United States. *Environmental Science & Technology* 43(8), 2688-2692.

Cowie A.L., Smith P., Johnson D. 2006. Does soil carbon loss in biomass production systems negate the greenhouse benefits of bioenergy? Mitigation and Adaptation Strategies for Global Change 11(5/6), 979-1002.

Coyle W. 2007. The future of biofuels: a global perspective. *Amber Waves* 5, 24–29.

Croezen H.J., Bergsma G.C., Otten M.B.J., van Valkengoed M.P.J. 2010. *Biofuels: indirect land use change and climate impact*. Report. CE Delft.

Crutzen P.J., Mosiera A.R., Smith K.A., Winiwarter W.W. 2008. N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels.

Daly H. 1995. On Wilfred Beckerman's critique of sustainable development. *Environmental Values* 4(1), 49- 55.

Das D. & Veziroglu T.N. 2001. Hydrogen production by biological processes: a survey of literature. *International Journal Hydrogen Energy* 26, 13–28.

de Fraiture C., Giordano M., Liao Y.S. 2008. Biofuels and implications for agricultural water use: blue impacts of green energy. *Water Policy* 10 (Supplement 1), 67–81.

Dewbre J., Giner C., Thompson W., Von Lampe M. 2008. High food commodity prices: will they stay ? who will pay ? Agricultural Economics Supplement S 39 (3), 393-403.

Dhyani S.K., Kareemulla K., Ajit, Handa A.K. 2009. Agroforestry potential and scope for development across agro-climatic zones in India. *Indian Journal of Forestry* 32(2), 181-190.

Dickmann D.I. 2006. Silviculture and biology of short-rotation woody crops in temperate regions: Then and now. *Biomass & Bioenergy* 30(8-9), 696-705.

Doornbosch R. & Steenblik R. 2007. Biofuels: Is the cure worse than the disease? Report SG/SD/RT(2007)3. Organisation for Economic Co-operation and Development, Paris, France.

DornburgV., Lewandowski I., Patel M. 2004. Comparing the land requirements, energy savings, and greenhouse gas emissions reduction of biobased polymers and bio-energy. An Analysis and System Extension of Life-Cycle Assessment Studies. *Journal of Industrial Ecology* 7(3-4), 93-116.

Dyck W.J. & Mees C.A. 1990.Nutritional consequences of intensive forest harvesting on site productivity. *Biomass* 22, 171-186.

Egnell G. & Valinger E. 2003. Survival, growth, and growth allocation of planted Scots pine trees after different levels of biomass removal in clear-felling. *Forest Ecology and Management* 177, 65-74.

Egnell G., Bergh J., Dahlberg A., Rytter L., Westling O. 2006. *Miljöeffekter av skogsbransleuttag och askåterföring i Sverige - En syntes av Energimyndighetens forskningsprogram 1997 till 2004.* Eskilstuna: Swedish Energy Agency; Report ER 44, pp. 211 [in Swedish].
Egnell G., Nohrstedt H.Ö., Weslien J., Westling Ö, Örlander G. 1998. Miljökonsekvensbeskrivning (MKB) av skogsbränsleuttag, asktillförsel och övrig näringskompensation. Rapport 1/1998. Swedish Forest Agency, Jönköping, Sweden. http://www.skogsstyrelsen.se/forlag/rapporter/1639.pdf [in Swedish].
Ehring R. & Dallos M. 2009. Survey on European 2nd Generation Biofuels Technology Suppliers. Report Bioenergy 2020+, 358 TR nk-IV-99, Wieselburg, May 2009. *Energy* 32, 1736–1741.
Eickhout B., Van den Born G.J., Notenboom J., Van Oorschot M., Ros J.P.M., Van Vuuren D.P., Westhoek H.J. 2008. Local and global consequences of the EU renewable directive for biofuels. Testing the sustainability criteria. MNP Report 500143001, Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.
Eliasson P. & Ågren G.I. 2011. Feedback from soil inorganic nitrogen on soil organic matter mineralisation and growth in a boreal forest ecosystem. Plant and Soil 338, 193-203.
EPA (Environmental Protection Agency). 2001. *Residential wood combustion. Emission inventory improvement program*, vol. 3.Washington, DC: US [Chapter 2].
Erbach D.C. & Wilhelm W.W. 2009. *Bioenergy: Energy Sources and Costs for Agriculture*. In: Pond W.G., Nichols B.L., Brown D.L. (eds) *Adequate Food For All: Culture, Science, and Technology of Food in the 21st Century*, pp. 263-281.
Erisman J.W., van Grinsven H., Leip A., Mosier A., Bleeker A. 2010. Nitrogen and biofuels; an overview of the current state of knowledge. Nutrient Cycling Agroecosystems 86(2), 211-223.
European Commission. 2008. Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. Report COM(2008) 30 final. European Commission, Brussels, Belgium.
Evans J.M. & Cohen M.J. 2009. Regional water resource implications of bioethanol production in the Southeastern United States. *Global Change Biology 15*(9)**,** 2261-2273**.**
Evans L.T. 2003. Agricultural intensification and sustainability. *Outlook on Agriculture* 32, 83-89.
Faaij A., J. van Doorn, T. Curvers, L. Waldheim, E. Olsson, A. van Wijk and C. Daey-Ouwens (1997), "Characteristics and Availability of Biomass Waste and Residues in the Netherlands for Gasification". *Biomass & Bioenergy* 12(4), 225-240.
Falloon P., Smith P., Bradley R.I., Milne R., Tomlinson R.W., Viner D., Livermore
FAO, 2000a. Land resource potential and constraints at regional and country levels. World Soil Resources Report 90. Food and Agriculture Organization of the United Nations, Rome ftp://ftp.fao.org/agl/agll/docs/wsr.pdf 2010-11-10.
FAO, 2000b. Carbon sequestration projects under the clean development mechanism to address land degradation. World soil resources reports 92, p.2, Rome
FAO, 2003. Terrastat database. Land resource potential and constraints statistics at country and regional level, Rome. http://www.fao.org/ag/agl/agll/terrastat/#terrastatdb
FAO, 2005. *Global forest resources assessment 2005, FAO Forestry Paper 147a*, p 99
FAO, 2010. Commodity Market Review 2009 – 2010. http://www.fao.org/docrep/012/i1545e/i1545e00.pdf 2010-12-01.

FAOSTAT—Statistics of the Food and Agriculture Organization of the United Nations http://faostat.fao.org/S 2009-09-04.

Fargione J., Hill J., Tilman D., Polasky S., Hawthorne P. 2008. Land Clearing and the Biofuel Carbon Debt. *Science 319*(5867), 1235–1238.

Farrell A.E. & O'Hare M. 2008. Greenhouse gas (GHG) emissions from indirect land use change (LUC). In: *Memorandum for the California Air Resources Board. Energy & Resources Group*, University of California, Berkeley, p. 4.

Farrell D. 2009. Feeding the future. *Livestock Research for Rural Development* 21**(**12**),** 219

Field C.B., Campbell J.E., Lobell D.B. 2008. Biomass energy: the scale of the potential resource. *Trends in ecology & evolution* 23(2), 65-72.

Field C.B., Lobell D.B., Peters H.A., Chiariello N.R. 2007. Feedbacks of terrestrial ecosystems to climate change. *The Annual Review of Environment and Resources* 32, 1–29.

Fine P., Cass G.R., Simoneit B. 2001. Chemical characterization of fine particle emissions from fireplace combustion of wood grown in the North-Eastern United States Environ Science and Technology 34, 2665–2675.

Fitzpatrick E.M., Ross A.B., Bates J., Andrews G., Jones J.M., Phylaktou H., Pourkashanian M., Williams A. 2007. Emission of oxygenated species from the combustion of pine wood and its relation to soot formation. *Process safety and environmental protection* 85, 430-440.

Freeman D.J. & Cattell F.C.R. 1990. Woodburning as a source of atmospheric polycyclic aromatic hydrocarbons. Environmental Science and Technology 2, 1581–1585.

Galbe M., Lidén G., Zacchi G., 2005. Production of ethanol from biomass – research in Sweden. *Journal of Scientific and Industrial Research* 64, 905–919.

Gaunt J.L. & Lehmann J. 2008. Energy balance and emissions associated with biochar sequestration and pyrolysis bioenergy production. *Environmental Science & Technology 42* (11), 4152–4158.

Geist H.J. & Lambin E.F. 2002. Proximate Causes and Underlying Driving Forces of Tropical Deforestation. *BioScience 52*(2), 143–150.

Gerbens-Leenes W., Hoekstra A.Y., van der Meer T.H. 2009. The water footprint of bioenergy. *Proceeding of the national academy of sciences of the United States of America.*106**(**25), 10219-10223.

Giampietro M., Ulgiati S., Pimentel D. 1997. Feasibilty of large-scale biofuel production. *BioScience* 47, 587-600.

Gnansounou E. 2010. Production and use of lignocellulosic bioethanol in Europe: Current situation and perspectives. *Bioresource technology* 101(13), Sp. Iss, 4842-4850.

Gnansounou E., Panichelli L., Dauriat A., Villegas J.D. 2008. *Accounting for indirect land-use changes in GHG balances of biofuels. Review of current approaches*. Working Paper EPFL, Lausanne, March 2008.

Goldemberg J. & Guardabassi P. 2009. Are biofuels a feasible option? *Energy Policy* 37(1), 10-14.

Gomez L.D., Stelle-King C.G., McQueen-Mason S.J. 2008. Sustainable liquid biofuels from biomass: the writing's on the walls. *New Phytologist* 178, 473–485.

Goodale C.L. & Aber J.D. 2001. The long-term effects of land-use history on nitrogen cycling in North hardwood forest. *Ecological Application* 11(1), 253-267.

Gopalakrishnan G., Negri M.C., Wang M., Wu M., Snyder S.W., Lafreniere L. 2009. Biofuels, Land, and Water: A Systems Approach to Sustainability. *Environmental Science & Technology* 43(15), 6094-6100.
Graf H.F. 2004. The complex interaction of aerosols and clouds. Science 303, 1309–1311.
Graham R.L., Nelson R., Sheehan J., Perlack R.D., Wright L.L. 2007. Current and Potential U.S. corn stover supplies. *Agronomy Journal* 99, 1-11.
Grigal D.F. 2000. Effects of extensive forest management on soil productivity. *Forest Ecology and Management* 138(1-3), 167-185.
Hakkila P. 2002. Operations in the reduced environmental impact. In: (eds) Richardson J., Bjorheden R., Hakkila P., Lowe A.T., Smith C.T. *Bioenergy from sustainable forestry: guiding principles and practice.* Kluwer Academic Publishers, Dordrecht, Netherlands, pp. 244-261.
Harrington T.B. & Schoenholtz S.H. 2010. Effects of logging debris treatments on five-year development of competing vegetation and planted Douglas-fir. *Canadian Journal of Forest Research* 40(3), 500–510.
Hartkamp R., Hillring B., Mabee W., Olsson O., Skog K., Spelter H., Vinterbäck J., Wahl A. 2009. Chapter 9. Continued growth expected for wood energy despite turbulence of the economic crisis:Wood energy markets, 2008-200953. In: *UNECE/FAO Forest Products Annual Market Review, 2008-2009. Geneva Timber and Forest Study Paper 24, New York and Geneva.*
Hellegers P., Zilberman D., Steduto P., McCornick P. 2008. Interactions between water, energy, food and environment: evolving perspectives and policy issues. *Water Policy* 10(S1), 1-10.
Heller M.C., Keoleian G.A., Volk T.A. 2003. Life cycle assessment of a willow bioenergy cropping system *Biomass & Bioenergy* 25(2), 147-165.
Hill J., Nelson E., Tilman D., Polasky S., Tiffany D. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. *Proceedings of the national academy of sciences of the United States of America* 103(30), 11206–11210.
Hiremath R.B, Shikha S., Ravindranath N.H. 2007. Decentralized energy planning; modeling and application - a review. *Renewable & Sustainable Energy Reviews* 11(5), 729-752.
Hoekstra A.Y. & Chapagain A.K. 2007. Water footprints of nations: Water use by people as a function of their consumption pattern. Water Resource Management 21(1), 35-48.
Holopainen A.L. & Huttunen P. 1992. Effects of forest clear-cutting and soil disturbance on the biology of small forest brooks. *Hydrobiologia* 243-244, 457-564.
Hoogwijk M., Faaij A., Eickhout B., de Vries B., Turkenburg W. 2005. Potential of biomass energy out to 2100, for four IPCCSRES land-use scenarios. *Biomass & Bioenergy* 29, 225–257.
Hoogwijk M., Faaij A., van den Broek R., Berndes G., Gielen D., Turkenburg W. 2003) Exploration of the ranges of the global potential of biomass for energy. *Biomass & Bioenergy* 25, 119–133.
Hopmans P. & Elms S.R. 2009. Changes in total carbon and nutrients in soil profiles and accumulation in biomass after a 30-year rotation of Pinus radiata on podzolized sands: Impacts of intensive harvesting on soil resources. *Forest Ecology and Management* 258(10) SI, 2183-2193.
Horn R. 1990. Aggregate characterization as compared to soil balk properties. *Soil Tillage Research* 17, 265-289.

Houghton R.A. 1991. Tropical deforestation and atmospheric carbon dioxide. *Climate Change* 19, 99-118.
Houghton R.A., Hobbie J.E., Melillo J.M., Peterson B.J., Shaver G.R., Woodwell G.M. 1983. Changes in the carbon content of terrestrial biota and soils between 1860 and 1980: A net release of CO_2 to the atmosphere. *Ecological Monographs* 53, 235–262.
Hueting R. & Reijnders L. 1998. Sustainability is an objective concept. *Ecological economics* 27, 139-147.
Huo H., Wang M., Bloyd C., Putsche V. 2009. Life-Cycle Assessment of Energy Use and Greenhouse Gas Emissions of Soybean-Derived Biodiesel and Renewable Fuels. *Environmental Science and Technology* 43**(3),** 750-756.
Huo H.,, Michael M., Bloyd C., Putsche V. 2009. Life-Cycle Assessment of Energy Use and Greenhouse Gas Emissions of Soybean-Derived Biodiesel and Renewable Fuels. Environmental Science and Technology 43(3), 750-756.
Hüttermann A., Hamza A.S., Chet I., Majcherczyk A., Fouad T., Badr A., Cohen R., Persky L., Hadar Y. 2000. Recycling of agricultural wastes by white-rot fungi for the production of fodder for ruminants. *Agro Food and High Technology* 11, 29-32.
IEA 2007. *Good Practice Guidelines: Bioenergy Project Development and Biomass Supply*. OECD/IEA, Paris.
IEA 2008c. *World Energy Outlook 2008*, OECD/IEA, Paris.
IEA 2008a. *From first- to second-generation Biofuel Technologies: An Overview of Current Industry and RD&D activities*. International Energy Agency, OECD/IEA, Paris, http://www.iea.org/papers/2008/2nd_Biofuel_Gen_Exec_Sum.pdf 2010-12-01.
IEA 2008b. *Energy Technology Perspectives 2008: Scenarios and Strategies to 2050*, OECD/IEA, Paris.
IEA 2009a. *World Energy Outlook 2009*, OECD/IEA, Paris.
IEA 2009b. *Medium Term Oil Market Report*. OECD/IEA, Paris.
IEA 2010. *Sustainable production of second -generation biofuels. Potential and perspectives in major economies and developing countries.* Information Paper. International Energy Agency, OECD/IEA, Paris, France, http://www.oecd.org/dataoecd/17/12/44567743.pdf 2010-12-01.
IEA Bioenergy 2009. Task 39 Business Meeting. *Commercializing 1st- and 2nd-generation liquid biofuels from biomass. Intercontinental San Francisco Hotel, San Francisco, USA, 02 May 2009.*
IPCC, 2001. Land use, landuse change and forestry. Intergovernmental Panel for Climate Change, Geneva.
IUFRO, 2010. A Summary Report of the XXIII IUFRO World Congress, *http://www.iisd.ca/ymb/forest/iufro/iufroxxiii/* 2010-09-20.
Inions G. 1995. Lessons from farm forestry in Western Australia. In: *Proceedings of the ABARE Outlook Conference - Farm Forestry Session, January 1995, Australia*. pp 416-422.
Jamieson D. 1998. Sustainability and beyond. *Ecological Economics* 24, 183–192.
Janowiak M.K. & Webster C.R. 2010. Promoting Ecological Sustainability in Woody Biomass Harvesting. *Journal of forestry* 108(1), 16-23.
Johnson J.M.F., Coleman M.D., Gesch R., Jaradat A., Mitchell R., Reicosky D., Wilhelm W.W. 2007. Biomass-bioenergy crops in the United States: a changing paradigm. *The American Journal of Plant Science & Biotechnology* 1, 1–28.

Jonard M., Misson L., Ponette Q. 2006. Long-term thinning effects on the forest floor and the foliar nutrient status of Norway spruce stands in the Belgian Ardennes. Canadian Journal of Forest Research 36, 2684-2695.

Jones H.S., Garrett L.G., Beets P.N., Kimberley M.O., Oliver G.R. 2008. Impacts of Harvest Residue Management on Soil Carbon Stocks in a Plantation Forest. Soil Science Society of America Journal 72(6), 1621-1627.

Jonsell M. 2008. The effects of forest biomass harvestings on biodiversity. In: Röser D., Asikainen A., Raulund-Rasmussen K., Stupak I. (eds) *Sustainable use of forest biomass for energy: a synthesis with focus on the Nordic and Baltic Region*. New York: Springer; Chapter 6.

Jonsell M. 2007. Effects on biodiversity of forest fuel extraction, governed by processes working on a large scale. *Biomass & Bioenergy* 31, 726–732.

Jordan P. 2006. The use of sediment budget concepts to assess the impact on watersheds of forestry operations in the southern interior of British Columbia. *Geomorphology* 79, 27-44.

Jürgens I., Schlamadinger B., Gomez P. 2006. Bioenergy and the CDM in the emerging market for carbon credits. *Mitigation and Adaptation Strategies for Global Change* 11, 1050-1081.

Kaenzig J., Houillon G., Rocher M., Bewa H., Bodineau L., Orphelin M., Poitrat E., Jolliet O. 2004. Comparison of the environmental impacts of bio-based products. In: *Platform presentation and proceedings of the 2nd World Conference on Biomass Technology and Exhibition, Rome, 9-14 Mai, 2004*.

Kahle P., Belau L., Boelcke B. 2002. Effects of 10 years of Miscanthus cultivation on different properties of mineral soil in North-east Germany. *Journal of Agronomy and Crop Science* 188(1), 43-50.

Karlen D.L., Wollenhaupt N.C., Erbach D.C., Berry E.C., Swan J.B., Eash N.S., Jordahl J.L. 1994. Crop residue effects on soil quality following 10-years of no-tillage corn. *Soil Tillage Research* 31, 149-167.

Karsenty A. 2010. Paying for the tropical rainforests? Toward an international forests regime based on their remunerated conservation. *Futuribles* 361, 25-41.

Kim H., Kim S., Dale, B.E. 2009. Biofuels, Land Use Change, and Greenhouse Gas Emissions: Some Unexplored Variables. *Environmental Science & Technology* 43**(**3**),** 961-967.

Kim S. & Dale B.E. 2009. Regional variations in greenhouse gas emissions of biobased products in the United States-corn-based ethanol and soybean oil. International Journal of Life Cycle Assessment 14(6), 540-546.

Kim S., Dale B.E. 2004. Global Potential bioethanol production from wasted crops and crops residues. *Biomasss & Bioenergy* 26, 361-375.

Kimetu J., Lehmann J., Ngoze S., Mugendi D., Kinyangi J., Riha S., Verchot L., Recha J., Pell A. 2008. Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient. *Ecosystems* 11(5), 726–739.

Kimmins J.P. 1997. Predicting sustainability of forest bioenergy production in the face of changing paradigms. *Biomass & Bioenergy* 13(4-5), 201-212.

King, C.W., Webber M.E. 2008. Water Intensity of Transportation. Policy Analysis. *Environmental Science & Technology* 42(21), 7866-7872.

Knight D.H., Yavitt J.B., Joyce G.D. 1991. Water and nitrogen outflow from lodgepole pine forests after two levels of tree mortality. *Forest Ecology and Management* 46(3-4), 215-225.

Kothari R. 1994. Environment, technology, and ethics. In: Gruen L., Jamieson D. (eds) *Reflecting on Nature: Readings in Environmental Philosophy*. Oxford University Press, New York, pp. 228–237.
Koutsoyiannis D., Makropoulos C., Langousis A., Baki S., Efstratiadis A., Christofides A., Karavokiros G., Mamassis N. 2009. 1HESS Opinions: "Climate, hydrology, energy, water: recognizing uncertainty and seeking sustainability" *Hydrology and Earth System Science Discussions* 13(2), 247-257.
Koyuncu T. & Pinar Y. 2007. The emissions from a space-heating biomass stove. *Biomass & Bioenergy* 31(1), 73-79.
Kvarnstrom E. & Nilsson M. 1999. Reusing phosphorus: Engineering possibilities and economic realities. *Journal of economic issues* 33**(**2)**,** 393-402.
Labat D.,GodderisY., Probst J.L., Guyot J.L. 2004. Evidence for global runoff increase related to climate warming. *Advances in Water Research* 27, 631–642.
Ladanai S. & Vinterbäck. 2009. Global potential of Sustainable Biomas for Energy. Swedish University of Agricultural Science, Department of Energy and Technology, Report 013.
Ladanai S., Ågren G.I., Olsson B.A. 2010. Relationships between tree and soil properties in *Picea abies* and *Pinus Sylvestris* forests in Sweden. *Ecosystems* 11, 302-316.
Lal R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304:1623–1627.
Lal R., DeYleeschauwer D., Nganje R.M. 1980. Changes in properties of newly cleared Alfisol as affected by mulching. *Soil Science Society of America Journal* 44, 827-833.
Lambin E.F., Geist H.J., Lepers E. 2003. Dynamics of Land-Use and Land-Cover Change in Tropical Regions. *Annual Reviev of Environment & Resources 28*, 205–41.
Langenheder S., Lindstrom E.S., Tranvik L.J. 2005. Weak coupling between community composition and functioning of aquatic bacteria. *Limnology & Oceanography* 50, 957–967.
Langeveld C.A., Segersa R., Dirks B.O.M., Dasselaarb A. van den Pol-van, Velthofc G.L., Hensend A. 1997. Emissions of CO2, CH4 and N2O from pasture on drained peat soils in the Netherlands*. European Journal of Agronomy* 7, 35–42
Larson E.A. 2005. Review of LCA studies on liquid biofuels for the transport sector. In: Scientific and Technical Advisory Panel of the Global Environment Facility (STAP) workshop on liquid biofuels, 29 August to 1 September 2005. New Delhi – India; 2005.
Lattimore B., Smith C.T., Titus B.D., Stupak I., Egnell G. 2009. Environmental factors in woodfuel production: Opportunities, risks, and criteria and indicators for sustainable practices *Biomass & Bioenergy* 33(10), 1321-1342.
Lee D.R., Barrett C.B., McPeak J.G. 2006. Policy, technology, and management strategies for achieving sustainable agricultural intensification. *Agricultural Economics* 34, 123-127.
Lehmann J. 2007. Bio-energy in the black. *Fronties in Ecology and the Environment 5*(7), 381–387.
Lehmann J., Pereira da Silva J., Steiner C., Nehls T., Zech W., Glaser B. 2003. 2003. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the CentralAmazonbasin: fertilizer, manure and charcoal amendments. *Plant and Soil 249* (2), 343–357.

Lemus R. & Lal R. 2005. Bioenergy crops and carbon sequestration. *Critical Reviews in Plant Sciences* 24(1), 1-21.
Levin D.B., Islam R., Cicek N., Sparling R. 2006. Hydrogen production by *Clostridium thermocellum* 27405 from cellulosic biomass substrates. *International Journal of Hydrogen Energy* 31, 1496–1503.
Levin R. & Eriksson, H. 2010. Good-practice guidelines for whole-tree harvesting in Sweden: Moving science into policy. *The forestry chronicle* 86(1), 51-55.
Linden D.R., Clapp C.E., Dowdy R.H. 2000. Long-term corn grain and stover yields as a function of tillage and residue removal in east central Minnesota. Soil Tillage Res. 56, 167-174.
Lindstrom D.K., Skidmore E.L., Gupta S.C., Onstad C.A. 1979. Soil Conservation limitation on removal of crop residues for energy production. *Journal of Environmental Quality* 8, 533-537.
Loustau D. & Klimo E. 2006. The impact of forest management on the carbon cycle. In: Edwards D (ed). *Social and Cultural Values Asssociated with European Forests in Relation to Key Indicators of Sustainability*. EFORWOOD D2.3.1.
Luiro J., Kukkola M., Saarsalmi A., Tamminen P., Helmisaari H.S. 2010. Logging residue removal after thinning in boreal forests: long-term impact on the nutrient status of Norway spruce and Scots pine needles. *Tree physiology* 30(1), 78-88. M., Brown T.A.W. 2006. RothCUK—a dynamic modelling system for estimating
Mabee W.E., Gregg D.J., Arato C., Berlin A., Bura R., Gilkes N., Mirochnik O., Pan X., Pue E.K., Saddler J.N. 2006. Updates on Softwood-to-Ethanol Process. Development. *Applied Biochemistry and Biotechnology* 129-132, 55-70.
Magnani F., Mencuccini M., Borghetti M., Berbigier P., Berninger F., Delzon S., Grelle A., Hari P., Jarvis P.G. Kolari P., Kowalski A.S., Lankreijer H., Law B.E., Lindroth A., Loustau D., Manca G., Moncrieff J.B., Rayment M., Tedeschi V., Valentini R., Grace J. 2007. The human footprint in the carbon cycle of temperate and boreal forests. Nature 447(7146), 848-850.
Markel T. & Simpson A. 2006. *Plug-In Hybrid Electric Vehicle Energy Storage System Design*. Conference Paper NREL/CP-540-39614. To be presented at Advanced Automotive Battery Conference Baltimore, Maryland, May 17–19, 2006, *http://www.spinnovation.com/sn/Batteries/Plug-in_Hybrid_Electric_Vehicle_Energy_Storage_System_Design_Conference_Paper.pdf* 2010-06-30.
Marland G. & Schlamadinger B. 1997. Forests for carbon sequestration or fossil fuel substitution? A sensitivity analysis. Biomass and Bioenergy 13, 389-397.
Marland G., Obersteiner M., Schlamadinger B. 2007. The carbon benefits of fuels and forests. *Science* 318 (5853), 1066-1068.
Marsden T. 2010. Food 2030: Towards a Redefinition of Food? A Commentary on the New United Kingdom Government Food Strategy. Political Quarterly 81(3), 443-446.
Mathews J.A. & Tan H. 2009. Biofuels and indirect land use change effects: the debate continues. Biofuels, Bioproducts & Biorefining (Biofpr) 3(3), 305-317.
McCornick P.G. Awulachew S.B. Abebe M. 2008. Water-food-energy-environment synergies and tradeoffs: major issues and case studies. *Water Policy* 10(1), 23-36.
McLaughlin S.B. & Walsh M.E. 1998. Evaluating environmental consequences of producing herbaceous crops for bioenergy *Biomass & Bioenergy* 14(4), 317-324.
Melillo J.M., Reilly J.M., Kicklighter D.W., Gurgel A.C., Cronin T.W., Paltsev S., Felzer B.S., Wang X.D., Sokolov A.P., Schlosser C.A. 2009. Indirect emissions from biofuels: how important? Science 326(5958), 1397-1399.

Metzger J.O. & Huttermann A. 2009. Sustainable global energy supply based on lignocellulosic biomass from afforestation of degraded areas. *Naturwissenschaften* 96(2), 279-288.
Morachan Y.B., Moldenhauer W.C., Larson W.E. 1972. Effects of increasing amounts of organic residues on continuous corn: I. Yields and soil physical properties. *Agronomy Journal* 64, 199-203.
Moreira J.R . 2006. Global biomass energy potential. *Mitigation and Adaption Strategies for Global Changes* 11:313–342.
Mrabet R. 2002. Stratification of soil aggregation and organic matter under conservation tillage systems in Africa. *Soil & Tillage Research* 66(2), 119-128.
Müller A. Schmidhuber J. Hoogeveen J., Steduto P. 2008. Some insights in the effect of growing bio-energy demand on global food security and natural resources. *Water Policy* 10(1), 83-94.
Neary D.G. 2002. Hydrologic value. In: (eds). Richardson J., Bjorheden R., Hakkila P., Lowe A.T., Smith C.T. *Bioenergy from sustainable forestry: guiding principles and practice*. Kluwer Academic Publishers, Dordrecht, Netherlands.
Nelson R.G. 2002. Resource assessment and removal analysis for corn stover and wheat straw in the Eastern and Midwestern United States – rainfall and wind-induced soil erosion methodology. *Biomass & Bioenergy* 22, 349-363.
Nentwig W. 1999. The importance of human ecology at the threshold of the next millennium: How can population growth be stopped? *Naturwissenschaften* 86(9), 411-421.
Ninni A. 2010. Policies to support biofuels in Europe: the changing landscape of instruments. AgBioForum 13(2), 131-141.
Nisbet T.R. 2001. The role of forest management in controlling diffuse pollution in UK forestry. *Forest Ecology and Management* 143(1-3), 215-226.
Nordstrom K.F. & Hotta S. 2004. Wind erosion from cropland solutions in the USA: a review of problems, and prospects. *Geoderma*121(3-4), 157-167.
NRBP. 2007-10. Bioenergy Technology Selection Matrix. Northeast Regional Biomass Program (http://www.nrbp.org/bioenergy/technology/index.htm) 2010-11-25.
NRC (National Research Council) 2007. *Water Implications of Biofuels Production in the United States. Report in Brief*. National Academy Press, Washington.
Nuberg I. & Brendan G. 2009. Agroforestry as integrated natural resource management. In: Nuberg I., Brendan G., Rowan R. (eds) *Agroforestry for natural resource management*. CSIRO Publishing, Collingwood, Australia.
Olah G.A., Goeppert A., Surya Prakash G.K. 2006. Beyond oil and gas: the methanol economy. Wiley, Weinheim.
Ohlrogge J., Allen D., Berguson B., DellaPenna D., Shachar-Hill Y., Stymne S. 2009. Driving on biomass. *Science 324* (5930), 1019–1020.
Pacala S. & Socolow R. 2004. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science* 305, 968–972.
Pacca S. & Moreira J.R. 2009. Historical carbon budget of the brazilian ethanol program. *Energy Policy* 37(11), 4863-4873.
Palmujoki E. 2009. Global principles for sustainable biofuel production and trade. *International Environmental Agreements – Politics Law and Economics* 9(2), 135-151.
Palviainen M., Finer L., Laiho R., Shorohova E., Kapitsa E., Vanha-Majamaa I. 2010. Carbon and nitrogen release from decomposing Scots pine, Norway spruce and silver birch stumps. *Forest Ecology and Management* 259(3), 390-398.

Patel M., Bastioli C., Marini L., Wurdinger E. 2003. Life cycle eassesment of bio-based polymers and natural fibers. *Biopolymers* 10(Wiley-VCH), 409-452.

Perlack R.D., Wright L.L., Turhollow A., Graham R., Stokes B., Erbach D. 2005. *Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion ton annual supply*. Oak Ridge Natl. Lab. Tech. Rep. ORNL/TM-2006/66. 60 p.

Pfeiffer D.A. 2004. Eating Fossil Fuels, From The Wilderness Publications, *http://www.fromthewilderness.com/free/ww3/100303_eating_oil.html* 2010-03-25.

Piao S.L., Friedlingstein P., Ciais P., de Noblet-Ducoudre N., Labat D., Zaehle S. 2007. Changes in climate and land use have a larger direct impact than rising CO2 on global river runoff trends. PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA 104(39), 15242-15247.

Pimentel D. 2006. Global environmental resources versus world population growth. *Ecological economics* 59, 195-198.

Pimentel D., Houser J., Preiss E., White O., Fang H., Mesnick L., Barsky T., Tariche S., Schreck J., Alpert S. 1997. Water resources: Agriculture, the environment, and society *Bioscience* 47(2), 97-106.

Pimentel D., Marklein A., Toth M.G., Karpoff M.N, Paul G.S., McCormack R., Kyriazis J., Krueger T. 2009. Food Versus Biofuels: Environmental and Economic Costs. *Human Ecology* 37, 1–12.

Pretty J. 1995. *Regenerating Agriculture. Policies and Practice for Sustainability and Self-Reliance*. London, Earthscan, p 20.

Pretty J. 2008c. Agricultural sustainability: concepts, principles and evidence. Source: *Philosophycal Transactions of the Royal Society, B-Biological Sciences* 363(1491), 447-465.

Pretty J. 2008a. Food System Overview: The Wider Policy Context. In: *Sustainable Agriculture and Food. Volume IV. Policies, Processes and Institutions.* London, Sterling, VA.

Pretty J. 2008b. Participatory Learning for Sustainable Agriculture. In: *Sustainable Agriculture and Food. Volume IV. Policies, Processes and Institutions.* Part II. Participatory Processes. London, Sterling, VA.

Proe M.F., Griffiths J.H., McKay H.M. 2001. Effect of whole-tree harvesting on microclimate during establishment of second rotation forestry. *Agricultural and Forest Meteorology* 110, 141–54.

Putsche V. 1999. Complete Process and Economic Model of Syngas Fermentation to Ethanol. C Milestone Completion Report. National Renewable Energy Laboratory, Golden, Colorado, USA.

Quinkenstein A., Wollecke J., Bohm C., Grunewald H., Freese D., Schneider B.U., Huttl R.F. 2009. Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe. *Environmental Science & Policy* 12(8) Special Issue, 1112-1121.

Ramanathan V., Crutzen P.J., Kiehl J.T., Rosenfeld D. 2001. Aerosols, climate, and the hydrological cycle. Science 294: 2119–2124.

Reijnders L. 2003. Loss of living nature and the posibilities for limitation thereof. In: van der Zwaan B. & Pedersen A. (eds) *Sharing the Planet*. Eburon Academic Publishers, Delft, the Netherlands.

Reijnders L. 2006. Conditions for the sustainability of biomass based fuel use. *Energy Policy* 34, 863-876.

Reindhard G.A. & Zamanek G. 2000. *Ökobilanz Bioenergieträger: Basisdaten, Ergebnisse, Bewertungen.* Erich Schmidt Verlag, Berlin, Germany.
RES Directive 2009/28/EC, 2009. Sustainability criteria for biofuels and bioliquids. Directive 2009/28/EC of the European Parlament and of the Council, Article 17.
Righelato R. & Spracklen D.V. 2007. The carbon benefits of fuels and forests - Response. *Science* 318 (5853), 1066-1068**.**
Riksen M., Brouwer F., de Graaff J. 2003. Soil conservation policy measures to control wind erosion in northwestern Europe. *Catena* 52(3-4), 309-326.
Ritter E. & Vesterdal L. 2006. Gap formation in Danish beech (Fagus sylvatica) forests of low management intensity: soil moisture and nitrate in soil solution. European Journal of Forest Research 125(2), 139-150.
Roberts K.G., Gloy B.A., Joseph S., Scott N.R., Lehmann J. 2010. Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change Potential. *Environmental Science & Technology* 44(2), 827-833.
Rondon M., Lehmann J., Ramirez J., Hurtado M. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.). *Biology and Fertility of Soils* 43(6), 699-708.
Rosegrant M.W., Paisner M.S., Meijer S., Witcover J. 2001. *Global food projections to 2020: Emerging trends and alternative futures*. International Food Policy Research Institute Washington USA, pp. 206.
Rosén K. 1986. Increased nitrogen leaching under piles of slash –a consequence of modern logging systems. In: *Predicting consequences of intensive forest harvesting on long-term productivity. Proceedings from IEA-FE project CPC-10 workshop, Jädraås. Swedish University of Agricultural Sciences. Dept. Ecology and Environmental Research; 1986.Sweden:* Report No. 26, 173–175.
Rosenberg O. & Jacobson S. 2004. Effect of repeated slash removal in thinned stands on soil chemistry and understorey vegetation. Silva Fennica 38, 133–142.
Rosillo-Calle F., de Groot P., Hemstock S.L., Woods J. 2006. *The biomass Assessment Handbook: Bioenergy for a Sustainable Environment*. Earthcan Publications Ltd., London.
Rosset P. 2009. Agrofuels, food sovereignty, and the contemporary food crisis. *Bulletin of Science, Technology and Society* 29(3),189-193.
Rowe R.L., Street N.R., Taylor G. 2009. Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. *Renewable & Sustainable Energy Reviews* 13(1), 260-279.
Röling N.G. & Wagemakers M.A.E. 2008. A New Practice: Facilitating Sustainable Agriculture: In: Pretty J. (ed) *Sustainable Agriculture and Food. Policies, Processes and Institutions.Volume IV, Part IV, Enabling Policies and Institutions for Sustainable Agricultural and Food Systems.* London, Sterling, VA.
Röling N.G. 1988. Extention science. In: *Information system in Agricultutal Development.* Cambridge, Cambridge University Press.
Röser D., Asikainen A., Raulund-Rasmussen K., Stupak I. 2008. Recommendations for sustainable forest fuel harvesting and wood ash recycling. In: Röser D., Asikainen A., Raulund-Rasmussen K., Stupak I. (eds) *Sustainable use of forest biomass for energy: a synthesis with focus on the Nordic and Baltic Region*. New York: Springer; p. 262.
Sagar A.D.& Kartha S. 2007. Bioenergy and sustainable development. *Annual Review of Environment and Resources* 32, 131–167.

Salinas-Garcia J.R., Báez-González A.D., Tiscareno-López M., Roslaes-Robles E. 2001. Residue removal and tillage interaction effects on soil properties under rain-fed corn production in Central Mexico. *Soil Tillage Research* 59, 67-79.
Sanchez F.G., Scott D.A., Ludovici K.H. 2006. Negligible effects of severe organic matter removal and soil compaction on loblolly pine growth over 10 years. *Forest Ecology and Management* 227, 145–154?.
Sanchez P.A. 1995. A step forward for Agroforestry systems. *Agroforestry Systems* 31(1), R5-R6.
Sathre R., Gustavsson L., Bergh J. 2010. Primary energy and greenhouse gas implications of increasing biomass production through forest fertilization. Biomass and bioenergy 34(4), 572-581.
Schaeffer M., Eickhout B., Hoogwijk M., Strengers B., Vuuren D. van., Leemans R., Opsteegh T. 2006. CO_2 and albedo climate impacts of extratropical carbon and biomass plantations. *Global Biogeochemical Cycles* 20(2), GB2020.
Scherr S.J. & Sthapit S. 2010. Mitigating climate change through food and land use. Miscellaneous. Worldwatch Institute; Washington; USA.
Schlamadinger B., Apps M., Bohlin F., Gustavsson L., Jungmeier G., Marland G., Pingoud K., Savolainen I. 1997. Towards a standard methodology for greenhouse gas balances of bioenergy systems in comparison with fossil energy systems. Biomass and Bioenergy 13(6), 359-375.
Schmer M.R., Vogel K.P., Mitchell R.B., Perrin R.K. 2008. Net energy of cellulosic ethanol from switchgrass. *Proceedings of the National Academy of Sciences 105(2), 464-469.*
Schoengold K. & Zilberman D. 2007. The economics of water, irrigation and evelopment. In: Evenson R.E., Pingali P., Schultz T.P. (eds) *Volume 3.Handbook of Agricultural Economics: Agricultural Development: Farmers Farm Production and Farm Markets.*North-Holland, Amsterdam.
Scott D.A. & Dean T.J. 2006. Energy trade-offs between intensive biomass utilization, site productivity loss, and ameliorative treatments in loblolly pine plantations. *Biomass & Bioenergy* 30(12), 1001-1010.
Scott D.A., Tiarks A.E., Sanchez F.G., Elliot-Smith M., Stagg R. 2004. Forest soil productivity on the southern long-term soil productivity sites at age 5. In: Connor K.F. (ed) *Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 594 p.*
Searchinger T., Heimlich R., Houghton R.A., Dong F., Elobeid A., Fabiosa J., Tokgoz S., Hayes D., Yu T. 2008. Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change. *Science 319*(5867), 1238–1240.
Sharratt B.S., Zhang M., Sparrow S. 2006. Twenty years of conservation tillage research in subarctic Alaska: II. Impact on soil hydraulic properties. *Soil Tillage Research* 91, 82-88.
Sims R., Mabee W., Saddler J., Taylor M. 2010. An overview of second generation biofuel technologies. *Bioresource Technology* 101(6), 1570-1580.
Singh B., Malhi S.S. 2006. Responce of soil physical properties to tillage and residue management on two soils in a cool temperature environment. *Soil Tillage Research* 85, 143-153.
Sivakumar G., Vail D.R., Xu J.F., Burner D.M., Lay Jr J.O., Ge X.M., Weathers P.J. 2010. Bioethanol and biodiesel: alternative liquid fuels for future generations. *Engineering in Life Sciences* 10(1), 8-18.

Smeets E.W.M., Bouwman A.F, Stehfest E., Van Vuuren D.P., Posthuma A. 2008. The contribution of N2O emissions to the greenhouse gas balance of first-generation biofuels. Global Change Biology 15, 1–23.

Smil V. 2005. *Energy at the Crossroads: Global Perspectives and Uncertainties*. MIT Press, Massachusetts Institution of Technology, England.

Smil V. 2006. *Energy at the Crossroads, OECD Global Science Forum Conference on Scientific Challenges for Energy Research, Paris 17-18 May 2006.*

Smith P., Martino D., Cai Z., Gwary D., Janzen H., Kumar P., McCarl B., Ogle S., O'Mara F., Rice C., Scholes B., Sirotenko O., Howden M., McAllister T., Pan G., Romanenkov V., Schneider U., Towprayoon S., Wattenbach M., Smith J. 2008. Greenhouse Gas Mitigation in Agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences B363*(1492), 789–813.

Smolikowski B., Puig H., Roose E. 2001. Influence of soil protection techniques on runoff, erosion and plant production on semi-arid hillsides of Cabo Verde. *Agriculture Ecosystems & Environment* 87**(1),** 67-80.

Sow A.A., Hossner L.R., Unger P.W., Stewart B.A. 1997. Tillage and residue effects on root growth and yields of grain sorghum following wheat. *Soil Tillage Research* 44, 121-129.

Stehfest E., Bouwman L. 2006. N_2O and NO emission from agricultural fields and soils under natural vegetation:summarizing available measurement data modeling of global annual emissions. Nutrient Cycling in Agroecosystems 74, 207–28.

Steiner C., Teixeira W., Lehmann J., Nehls T., de Maceˆdo J., Blum W., Zech W. 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant & Soil* 291 (1), 275–290.

Stokstad E. 2010. Could Less Meat Mean More Food? *Science* 12, 810-811.

Sugiura A., Tyrrel S., Seymour I. 2008. Growth and water use of Salix viminalis, Populus trichocarpa and Eucalyptus gunnii field trial plantation irrigated with secondary treated effluent. In: Booth E., Green M., Karp A., Shield I., Stock D., Turley D. (eds). *Aspects of Applied Biology* 90, 119-126.

Swallow M., Quideau S.A., MacKenzie M.D., Kishchuk B.E., 2009 Microbial community structure and function: The effect of silvicultural burning and topographic variability in northern Alberta. *Soil Biology & Biochemistry* 41(4), 770-777.

Swedish Forestry Agency, 2008. Rekommendationer vid uttag av avverkningsrester och askåterföring (in swedish) http://www.skogsstyrelsen.se/PageFiles/395/Meddelande-2-2008.pdf 2010-12-01.

Taheripour F., Hertel T.W., Tyner W.E., Beckman J.F., Birur D.K. 2010. Biofuels and their by-products: Global economic and environmental implications. *Biomass & Bioenergy* 34(3), 278-289.

Thelen K.D., Fronning B.E., Kravchenko A., Min D.H., Robertson G.P. 2010. Integrating livestock manure with a corn-soybean bioenergy cropping system improves short-term carbon sequestration rates and net global warming potential. Biomass and Bionergy 34(7), 960-966.

Tilman D. Hill J., Lehman C. 2006. Carbon-negative biofuels from low-input highdiversity grassland biomass. *Science* 314, 1598–1600.

Tilman D., Cassman K.G., Matson P.A., Naylor R., Polasky S. 2002. Agricultural Sustainability and intensive production practices. *Nature* 418, 671-677.

Tolbert V.R. 1998. Environmental effects of biomass crop production; what do we know? What do we need to know? *Biomass & Bioenergy* 14, 301-306.

Toulmin C. & Scoones I. 2008. Ways Forward? Technical choices, Intervention Strategies and Policy Options. In: Pretty J. (ed) *Sustainable Agriculture and Food. Policies, Processes and Institutions, Volume IV, Part IV, Enabling Policies and Institutions for Sustainable Agricultural and Food Systems*. London, Sterling, VA.

Troeh F.R., Hobbs J.A., Donahue R.L. 1980. *Soil and water conservation for productivity and environmental protection*. Prentice-Hall, Inc. Englewood Cliffs, New Jersey USA, 718 pp.

Tutuaa S.S., Xub Z.H., Blumfieldb T.J., Bubbd K.A. 2008. Long-term impacts of harvest residue management on nutrition, growth and productivity of an exotic pine plantation of sub-tropical Australia. *Forest Ecology and Management* 256(4), 741-748.

Turner J.A. 2004. Sustainable Hydrogen Production. *Science* 305(5686), 972-974.

UN, 2006. Water, a shared responsibility, the United Nations World Water Development Report 2. http://www.unesco.org/water/wwap/wwdr2 2010 10-10.

U.S. Census Bureau. 2010-06-28. International Data Base. World Population: 1950-2050. United States Census Bureau http://www.census.gov/ipc/www/idb/worldpopgraph.php 2010-11-10.

Ust'ak S., Havrland B., Muñoz J.O.J., Fernández E.C., Lachman J. 2007. Experimental verification of various methods for biological hydrogen production. *International Journal of Hydrogen Energy* 32(12), 1736-1741.

Wackernagel M., Schulz N.B., Deumling D., Linares A.C., Jenkins M., Kapos V., Monfreda C., Loh J., Myers,N., Norgaard R., Randers J. 2002 Tracking the ecological overshoot of the human economy. *Proceedings of the national academy of sciences of the United States of America* 99, 9266–9271.

Vance E.D. 2000. Agricultural site productivity: principles derived from long-term experiments and their implications for intensively managed forests. *Forest Ecology and Management* 138(1-3), 369-396.

Wang M., Wu M., Huo H. 2007. Life cycle energy and greenhouse gas emission impact of different maize ethanol plant types. *Environmental Research Letters* 2(2), 024001

Varvel G.E., Vogel K.P., Mitchell R.B., Follett RF., Kimble J.M. 2008. Comparison of corn and switchgrass on marginal soils for bioenergy. *Biomass & Bioenergy* 32, 18-21.

Weiss M., Patel M., Heilmeier H., Bringezu S. 2007. Applying distance-to-target weighing methodology to evaluate the environmental performance of bio-based energy, fuels, and materials. *Resources, Conservation and Recycling* 50, 260–281.

Wihersaari M. 2005. Greenhouse gas emissions from final harvest fuel chip production in Finland. Source: Biomass and Bionergy 28(5), 435-443.

Wilhelm W.W., Doran J.W., Power J.F. 1986. Corn and soybean yield response to crop residue management under no-tillage production systems. *Agronomy Jou*rnal 78, 184-189.

Williams M. 2003. *Deforesting the earth, from prehistory to global crisis.* The University of Chicago Press, Chicago.

Wirsenius S., Azar C., Berndes G. 2010. How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? *Agricultural Systems* 103(9), 621-638.

Vitousek P.M. & Melillo J.M. 1979. Nitrate losses from disturbed forests: Pattern and mechanisms. For*est Science* 25, 605-619.

Vlachos E. & Braga B. 2001. The challenge in urban water management. In: *Frontiers in urban water management: Deadlock or hope.* IWA Publishing, Cornwall, 1-36.

Wolf J., Bindraban P.S., Luijten J.C., Vleeshouwers L.M. 2003. Exploratory study on the land area required for global food supply and the potential global production of bioenergy. Agric. Syst. 76, 841–861.

Woodhill J. 1993. Science and the facilitation of social learning: a system perspective. Paper for the 37th Annual Meeting of the International Society for the System Sciences, University of Western Sydney. www.task39.org/About/Definitions/tabid/1761/language/en-US/Default.aspx.

Mabee W.E., Gregg D.J., Arato C., Berlin A., Bura R., Gilkes N., Mirochnik O., Pan X., Pye E.K., Saddler J.N. 2006. Update on softwood-to-ethanol process development. Appl. Biochem. Biotechnol. 29, 55–70.

Xiong Shao Jun; Katterer T. 2010. Carbon-allocation dynamics in reed canary grass as affected by soil type and fertilization rates in northern Sweden. *Acta Agricultura Scandinavica.* Section B, Plant Soil Science 60(1) 24-32.

Zah R., Böni H., Gauch M., Hischier R., Lehmann M.,Wäger P. 2007. *Life Cycle Assessment of Energy Products: Environmental Assessment of Biofuels*. EMPA, Bern, Switzerland, 2007.

Zhao S.Q., Liu S.G., Yin R.S., Li Z.P., Deng Y.L., Tan K., Deng X.Z., Rothstein D., Qi J.G. 2010. Quantifying Terrestrial Ecosystem Carbon Dynamics in the Jinsha Watershed, Upper Yangtze, China from 1975 to 2000. *Environmental Management* 45(3), 466-475.

Zilberman D., Sproula T., Rajagopalb D., Sextona S., Hellegersc P. 2008. Rising energy prices and the economics of water in agriculture. *Water Policy* 10(1), 11–21.

Ågren G.I., Svensson M., Olsson M. 2010. Carbon balances and biofuel production at land use changes. Swedish Energy Agency Report for project 32273-1.